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MINERALS YEARBOOK

U.S.
DEPARTMENT
OF THE
INTERIOR

BUREAU
OF
MINES

1992

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 sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; 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 by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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Foreword

This edition of the Minerals Yearbook discusses the performance of the worldwide minerals and materials industry during 1992 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, nonrenewable organic materials, and nonferrous metals recycling also were added to the Minerals Yearbook series beginning with the 1989, 1990, and 1991 volumes, respectively. A new chapter on materials recycling has been initiated in this 1992 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, Minerals Yearbook—International Review, contains the latest available mineral data on more than 150 foreign countries and discusses the importance of minerals to the economies of these nations. Since the 1989 International Review, this volume has been 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. The 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 more than 60 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 Summay of Nonfuel Minerals" discusses in greater detail procedures for canvassing the minerals industry and this processing and evaluation of these data.

Other information appearing in this 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 7 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; Ivette E. Torres, Chief, Section of International Data; and Jim F. Lemons, Jr., Chief, Branch of Materials.

SURVEY METHODS

The U.S. Bureau of Mines (USBM) 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 USBM'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 USBM 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 USBM 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 USBM 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 161 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. USBM 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 individuals or establishments 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.

Survey Processing

The USBM surveys approximately 25,500 establishments. Each year the USBM mails about 45,000 forms that gather information for 161 different surveys. Each completed survey form returned to the USBM 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 USBM 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. Also, information on minerals and mineral-related publications is now available through an easy-to-use automated facsimile (fax) response system known as MINES FaxBack.

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 USBM 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 USBM 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 USBM 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 USBM 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 USBM relies on the cooperation of the U.S. minerals industry to provide the mineral data that are presented in this and other USBM publications. Without a strong response to survey requests, the USBM would not be able to present reliable statistics. The USBM 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 USBM 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 USBM 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 USBM will publish the data as long as the data from other respondents are protected from disclosure.

International Data

International data are collected by country specialists in the USBM 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 USBM country specialists based on historical trends and specialists' knowledge of current production capabilities in each country.

Publications

The USBM 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 contains the latest available mineral data

for the year of review on more than 170 foreign countries and discusses the importance of minerals to the economies of these nations. Volume III is presented as five area reports and one world overview: 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, Mineral Industries of the Middle East, and 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 USBM 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.

Order free copies of the Mineral Industry Surveys or the Metal Industry Indicators from Publication Distribution, U.S. Bureau of Mines, Cochrans Mill Road, P.O. Box 18070, Pittsburgh, PA 15236, (412) 8992-4338.

To purchase Minerals Today, Annual Commodity Reports, Minerals Yearbook, Mineral Commodity Summaries, and State Mineral Summaries, order from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402, (202) 783-3238.

Information Circulars, Mineral Commodity Summaries, and State Mineral Summaries also may be purchased from the National Technical Information Service, Springfield, VA 22161, 1-800-553 NTIS (in Virginia and foreign countries: 1-703-487-4650).

Electronic Data Dissemination

In addition to the USBM's printed publications, current Mineral Industry Surveys for all commodities and 85 annual reports from the Minerals Yearbook are now available through the USBM'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.

Also, current information on minerals and mineral-related publications from the USBM is now available through an easy-to-use automated fax response system. The MINES FaxBack service allows callers to retrieve information and order some publications for delivery to their fax machines in minutes, 24 hours per day, 7 days per week. MINES FaxBack makes monthly and quarterly Mineral Industry Surveys publications available to the public at the same time they are forwarded to the printer.

MINES FaxBack works from any Group III-compatible fax machine equipped with a touch-tone telephone (either a built-in handset with touch-tone capability or a separate touch-tone telephone plugged into the fax machine's phone jack). After calling MINES FaxBack, the requestor is guided by a series of voice messages that assist the caller in ordering the desired documents. The caller pays for the phone call that also includes the time needed to deliver the requested document to the caller's fax machine.

To access the MINES FaxBack System, use a touch-tone handset attached to a fax machine or connect a touch-tone telephone to the fax machine's telephone jack and dial (412) 892-4088. Listen to the menu options and select an option using the touch-tone telephone. After completing a selection, press the start button on the fax machine.

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 PRODUCTION[1] IN THE UNITED STATES

Mineral		1990		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
METALS							
Beryllium concentrates	metric tons	4,548	e$5	4,339	$5	4,826	$5
Copper[2]	do.	1,587,742	4,311,204	1,631,078	3,931,305	1,765,102	4,180,245
Gold[2]	kilograms	294,527	3,649,914	r295,957	r3,456,786	329,124	3,650,325
Iron ore (includes byproduct material)	thousand metric tons	57,010	1,740,925	56,775	1,674,100	55,569	1,732,416
Iron oxide pigments (crude)	metric tons	37,071	4,615	40,220	4,485	39,272	4,669
Lead[2]	do.	483,704	490,771	465,931	343,948	397,923	307,922
Magnesium metal	do.	139,333	433,119	131,288	336,577	136,947	359,534
Mercury	do.	W	W	58	206	64	376
Molybdenum[3]	do.	61,580	348,256	53,607	249,909	49,554	208,657
Nickel ore[4]	do.	330	NA	5,523	NA	6,671	W
Palladium metal	kilograms	5,930	21,735	6,050	16,923	6,470	18,097
Platinum metal	do.	1,810	27,176	1,730	20,635	1,840	21,060
Silver[2]	metric tons	2,125	329,329	r1,855	r240,908	1,804	228,563
Zinc[2]	do.	515,355	847,485	517,804	602,426	523,430	673,686
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	237,468	XX	143,298	XX	151,091
Total metals[5]		XX	12,442,000	XX	r11,022,000	XX	11,537,000
INDUSTRIAL MINERALS (EXCLUDING FUELS)							
Abrasives[6]	metric tons	3,734	231	2,205	161	1,732	239
Asbestos	do.	W	W	W	W	15,573	6,138
Barite	do.	430,000	16,000	448,000	21,310	325,743	19,633
Boron minerals (B_2O_3)	do.	1,093,919	436,176	1,240,158	442,531	1,008,889	338,700
Bromine[e]	thousand kilograms	177,000	r173,000	170,000	167,000	171,000	170,000
Cement:							
Masonry	thousand short tons	3,274	225,404	e2,637	e187,679	2,930	195,000
Portland	do.	75,596	3,683,400	e68,722	e3,343,223	72,817	3,500,150
Clays	metric tons	42,904,437	1,619,826	44,091,697	1,505,088	40,712,064	1,481,893
Diatomite	do.	631,062	137,982	609,652	139,857	595,122	119,697
Feldspar	do.	630,000	28,471	580,000	26,000	r726,000	r28,500
Fluorspar	do.	e63,500	W	W	W	W	W
Garnet (abrasive)	do.	47,009	6,937	50,860	7,534	54,139	4,842
Gemstones		NA	52,867	NA	84,386	NA	66,195
Gypsum (crude)	thousand short tons	16,406	99,567	15,456	94,199	16,269	100,583
Helium (Grade-A)	million cubic meters	87	113,183	88	174,706	94	187,179
Iodine	thousand kilograms	1,973	30,486	1,999	31,389	1,995	20,877
Lime	thousand short tons	17,452	901,549	17,270	890,482	17,857	949,674
Mica (scrap)	thousand metric tons	109	5,841	103	5,542	85	4,638
Peat	thousand short tons	795	19,200	777	17,887	719	16,747

See footnotes at end of table.

TABLE 1—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES

Mineral		1990 Quantity	1990 Value (thousands)	1991 Quantity	1991 Value (thousands)	1992 Quantity	1992 Value (thousands)
INDUSTRIAL MINERALS (EXCLUDING FUELS)—Continued							
Perlite	metric tons	717,172	17,443	514,047	15,086	541,164	16,368
Phosphate rock	thousand metric tons	46,343	1,075,093	48,096	1,030,913	46,965	1,058,393
Potash (K_2O equivalent)	do.	1,716	303,337	1,709	304,500	1,767	334,407
Pumice	metric tons	442,848	10,687	401,376	9,190	480,855	14,903
Salt	thousand metric tons	36,916	826,659	35,902	801,507	34,784	802,563
Sand and gravel:							
Construction	thousand short tons	910,600	3,249,400	r e913,500	r e3,267,500	919,300	3,341,300
Industrial	do.	28,406	436,200	25,600	390,477	26,967	424,968
Sodium compounds:							
Soda ash	thousand metric tons	9,156	836,188	9,005	835,577	9,379	836,431
Sodium sulfate (natural)	metric tons	349,000	33,748	354,000	30,903	336,829	26,262
Stone:[8]							
Crushed	thousand short tons	e1,222,000	e5,591,300	1,102,878	5,186,821	e1,161,500	e5,593,700
Dimension	short tons	r e1,229,211	r e231,040	r1,270,241	r209,611	e1,080,931	e180,942
Sulfur (Frasch)	thousand metric tons	3,676	335,189	3,119	271,598	2,600	158,727
Tripoli	metric tons	94,389	3,188	88,642	3,271	84,924	3,256
Vermiculite	do.	208,275	19,075	167,923	13,410	190,052	15,062
Combined value of aplite, brucite, calcium chloride (natural), emery, helium (crude), kyanite, lithium minerals, magnesite, magnesium compounds, marl (greensand), olivine, pyrites, staurolite, wollastonite, and values indicated by symbol W		XX	473,453	XX	506,275	XX	456,896
Total industrial minerals[5]		XX	r20,992,000	XX	r20,016,000	XX	20,475,000
Grand total[5]		XX	r33,434,000	XX	r31,038,000	XX	32,012,000

eEstimated. rRevised. NA Not available. W Withheld to avoid disclosing company proprietary data; value included with "Combined value" data. XX Not applicable.

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

[2]Recoverable content of ores, etc.

[3]Content of ore and concentrate.

[4]The Riddle nickel smelter uses lateritic ore mined on Nickel Mountain, lateritic ore imported from New Caledonia, and small tonnages of recycled Ni-bearing catalysts. In 1989, the Glenbrook Nickel Co. purchased the idled mining and smelting complex and restarted the operation. Since then, production of ferronickel on a contained Ni basis has been as follows: 1990—3,701 metric tons (mt) valued at $32.8 million; 1991—7,065 mt valued at $57.6 million; and 1992—8,962 mt valued at $62.7 million.

[5]Rounded.

[6]Grindstones, pulpstones, and sharpening stones; excludes mill liners and grinding pebbles.

[7]Beginning in 1992; aplite is combined with feldspar.

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

TABLE 2

TOTAL U.S. NONRENEWABLE ORGANIC MATERIALS PRODUCTION, BY QUANTITY AND VALUE[1]

(Million metric tons and million dollars)

Category	1990		1991		1992[p]	
	Quantity	Value	Quantity	Value[r]	Quantity	Value
Asphalt and road oil	25.02	3,480	[r]25.85	2,979	25.25	2,794
Lubricants, waxes, and miscellaneous products	12.51	1,863	12.10	1,540	11.05	1,335
Petrochemical industries	57.75	7,759	[r]67.79	7,889	65.91	7,467
Petroleum coke and coal	13.05	1,291	[r]12.93	1,071	13.83	1,102
Total	108.33	[2]14,394	[r]118.67	13,479	116.04	12,698

[p]Preliminary. [r]Revised.

[1]Quantities valued at the fossil fuel prices given in the Department of Energy, Energy Information Administration, Annual Energy Review 1992, June 1993, p. 71.

[2]Data do not add to total 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 3

NONFUEL MINERALS PRODUCED IN THE UNITED STATES AND PRINCIPAL PRODUCING STATES IN 1992

Mineral	Principal producing States, in order of quantity	Other producing States
Abrasives[1]	AR, WI, OH	
Antimony[2]	ID	
Aplite	(3)	
Asbestos	CA and VT	
Barite	NV, GA, MO, MT	IL.
Bauxite	AL and GA	
Beryllium concentrate	UT	
Boron minerals	CA	
Bromine[e]	AR	
Brucite	NV	
Calcium chloride (natural)	MI and CA	
Cement:		
Masonry	IN, FL, PA, MI	All other States except AK, CT, DE, LA, MA, MN, NV, NH, NJ, NC, ND, RI, VT, WI.
Portland	CA, TX, PA, MI	All other States except AK, CT, DE, LA, MA, MN, NH, NJ, NC, ND, RI, VT, WI.
Clays	GA, WY, AL, TX	All other States except AK, DE, HI, RI, VT, WI.
Copper[2]	AZ, UT, NM, MT	CO, ID, IL, MI, MO, NV, OR, TN.
Diatomite	CA, NV, WA, OR	
Emery	OR	
Feldspar[3]	NC, VA, OK, CA	GA, ID, SD.
Fluorspar	IL	
Garnet (abrasive)	ID and NY	
Gemstones (natural)[4]	TN, CA, AZ, LA	All other States.
Gold[2]	NV, CA, UT, SD	AK, AZ, CO, ID, MT, NM, OR, SC, WA.
Graphite (natural)	(5)	
Greensand marl	NJ	
Gypsum (crude)	OK, IA, TX, MI	AR, AZ, CA, CO, IN, KS, LA, NM, NV, NY, OH, SD, UT, VA, WY.
Helium (crude and Grade-A)	KS, WY, TX, CO	
Iodine	OK	
Iron ore (usable)[6]	MN, MI, UT, CA	MO, MT, SD, TX.
Iron oxide pigments (crude)	MI, MO, GA, VA	AZ.
Kyanite	VA	
Lead[2]	MO, AK, ID, MT	AZ, CO, IL, NM, NY, TN, WA.
Lime	MO, OH, PA, AL	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, UT, FL	DE and TX.
Magnesium metal	TX, UT, WA	
Manganiferous ore	SC	
Mercury	NV, UT, CA	
Mica (scrap)	NC, NM, GA, SD	SC.
Molybdenum	CO, AZ, UT, ID	CA, MT, NM.
Nickel ore	OR	
Olivine	WA and NC	
Palladium metal	MT	

See footnotes at end of table.

TABLE 3—Continued

NONFUEL MINERALS PRODUCED IN THE UNITED STATES AND PRINCIPAL PRODUCING STATES IN 1992

Mineral	Principal producing States, in order of quantity	Other producing States
Peat	FL, MI, WI, MN	CO, IA, IL, IN, MA, ME, MT, NC, ND, NJ, NY, OH, PA, SC, WA, WV.
Perlite	NM, AZ, CA, NV	CO and ID.
Phosphate rock	FL, NC, ID, UT	MT.
Platinum metal	MT	
Potash	NM, UT, CA, MI	
Pumice	OR, NM, ID, CA	AZ and KS.
Pyrites (ore and concentrate)	AZ	
Rare-earth metal concentrates	CA and FL	
Salt	LA, TX, NY, OH	AL, AZ, CA, KS, MI, NM, NV, OK, UT, WV.
Sand and gravel:		
Construction	CA, OH, TX, MI	All other States.
Industrial	IL, CA, MI, NJ	All other States except AK, DE, HI, KY, ME, NH, NM, OR, SD, UT, VT, WY.
Silver[2]	NV, AK, ID, MT	AZ, CA, CO, IL, MI, MO, MN, NY, OR, SC, SD, TN, UT, WA.
Sodium compounds:		
Soda ash	WY and CA	
Sodium sulfate (natural)	CA, TX, UT	
Staurolite	FL	
Stone:		
Crushed	IL, PA, TX, FL	All other States except DE.
Dimension	IN, GA, VT, MA	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, TX, VT, NY	CA, NC, OR, VA.
Tin	AZ	
Titanium concentrates	FL, CA, NJ	
Tripoli	IL, OK, AR, PA	
Tungsten[2]	CA	
Vanadium[2]	ID	
Vermiculite (crude)	SC, VA, MT	
Wollastonite	NY	
Zeolites	TX, NM, OR, NV	AZ, IA, ID, WY.
Zinc[2]	AK, TN, NY, MO	CO, ID, IL, MT, WA.
Zircon concentrates	FL and NJ	

[e]Estimated.
[1]Grindstones, pulpstones, and sharpening stones; excludes mill liners and grinding pebbles.
[2]Content of ores, etc.
[3]Beginning in 1992; aplite is combined with feldspar.
[4]Principal and other producing States based on value.
[5]No production reported.
[6]Includes byproduct material.

TABLE 4

VALUE OF NONFUEL MINERAL PRODUCTION IN THE UNITED STATES AND PRINCIPAL NONFUEL MINERALS PRODUCED IN 1992

State	Value (thousands)	Rank	Percent of U.S. total	Principal minerals, in order of value
Alabama	$542,714	19	1.70	Cement (portland), stone (crushed), lime, sand and gravel (construction).
Alaska	526,112	21	1.64	Zinc, gold, lead, sand and gravel (construction).
Arizona	3,165,938	1	9.89	Copper, sand and gravel (construction), gold, cement (portland).
Arkansas	403,822	26	1.26	Bromine, stone (crushed), sand and gravel (construction), cement (portland).
California	2,345,838	3	7.33	Sand and gravel (construction), cement (portland), gold, boron.
Colorado	384,778	29	1.20	Sand and gravel (construction), cement (portland), molybdenum, stone (crushed).
Connecticut	97,192	44	.30	Stone (crushed), sand and gravel (construction), stone (dimension), sand and gravel (industrial).
Delaware[1]	8,575	50	.03	Sand and gravel (construction), magnesium compounds, gemstones.
Florida	1,439,760	5	4.50	Phosphate rock, stone (crushed), cement (portland), sand and gravel (construction).
Georgia	1,346,254	8	4.21	Clays, stone (crushed), cement (portland), sand and gravel (construction).
Hawaii[1]	148,857	39	.47	Stone (crushed), cement (portland), sand and gravel (construction), cement (masonry).
Idaho	306,061	33	.96	Phosphate rock, sand and gravel (construction), gold, silver.
Illinois	733,572	16	2.29	Stone (crushed), sand and gravel (construction), cement (portland), sand and gravel (industrial).
Indiana	476,886	22	1.49	Stone (crushed), cement (portland), sand and gravel (construction), stone (dimension).
Iowa	391,163	28	1.22	Stone (crushed), cement (portland), sand and gravel (construction), gypsum (crude).
Kansas	405,082	25	1.27	Salt, helium (Grade-A), cement (portland), stone (crushed).
Kentucky	400,574	27	1.25	Stone (crushed), lime, cement (portland), sand and gravel (construction).
Louisiana	309,280	32	.97	Salt, sulfur (Frasch), sand and gravel (construction), stone (crushed).
Maine	55,919	46	.17	Sand and gravel (construction), cement (portland), stone (crushed), cement (masonry).
Maryland	339,366	31	1.06	Stone (crushed), cement (portland), sand and gravel (construction), cement (masonry).
Massachusetts	147,401	40	.46	Stone (crushed), sand and gravel (construction), lime, stone (dimension).
Michigan	1,586,977	4	4.96	Iron ore (usable), cement (portland), sand and gravel (construction), stone (crushed).
Minnesota	1,363,939	6	4.26	Iron ore (usable), sand and gravel (construction), stone (crushed), sand and gravel (industrial).
Mississippi	119,964	41	.37	Sand and gravel (construction), clays, cement (portland), stone (crushed).
Missouri	897,189	11	2.80	Lead, cement (portland), stone (crushed), lime.
Montana	539,154	20	1.68	Gold, copper, cement (portland), sand and gravel (construction).
Nebraska	114,790	42	.36	Cement (portland), sand and gravel (construction), stone (crushed), lime.
Nevada	2,588,251	2	8.09	Gold, sand and gravel (construction), silver, diatomite.
New Hampshire[1]	42,034	47	.13	Sand and gravel (construction), stone (crushed and dimension), clays.
New Jersey	240,439	36	.75	Stone (crushed), sand and gravel (construction and industrial), stone (dimension).
New Mexico	871,279	13	2.72	Copper, potash, sand and gravel (construction), stone (crushed).
New York	765,747	14	2.39	Stone (crushed), salt, sand and gravel (construction), cement (portland).
North Carolina	595,648	17	1.86	Stone (crushed), phosphate rock, lithium minerals, sand and gravel (construction).
North Dakota	25,750	48	.08	Sand and gravel (construction), lime, gemstones, sand and gravel (industrial).
Ohio	741,903	15	2.32	Stone (crushed), sand and gravel (construction), salt, lime.
Oklahoma	252,596	35	.79	Stone (crushed), cement (portland), sand and gravel (construction), iodine (crude).
Oregon	214,170	38	.67	Stone (crushed), sand and gravel (construction), cement (portland), lime.
Pennsylvania	879,380	12	2.75	Stone (crushed), cement (portland), sand and gravel (construction), lime.
Rhode Island[1]	21,465	49	.07	Sand and gravel (construction), stone (crushed), sand and gravel (industrial), gemstones.
South Carolina	346,896	30	1.08	Cement (portland), stone (crushed), gold, clays.
South Dakota	300,670	34	.94	Gold, cement (portland), sand and gravel (construction), stone (crushed).
Tennessee	575,804	18	1.80	Stone (crushed), zinc, cement (portland), sand and gravel (construction).
Texas	1,303,378	9	4.07	Cement (portland), stone (crushed), magnesium metal, sand and gravel (construction).
Utah	1,347,663	7	4.21	Copper, gold, magnesium metal, cement (portland).

See footnotes at end of table.

TABLE 4—Continued

VALUE OF NONFUEL MINERAL PRODUCTION IN THE UNITED STATES AND PRINCIPAL NONFUEL MINERALS PRODUCED IN 1992

State	Value (thousands)	Rank	Percent of U.S. total	Principal minerals, in order of value
Vermont[1]	$59,817	45	0.19	Stone (dimension and crushed), sand and gravel (construction), talc and pyrophyllite.
Virginia	461,863	24	1.44	Stone (crushed), cement (portland), lime, sand and gravel (construction).
Washington	469,039	23	1.47	Sand and gravel (construction), gold, magnesium metal, stone (crushed).
West Virginia	111,598	43	.35	Stone (crushed), cement (portland), sand and gravel (construction), lime.
Wisconsin[1]	222,369	37	.69	Stone (crushed), sand and gravel (construction), lime, sand and gravel (industrial).
Wyoming	950,757	10	2.97	Soda ash, clays, helium (Grade-A), cement (portland).
Undistributed	25,757	—	—	
Total[2]	32,011,000	XX	100.00	

XX Not applicable.
[1]Partial total, excludes values that must be concealed to avoid disclosing company proprietary data. Concealed values included with "Undistributed" figure.
[2]Rounded.

TABLE 5

VALUE OF NONFUEL MINERAL PRODUCTION PER CAPITA AND PER SQUARE MILE IN 1992, BY STATE

State	Area (square miles)	Population (thousands)	Total value (thousands)	Per square mile		Per capita	
				Dollars	Rank	Dollars	Rank
Alabama	51,705	4,136	$542,714	10,496	25	131	17
Alaska	591,004	587	526,112	890	49	896	3
Arizona	114,000	3,832	3,165,938	27,771	3	826	4
Arkansas	53,187	2,399	403,822	7,592	28	168	13
California	158,706	30,867	2,345,838	14,781	17	76	29
Colorado	104,091	3,470	384,778	3,697	41	111	20
Connecticut	5,018	3,281	97,192	19,369	10	30	47
Delaware	2,044	689	[1]8,575	4,195	38	12	50
Florida	58,664	13,488	1,439,760	24,542	5	107	21
Georgia	58,910	6,751	1,346,254	22,853	8	199	11
Hawaii	6,471	1,160	[1]148,857	23,004	7	128	18
Idaho	83,564	1,067	306,061	3,663	43	287	10
Illinois	56,345	11,631	733,572	13,019	20	63	38
Indiana	36,185	5,662	476,886	13,179	19	84	27
Iowa	56,275	2,812	391,163	6,951	30	139	16
Kansas	82,277	2,523	405,082	4,923	34	161	15
Kentucky	40,409	3,755	400,574	9,913	26	107	22
Louisiana	47,751	4,267	309,280	6,477	32	72	32
Maine	33,265	1,235	55,919	1,681	47	45	41
Maryland	10,460	4,908	339,366	32,444	1	69	36
Massachusetts	8,284	5,998	147,401	17,793	12	25	48
Michigan	58,527	9,437	1,586,977	27,115	4	168	14
Minnesota	84,402	4,480	1,363,939	16,160	14	304	9
Mississippi	47,689	2,614	119,964	2,516	45	46	40
Missouri	69,697	5,193	897,189	12,873	21	173	12
Montana	147,046	824	539,154	3,667	42	654	6

See footnotes at end of table.

TABLE 5—Continued

VALUE OF NONFUEL MINERAL PRODUCTION PER CAPITA AND PER SQUARE MILE IN 1992, BY STATE

State	Area (square miles)	Population (thousands)	Total value (thousands)	Per square mile		Per capita	
				Dollars	Rank	Dollars	Rank
Nebraska	77,355	1,606	$114,790	1,484	48	71	35
Nevada	110,561	1,327	2,588,251	23,410	6	1,950	2
New Hampshire	9,279	1,111	[1]42,034	4,530	37	38	45
New Jersey	7,787	7,789	240,439	30,877	2	31	46
New Mexico	121,593	1,581	871,279	7,166	29	551	7
New York	49,107	18,119	765,747	15,593	16	42	43
North Carolina	52,669	6,843	595,648	11,309	23	87	26
North Dakota	70,703	636	25,750	364	50	40	44
Ohio	41,330	11,016	741,903	17,951	11	67	37
Oklahoma	69,956	3,212	252,596	3,611	44	79	28
Oregon	97,073	2,977	214,170	2,206	46	72	34
Pennsylvania	45,308	12,009	879,380	19,409	9	73	31
Rhode Island	1,212	1,005	[1]21,465	17,710	13	21	49
South Carolina	31,113	3,603	346,896	11,150	24	96	24
South Dakota	77,116	711	300,670	3,899	40	423	8
Tennessee	42,144	5,024	575,804	13,663	18	115	19
Texas	266,807	17,656	1,303,378	4,885	35	74	30
Utah	84,899	1,813	1,347,663	15,874	15	743	5
Vermont	9,614	570	[1]59,817	6,222	33	105	23
Virginia	40,767	6,377	461,863	11,329	22	72	33
Washington	68,138	5,136	469,039	6,884	31	91	25
West Virginia	24,231	1,812	111,598	4,606	36	62	39
Wisconsin	56,153	5,007	[1]222,369	3,960	39	44	42
Wyoming	97,809	466	950,757	9,721	27	2,040	1
Undistributed	XX	XX	25,757	XX	XX	XX	XX
Total[2] or average	3,618,700	254,472	[3]32,011,000	8,846	XX	126	XX

XX Not applicable.

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

[2]Excludes Washington, DC (which has no mineral production), with an area of 69 square miles and a population of 589,000.

[3]Rounded.

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

TABLE 6

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
ALABAMA							
Cement:							
Masonry	thousand short tons	262	$15,462	e238	e$14,042	213	$11,105
Portland	do.	3,585	165,344	e3,937	e181,102	4,102	180,763
Clays[2]	metric tons	2,049,776	27,747	2,124,380	22,103	2,380,981	20,914
Lime	thousand short tons	1,526	70,816	1,510	75,506	1,603	82,619
Sand and gravel:							
Construction	do.	r13,886	r49,842	e12,700	e45,700	12,294	42,038
Industrial	do.	878	9,075	531	6,133	667	6,768
Stone:							
Crushed[3]	do.	e36,100	e202,400	27,145	161,843	e28,600	e175,600
Dimension	short tons	W	W	9,552	2,449	W	W
Combined value of bauxite, clays (bentonite, kaolin), gemstones, salt, stone [crushed dolomite and granite (1991-92), crushed granite (1990)], talc and pyrophyllite (1990-91), and values indicated by symbol W		XX	r18,742	XX	31,037	XX	22,907
Total		XX	r559,428	XX	539,915	XX	542,714
ALASKA							
Gemstones		NA	W	NA	5	NA	10
Gold[4]	kilograms	3,232	40,200	r3,200	r37,376	5,003	55,492
Sand and gravel (construction)	thousand short tons	15,100	41,800	e14,000	e39,200	15,006	43,335
Stone (crushed)	do.	e2,700	e19,800	31,085	34,688	e 33,000	e 313,400
Combined value of cement [portland (1990-91)], lead, silver, stone [crushed sandstone (1991-92)], tin (1990-91), zinc, and value indicated by symbol W		XX	474,781	XX	412,840	XX	413,875
Total		XX	576,581	XX	r494,109	XX	526,112
ARIZONA							
Clays	metric tons	140,162	2,318	228,411	3,830	2102,337	2463
Copper[4]	do.	978,767	2,657,649	1,024,066	2,468,255	1,153,225	2,731,152
Gemstones		NA	2,098	NA	3,173	NA	5,416
Gold[4]	kilograms	5,000	62,191	r6,195	r72,362	6,656	73,818
Iron oxide pigments (crude)	metric tons	W	W	18	22	77	62
Sand and gravel (construction)	thousand short tons	r31,590	r112,785	e22,500	e79,400	33,842	123,517
Silver[4]	metric tons	r149	r19,346	148	19,212	165	20,873
Stone (crushed)	thousand short tons	e5,300	e13,500	7,060	32,842	e5,500	e26,300
Combined value of cement, clays, [bentonite (1992)], diatomite (1990), gypsum (crude), iron ore [usable (1991)], lead (1991-92), lime, molybdenum, perlite, pumice, pyrites, salt, sand and gravel (industrial), stone (dimension), tin (1992), and values indicated by symbol W		XX	207,591	XX	198,230	XX	184,337
Total		XX	r3,077,478	XX	r2,877,326	XX	3,165,938

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990 Quantity	1990 Value (thousands)	1991 Quantity	1991 Value (thousands)	1992 Quantity	1992 Value (thousands)
ARKANSAS							
Abrasives[5]	metric tons	W	W	W	154	W	W
Bromine[e]	thousand kilograms	177,000	r$173,000	170,000	$167,000	171,000	$170,000
Clays	metric tons	989,383	21,578	[2]856,582	[2]8,048	[2]837,427	[2]2,972
Gemstones		NA	1,503	NA	1,846	NA	1,493
Sand and gravel:							
Construction	thousand short tons	r10,411	r37,371	e8,300	e31,100	10,908	39,627
Industrial	do.	742	7,209	746	7,738	868	10,458
Stone (crushed)[3]	do.	e17,800	e76,900	22,140	101,427	e25,200	e118,900
Combined value of bauxite (1990), cement, clays [fire (1991-92), kaolin (1992)], gypsum (crude), lime, stone [crushed dolomite and traprock (1991-92), crushed slate and dolomite (1990), dimension], talc and pyrophyllite (1990), tripoli, vanadium (1990), and values indicated by symbol W		XX	r63,357	XX	r43,677	XX	60,372
Total		XX	r380,918	XX	r360,990	XX	403,822
CALIFORNIA							
Asbestos	metric tons	W	W	W	W	10,998	4,452
Boron minerals	do.	1,093,919	436,176	1,240,158	442,531	1,008,889	338,700
Cement (portland)	thousand short tons	10,032	604,080	e8,702	e522,120	8,035	428,016
Clays[2]	metric tons	2,163,515	40,217	2,074,707	27,464	1,905,710	26,173
Gemstones		NA	1,501	NA	10,450	NA	9,916
Gold[4]	kilograms	29,607	368,300	r30,404	r355,125	33,335	369,723
Lime	thousand short tons	345	19,425	307	20,389	280	18,072
Mercury	metric tons	(6)	(6)	(6)	1	(6)	(6)
Pumice	do.	71,739	5,088	61,237	4,372	W	W
Rare-earth metal concentrates	do.	W	W	16,465	W	20,699	W
Sand and gravel:							
Construction	thousand short tons	r130,491	r617,984	e101,900	e489,100	112,888	522,108
Industrial	do.	2,452	48,055	2,104	41,690	2,096	42,396
Silver[4]	metric tons	21	3,209	W	W	18	2,259
Stone:							
Crushed	thousand short tons	e42,500	e200,600	45,816	216,156	e40,800	e198,300
Dimension	short tons	r e45,547	r e4,946	44,757	5,254	e23,292	e4,148
Combined value of barite (1990), calcium chloride (natural), cement (masonry), clays (fuller's earth), copper (1990-91), diatomite, feldspar, gypsum (crude), iron ore (usable), magnesium compounds, mica [crude (1991)], molybdenum, perlite, potash, salt, soda ash, sodium sulfate (natural), talc and pyrophyllite, titanium concentrates (ilmenite), tungsten, and values indicated by symbol W		XX	421,820	XX	r403,592	XX	381,575
Total		XX	r2,771,401	XX	r2,538,244	XX	2,345,838

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990 Quantity	1990 Value (thousands)	1991 Quantity	1991 Value (thousands)	1992 Quantity	1992 Value (thousands)
COLORADO							
Clays	metric tons	262,292	[2]$1,864	[2]263,866	[2]$1,964	[2]242,310	[2]$1,796
Gemstones		NA	66	NA	287	NA	225
Gold[4]	kilograms	2,357	29,176	3,181	37,154	3,763	41,741
Peat	thousand short tons	W	W	W	396	W	333
Sand and gravel (construction)	do.	r23,051	r77,761	e26,400	e88,200	29,455	105,281
Silver[4]	metric tons	23	3,557	20	2,565	W	W
Stone:							
Crushed	thousand short tons	e 37,600	e 36,100	8,401	41,022	e12,000	e60,400
Dimension	short tons	r e5,483	e(7)	W	W	e6,454	e252
Combined value of cement, clays, [bentonite (1990-91), fire (1992)], copper, gypsum (crude), helium (Grade-A), lead, lime, molybdenum, perlite, sand and gravel (industrial), stone [crushed traprock (1990)], vanadium (1990), zinc, and values indicated by symbol W		XX	r228,181	XX	166,817	XX	174,750
Total		XX	r376,705	XX	338,405	XX	384,778
CONNECTICUT							
Gemstones		NA	2	NA	62	NA	5
Sand and gravel (construction)	thousand short tons	r8,416	r37,387	e5,400	e24,800	6,025	30,107
Stone:							
Crushed[3]	do.	e10,200	e70,600	5,873	52,701	e5,900	e54,500
Dimension	short tons	e14,156	e7,113	r16,545	1,739	W	W
Combined value of clays (common), feldspar (1990-91), mica [scrap (1990-91)], sand and gravel (industrial), stone [crushed dolomite and other (1991-92), crushed granite (1990)], and value indicated by symbol W		XX	r7,165	XX	11,531	XX	12,580
Total		XX	r122,267	XX	90,833	XX	97,192
DELAWARE							
Gemstones		NA	1	NA	1	NA	1
Sand and gravel (construction)	thousand short tons	r2,953	r9,831	e1,600	e5,100	2,488	8,574
Total[8]		XX	r9,832	XX	5,101	XX	8,575
FLORIDA							
Cement:							
Masonry	thousand short tons	442	27,777	e214	e13,482	342	22,424
Portland	do.	3,954	186,404	e3,023	e142,081	3,195	161,969
Clays[2]	metric tons	391,334	39,625	363,253	39,150	367,133	37,201
Gemstones		NA	W	NA	6	NA	1
Peat	thousand short tons	252	4,381	244	3,991	211	3,158
Sand and gravel:							
Construction	do.	r20,680	r66,401	e16,000	e51,400	23,266	66,141
Industrial	do.	520	7,024	551	5,989	477	5,167

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990 Quantity	1990 Value (thousands)	1991 Quantity	1991 Value (thousands)	1992 Quantity	1992 Value (thousands)
FLORIDA—Continued							
Stone (crushed)	thousand short tons	e74,000	e$317,400	59,132	$260,901	p 59,300	p $266,900
Combined value of clays (common), magnesium compounds, phosphate rock, rare-earth metal concentrates, staurolite, stone [crushed marl (1991-92)], titanium concentrates (ilmenite and rutile), zircon concentrates, and value indicated by symbol W		XX	924,788	XX	879,164	XX	876,799
Total		XX	r1,573,800	XX	1,396,164	XX	1,439,760
GEORGIA							
Clays	metric tons	9,855,248	1,060,539	9,518,026	949,737	8,962,374	970,905
Gemstones		NA	20	NA	10	NA	645
Sand and gravel:							
Construction	thousand short tons	r4,827	r15,577	e4,700	e14,500	4,860	15,581
Industrial	do.	W	W	W	W	588	8,783
Stone:							
Crushed	do.	e53,000	e317,300	41,339	$222,900	p 44,000	p $244,200
Dimension[3]	short tons	r e200,531	r e20,451	r216,938	r21,282	e159,093	e13,138
Combined value of barite, bauxite (1991-92), cement, clays [fire (1992)], feldspar, iron oxide pigments (crude), mica (scrap), peat (1990), stone [crushed marl, marble and other (1991-92)], dimension marble), talc and pyrophyllite (1990), and values indicated by symbol W		XX	r90,164	XX	97,307	XX	93,002
Total		XX	r1,504,051	XX	r1,305,736	XX	1,346,254
HAWAII							
Cement:							
Masonry	thousand short tons	12	1,870	e10	e600	8	1,421
Portland	do.	532	46,311	e547	e47,589	573	53,936
Gemstones		NA	55	NA	60	NA	W
Sand and gravel (construction)	thousand short tons	438	2,459	e400	e2,300	W	W
Stone (crushed)	do.	e7,000	e55,400	10,486	$90,563	p 10,500	p $93,500
Total[5]		XX	106,095	XX	141,112	XX	148,857
IDAHO							
Clays	metric tons	W	W	967	W	W	W
Gemstones		NA	320	NA	426	NA	390
Gold[4]	kilograms	W	W	3,348	39,107	3,177	35,241
Lime	thousand short tons	W	W	150	9,124	W	W
Phosphate rock	thousand metric tons	4,380	67,978	5,921	86,328	5,208	84,000
Pumice	metric tons	31,333	220	36,868	267	55,525	401
Sand and gravel:							
Construction	thousand short tons	r8,563	r22,842	e11,600	e31,300	14,906	40,728
Industrial	do.	552	6,234	W	W	802	9,214
Silver[4]	metric tons	442	68,418	337	43,807	254	32,131
Stone:							
Crushed	thousand short tons	e4,300	e12,900	3,230	15,057	e4,000	e19,200

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
IDAHO—Continued							
Stone—Continued:							
Dimension	short tons	e7,121	e$749	r10,883	r$970	W	W
Combined value of antimony, cement, clays, [common, kaolin (1990-91)], copper, feldspar, garnet (abrasive), lead, molybdenum, perlite,vanadium ore, zinc, and values indicated by symbol W		XX	r195,657	XX	r71,147	XX	$84,756
Total		XX	r375,318	XX	r297,533	XX	306,061
ILLINOIS							
Cement (portland)	thousand short tons	2,842	116,781	e2,654	e108,814	2,860	118,982
Clays	metric tons	2598,479	2,516	935,154	38,877	2535,282	2,362
Gemstones		NA	W	NA	547	NA	715
Sand and gravel:							
Construction	thousand short tons	r33,118	r107,013	e26,300	e90,400	35,695	123,720
Industrial	do.	4,486	62,531	4,146	57,210	4,410	56,741
Stone (crushed)[3]	do.	e62,700	e283,100	68,586	295,362	e72,700	e322,800
Combined value of barite, cement (masonry), clays [fuller's earth (1990, 1992)], copper (1990, 1992), fluorspar, lead (1990, 1992), lime, peat, silver (1990, 1992), stone [crushed sandstone (1990), crushed sandstone and limestone (1991-92), dimension], tripoli, zinc, and value indicated by symbol W		XX	95,478	XX	82,081	XX	108,252
Total		XX	r667,419	XX	673,291	XX	733,572
INDIANA							
Cement:							
Masonry	thousand short tons	368	27,813	e317	e24,092	371	24,822
Portland	do.	2,417	114,414	e2,252	e105,844	2,466	110,737
Clays[2]	metric tons	1,051,703	3,273	929,964	3,516	841,723	3,016
Gemstones		NA	W	NA	561	NA	720
Peat	thousand short tons	37	W	26	W	27	512
Sand and gravel:							
Construction	do.	r23,489	r74,373	e18,100	e60,400	28,862	95,889
Industrial	do.	W	W	W	W	118	1,278
Stone:							
Crushed	do.	e 336,700	e 3147,700	37,924	152,489	e43,000	e178,000
Dimension	short tons	r e 3198,242	r e 328,565	r 3189,010	r 327,596	e190,412	e26,767
Combined value of clays (ball), gypsum (crude), lime, stone [crushed marl and miscellaneous stones (1990), dimension limestone and sandstone (1990-91), dimension sandstone (1990)], and values indicated by symbol W		XX	r32,281	XX	r28,797	XX	35,145
Total		XX	r428,419	XX	403,295	XX	476,886
IOWA							
Cement:							
Masonry	thousand short tons	53	5,054	e34	e3,264	50	4,120
Portland	do.	2,525	122,466	e2,301	e112,749	2,824	116,477
Clays	metric tons	423,227	1,376	530,477	2,226	389,008	1,612

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990 Quantity	1990 Value (thousands)	1991 Quantity	1991 Value (thousands)	1992 Quantity	1992 Value (thousands)
IOWA—Continued							
Gemstones		NA	$14	NA	$8	NA	$1,606
Gypsum (crude)	thousand short tons	2,192	14,243	2,162	12,285	2,193	11,626
Sand and gravel (construction)	do.	r12,125	r39,488	e17,400	e55,800	16,825	58,382
Stone (crushed)	do.	e29,000	e118,600	3 31,057	3 147,815	e 3 38,000	e 3 186,200
Combined value of lime, peat, sand and gravel [industrial (1992)], and stone [crushed dolomite and sandstone (1991-92), dimension]		XX	r8,888	XX	r10,045	XX	11,140
Total		XX	r310,129	XX	r344,192	XX	391,163
KANSAS							
Cement:							
Masonry	thousand short tons	39	2,011	e30	e1,530	34	1,914
Portland	do.	1,707	76,564	e1,466	e65,970	1,710	79,464
Clays	metric tons	625,969	4,056	607,419	2,828	544,052	3,921
Gemstones		NA	W	NA	527	NA	W
Helium (Grade-A)	million cubic meters	W	W	39	76,540	W	W
Salt[9]	thousand metric tons	2,168	92,119	2,101	97,713	1,852	98,620
Sand and gravel (construction)	thousand short tons	r10,737	r23,771	e9,600	e22,100	11,979	27,289
Stone:							
Crushed[3]	do.	e20,800	e79,200	16,802	67,249	e16,900	e69,600
Dimension	short tons	e 3 30,315	e 3 3,142	r 3 30,807	r 3 3,128	W	W
Combined value of gypsum (crude), helium (crude), pumice, salt (brine), sand and gravel (industrial), stone [crushed quartzite (1991-92), crushed sandstone and quartzite (1990)], dimension sandstone (1990-91), and values indicated by symbol W		XX	r67,875	XX	r29,156	XX	124,274
Total		XX	r348,738	XX	r366,741	XX	405,082
KENTUCKY							
Clays[2]	metric tons	826,205	8,282	707,587	2,942	760,310	3,777
Gemstones		NA	W	NA	548	NA	W
Sand and gravel (construction)	thousand short tons	8,802	29,581	e7,700	e27,200	7,396	24,412
Stone (crushed)	do.	e 3 50,100	e 3 182,900	46,266	191,893	e58,800	e251,100
Combined value of cement, clays (ball), lead (1990), lime, sand and gravel [industrial (1990-91)], silver (1990), stone [crushed dolomite (1990)], zinc (1990), and values indicated by symbol W		XX	138,101	XX	120,541	XX	121,285
Total		XX	358,864	XX	343,124	XX	400,574
LOUISIANA							
Clays	metric tons	368,322	1,066	360,154	3,646	384,123	3,589
Gemstones		NA	7	NA	27	NA	3,960
Salt	thousand metric tons	13,016	120,827	13,240	130,587	12,054	112,334
Sand and gravel:							
Construction	thousand short tons	r14,588	r56,375	e13,300	e48,900	12,664	48,698
Industrial	do.	559	10,003	W	W	519	9,267

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990 Quantity	1990 Value (thousands)	1991 Quantity	1991 Value (thousands)	1992 Quantity	1992 Value (thousands)
LOUISIANA—Continued							
Stone (crushed)	thousand short tons	°2,100	°$16,800	W	W	W	W
Sulfur (Frasch)	thousand metric tons	1,337	W	1,063	W	1,105	W
Combined value of gypsum (crude), lime, stone [crushed miscellaneous (1991), crushed miscellaneous and shell (1992)], and values indicated by symbol W		XX	163,313	XX	$168,642	XX	$131,432
Total		XX	r368,391	XX	351,802	XX	309,280
MAINE							
Gemstones		NA	W	NA	174	NA	108
Sand and gravel (construction)	thousand short tons	7,865	29,349	°3,900	°14,800	6,703	26,932
Stone:							
Crushed	do.	°1,700	°8,700	1,706	9,899	°1,900	°11,400
Dimension	short tons	W	W	73	88	W	W
Combined value of cement, clays (common), peat, and values indicated by symbol W		XX	r17,235	XX	16,343	XX	17,479
Total		XX	r55,284	XX	41,304	XX	55,919
MARYLAND							
Cement (portland)	thousand short tons	1,798	91,172	°1,580	°80,580	1,669	84,191
Clays	metric tons	338,775	1,712	°258,760	°1,141	227,013	980
Gemstones		NA	3	NA	3	NA	1
Peat	do.	3	W	—	—	—	—
Sand and gravel (construction)	do.	18,271	104,023	°13,000	°72,800	11,988	69,297
Stone:							
Crushed	do.	°30,500	°163,900	25,545	188,001	°23,800	°180,400
Dimension	short tons	r °12,479	r °1,079	r12,355	r1,067	°11,365	°1,024
Combined value of other industrial minerals and value indicated by symbol W		XX	6,053	XX	4,720	XX	3,473
Total		XX	r367,942	XX	r348,312	XX	339,366
MASSACHUSETTS							
Gemstones		NA	1	NA	1	NA	1
Sand and gravel:							
Construction	thousand short tons	r13,143	r53,461	°10,100	°39,400	12,033	48,671
Industrial	do.	30	401	30	401	9	151
Stone:							
Crushed	do.	°9,200	°54,500	7,131	51,362	°10,400	°77,200
Dimension	short tons	r °54,566	r °9,684	69,332	11,646	°65,836	°9,292
Combined value of clays (common), lime, and peat		XX	10,138	XX	8,787	XX	12,086
Total		XX	r128,185	XX	111,597	XX	147,401
MICHIGAN							
Cement:							
Masonry	thousand short tons	272	23,880	°225	°22,440	234	20,381
Portland	do.	5,906	263,607	°4,935	°222,075	5,509	262,063
Clays	metric tons	1,201,542	4,094	2,061,861	8,770	1,264,692	4,345
Gemstones		NA	11	NA	10	NA	1
Gypsum (crude)	thousand short tons	2,000	11,511	1,721	13,052	1,770	13,889

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990 Quantity	1990 Value (thousands)	1991 Quantity	1991 Value (thousands)	1992 Quantity	1992 Value (thousands)
MICHIGAN—Continued							
Iron ore (usable)	thousand metric tons	10,034	W	°12,662	W	12,881	W
Lime	thousand short tons	622	$30,898	613	$30,959	636	$31,253
Peat	do.	280	6,264	249	6,442	199	5,894
Sand and gravel:							
Construction	do.	r51,761	r155,559	°44,800	°132,200	47,994	143,107
Industrial	do.	2,310	19,285	2,093	18,464	1,897	19,506
Stone (crushed)	do.	°43,100	°129,000	40,989	129,490	°38,600	°125,500
Combined value of calcium chloride (natural), copper, iron oxide pigments (crude), magnesium compounds, potash, salt, silver, stone (dimension), and values indicated by symbol W		XX	r796,354	XX	919,366	XX	961,038
Total		XX	r1,440,463	XX	1,503,268	XX	1,586,977
MINNESOTA							
Gemstones		NA	46	NA	62	NA	686
Iron ore (usable)	thousand metric tons	45,139	1,308,920	42,966	°1,157,920	42,348	1,180,563
Peat	thousand short tons	48	2,972	35	1,910	40	2,764
Sand and gravel (construction)	do.	r39,616	r91,363	°24,500	°58,800	37,604	98,673
Stone:							
Crushed	do.	°9,100	°31,900	8,378	30,624	°10,500	°39,500
Dimension	short tons	r °54,705	r °19,487	45,795	13,962	°36,192	°11,436
Combined value of clays (common, kaolin), lime, sand and gravel (industrial), and value indicated by symbol W		XX	27,746	XX	25,607	XX	30,317
Total		XX	r1,482,434	XX	1,288,885	XX	1,363,939
MISSISSIPPI							
Clays[2]	short tons	817,828	16,196	1,172,213	34,382	1,119,568	38,090
Gemstones		NA	1	NA	1	NA	1
Sand and gravel (construction)	thousand short tons	r12,839	r44,682	°9,900	°33,000	11,467	44,124
Stone (crushed)	do.	°1,400	°5,500	1,632	6,603	°2,500	°10,400
Combined value of cement, clays (ball, fuller's earth [1990], kaolin [1990]), and sand and gravel (industrial)		XX	44,799	XX	27,873	XX	27,349
Total		XX	r111,178	XX	101,859	XX	119,964
MISSOURI							
Cement (portland)	thousand short tons	4,481	180,090	°4,276	°171,040	4,725	196,073
Clays[2]	metric tons	1,347,558	12,864	2,001,537	11,060	1,195,412	8,327
Copper[4]	do.	W	W	W	W	10,766	25,497
Gemstones		NA	W	NA	W	NA	862
Iron ore (usable)	thousand metric tons	1,002	W	°224	W	19	W
Lead[4]	metric tons	380,781	386,345	351,995	259,841	300,589	232,602
Sand and gravel:							
Construction	thousand short tons	9,243	25,097	°7,400	°20,100	9,024	26,457
Industrial	do.	W	W	W	W	710	10,931
Silver[4]	metric tons	42	6,434	35	4,483	32	4,084
Stone (crushed)	thousand short tons	°53,100	°190,900	47,938	167,233	°52,200	°187,400
Zinc[4]	metric tons	48,864	80,355	42,506	49,453	44,031	56,670

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
MISSOURI—Continued							
Combined value of barite, cement (masonry), clays (fuller's earth), iron oxide pigments (crude), lime, sand and gravel (industrial), stone (dimension), and values indicated by symbol W		XX	r$223,034	XX	r$197,141	XX	$148,286
Total		XX	r1,105,119	XX	r880,351	XX	897,189
MONTANA							
Clays	metric tons	229,741	2193	362,635	11,332	235,368	2101
Gemstones		NA	3,692	NA	2,796	NA	674
Gold[4]	kilograms	13,012	161,861	r13,715	r160,197	13,994	155,210
Palladium metal	do.	5,930	21,735	6,050	16,923	6,470	18,097
Platinum metal	do.	1,810	27,176	1,730	20,635	1,840	21,060
Sand and gravel (construction)	thousand short tons	5,114	14,319	e4,800	e13,700	11,109	31,375
Silver[4]	metric tons	220	r34,114	222	r28,893	197	24,990
Stone (crushed)	thousand short tons	e4,000	e15,300	2,107	5,725	e2,200	e6,200
Talc and pyrophyllite	metric tons	430,125	18,883	W	W	407,657	16,162
Zinc[4]	do.	W	W	W	W	20,588	26,498
Combined value of barite, cement, clays (bentonite [1990, 1992]), copper, iron ore (usable), lead, lime, molybdenum, peat, phosphate rock, sand and gravel (industrial), stone (dimension), vermiculite, and values indicated by symbol W		XX	r276,021	XX	274,082	XX	238,787
Total		XX	r573,294	XX	r534,283	XX	539,154
NEBRASKA							
Clays	metric tons	227,292	1,685	198,319	909	182,873	879
Gemstones		NA	7	NA	1	NA	645
Lime	thousand short tons	W	W	W	W	29	1,741
Sand and gravel (construction)	thousand short tons	11,453	30,056	e10,100	e27,300	13,206	38,108
Stone (crushed)	do.	e4,000	e21,200	4,861	23,328	e5,900	e29,100
Combined value of cement, sand and gravel (industrial), and values indicated by symbol W		XX	37,381	XX	37,854	XX	44,317
Total		XX	90,329	XX	89,392	XX	114,790
NEVADA							
Barite	metric tons	337,000	5,884	374,000	11,933	W	W
Clays[2]	do.	34,625	4,098	15,553	3,204	50,517	7,722
Gemstones		NA	407	NA	958	NA	661
Gold[4]	kilograms	179,078	2,216,233	r180,382	r2,106,866	203,165	2,253,305
Lead[4]	metric tons	830	842	W	W	—	—
Mercury	do.	W	W	57	202	64	373
Sand and gravel:							
Construction	thousand short tons	18,377	59,008	e20,300	e69,000	24,273	93,585
Industrial	do.	607	W	546	W	531	W
Silver[4]	metric tons	r583	r75,783	578	75,050	614	77,724
Stone (crushed)	thousand short tons	e1,600	e5,000	1,199	6,527	e1,200	e6,700
Zinc[4]	metric tons	7,889	12,973	W	W	—	—

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral	1990		1991		1992	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
NEVADA—Continued						
Combined value of brucite, cement (portland), clays [fuller's earth (1990-91), kaolin], copper, diatomite, fluorspar (1990), gypsum (crude), lime, lithium minerals, magnesite, molybdenum (1990-91), perlite, salt, and values indicated by symbol W	XX	$216,820	XX	$155,018	XX	$148,181
Total	XX	r2,597,048	XX	r2,428,758	XX	2,588,251
NEW HAMPSHIRE						
Gemstones	NA	38	NA	31	NA	4
Sand and gravel (construction) thousand short tons	7,901	26,599	e4,700	e16,200	6,436	25,570
Stone:						
Crushed do.	e600	e2,500	1,542	9,148	e1,700	e11,000
Dimension short tons	r e16,559	r e6,910	34,803	5,013	e37,647	e5,460
Total[5]	XX	r36,047	XX	30,392	XX	42,034
NEW JERSEY						
Gemstones	NA	3	NA	3	NA	1
Peat thousand short tons	W	527	W	541	W	W
Sand and gravel:						
Construction do.	13,862	64,245	e10,300	e47,900	16,416	79,993
Industrial do.	1,762	26,190	1,634	23,738	1,518	24,727
Stone (crushed) do.	e21,200	e131,700	e3,16,680	e3,119,287	e3,17,100	e3,126,000
Combined value of clays (common, fire), greensand marl, stone [crushed sandstone and other (1991-92)], titanium concentrates [ilmenite and rutile (1991-92)], zircon concentrates, and values indicated by symbol W	XX	6,805	XX	13,519	XX	9,718
Total	XX	229,470	XX	204,988	XX	240,439
NEW MEXICO						
Clays[2] metric tons	27,994	74	27,794	74	32,645	79
Copper[4] do.	262,815	713,622	252,859	609,454	211,337	500,504
Gemstones	NA	225	NA	100	NA	34
Gold[4] kilograms	888	11,041	W	W	W	W
Lead[4] metric tons	W	W	193	142	W	W
Perlite do.	454,500	13,181	W	W	W	W
Potash thousand metric tons	1,451	245,571	1,469	250,900	1,436	256,620
Sand and gravel (construction) thousand short tons	r10,311	r39,631	e9,200	e35,900	11,210	46,176
Silver[4] metric tons	48	7,431	W	W	W	W
Stone (crushed) thousand short tons	e2,400	e12,800	2,801	13,089	e3,000	e14,400
Combined value of cement (portland), clays (fire), gypsum (crude), helium [Grade-A (1990-91)], iron ore [includes byproduct material (1990), usable], mica (scrap), molybdenum, pumice, salt, stone (dimension), zinc, and values indicated by symbol W	XX	r59,445	XX	r75,851	XX	53,466
Total	XX	r1,103,021	XX	r985,510	XX	871,279
NEW YORK						
Clays metric tons	490,552	2,906	421,003	2,417	414,766	2,412

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
NEW YORK—Continued							
Gemstones		NA	$365	NA	$125	NA	$170
Peat	thousand short tons	W	W	1	21	W	W
Salt	thousand metric tons	4,900	162,900	4,534	173,837	4,703	164,729
Sand and gravel (construction)	thousand short tons	r29,912	r121,780	e23,700	e95,500	31,458	130,379
Stone:							
Crushed	do.	e39,900	e207,600	34,871	195,639	e36,800	e212,700
Dimension	short tons	r e20,981	r e3,918	r17,959	r3,162	e18,217	e2,779
Combined value of cement, garnet, (abrasive), gypsum (crude), lead, sand and gravel (industrial), silver, talc and pyrophyllite, wollastonite, zinc, and values indicated by symbol W		XX	273,954	XX	228,142	XX	252,578
Total		XX	r773,423	XX	r698,843	XX	765,747
NORTH CAROLINA							
Clays[2]	metric tons	2,179,428	9,356	2,063,875	9,015	2,119,890	9,775
Feldspar	do.	418,402	14,460	402,448	13,027	438,624	15,498
Gemstones		NA	1,057	NA	785	NA	1,219
Mica (scrap)	thousand metric tons	65	3,796	64	3,747	51	2,967
Peat	thousand short tons	13	W	21	W	W	108
Sand and gravel:							
Construction	do.	r11,289	r42,530	e9,900	e35,000	10,233	42,717
Industrial	do.	1,177	15,338	1,174	15,565	1,199	17,533
Stone:							
Crushed	do.	e52,900	e276,200	346,514	3243,920	e 348,600	e 3262,400
Dimension	short tons	r e36,163	r e9,758	r37,056	r10,568	e25,369	e7,469
Combined value of clays (kaolin), lithium minerals, olivine, phosphate rock, stone [crushed volcanic cinder (1991-92)], talc and pyrophyllite, and values indicated by symbol W		XX	213,112	XX	221,711	XX	235,962
Total		XX	r585,607	XX	r553,338	XX	595,648
NORTH DAKOTA							
Clays	metric tons	50,485	W	27,825	W	W	W
Gemstones		NA	10	NA	6	NA	643
Lime	thousand short tons	82	4,623	98	5,360	111	4,288
Sand and gravel (construction)	do.	r7,046	r16,111	e5,000	e12,000	8,740	20,609
Stone (crushed)	do.	e1,000	e4,600	11	W	11	W
Combined value of other industrial minerals and values indicated by symbol W		XX	116	XX	(10)	XX	210
Total		XX	r25,460	XX	s17,366	XX	25,750
OHIO							
Cement:							
Masonry	thousand short tons	124	10,880	e109	e9,591	113	10,260
Portland	do.	1,426	72,883	e1,356	e69,156	1,455	77,053
Clays	metric tons	2,546,151	13,334	2,204,635	11,015	2,288,245	12,062
Gemstones		NA	W	NA	57	NA	5
Lime	thousand short tons	1,884	92,817	1,783	85,976	1,841	96,739
Peat	do.	12	182	9	222	W	W

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990 Quantity	1990 Value (thousands)	1991 Quantity	1991 Value (thousands)	1992 Quantity	1992 Value (thousands)
OHIO—Continued							
Sand and gravel:							
Construction	thousand short tons	r45,717	r$170,319	e42,300	e$160,100	47,260	$177,508
Industrial	do.	1,349	24,205	1,294	23,462	1,406	26,445
Stone:							
Crushed	do.	e48,400	e190,900	3 47,310	3 184,177	e 3 48,500	e 3 194,500
Dimension	short tons	r e 3 33,976	r e 3 2,202	r 3 47,031	r 3 2,443	e35,059	e2,244
Combined value of abrasives, gypsum (crude), salt, stone [crushed limestone and dolomite (1991-92), dimension limestone (1990-91)], and values indicated by symbol W		XX	r154,938	XX	137,550	XX	145,087
Total		XX	r732,660	XX	r683,749	XX	741,903
OKLAHOMA							
Cement (portland)	thousand short tons	1,544	60,457	e1,620	e63,180	1,026	39,280
Clays	metric tons	631,302	3,156	e824,176	e4,178	621,944	3,296
Gemstones		NA	W	NA	W	NA	1,863
Gypsum (crude)	thousand short tons	2,184	11,154	2,356	12,925	2,603	14,915
Iodine (crude)	thousand kilograms	1,973	30,486	1,999	31,389	1,995	20,877
Sand and gravel:							
Construction	thousand short tons	r9,145	r21,753	e9,000	e22,300	9,904	24,204
Industrial	do.	1,258	22,984	1,241	20,918	1,071	19,011
Stone:							
Crushed[5]	do.	e25,300	e89,500	25,678	95,509	e27,500	e105,300
Dimension	short tons	r e 3 4,267	r e 3 153	r 3 3,777	3 596	e5,182	e706
Tripoli	metric tons	18,801	155	15,885	141	W	W
Combined value of cement (masonry), feldspar, lime, salt, stone [crushed dolomite (1990-91), crushed granite (1992), dimension sandstone (1990-91)], tripoli (1992), and values indicated by symbol W		XX	r19,627	XX	r24,390	XX	23,144
Total		XX	r259,425	XX	r275,526	XX	252,596
OREGON							
Cement (portland)	thousand short tons	W	W	e249	e18,675	W	W
Clays	metric tons	223,452	1,390	213,356	1,086	2 202,530	2 326
Copper[4]	do.	—	—	W	W	152	2 361
Gemstones		NA	1,683	NA	2,758	NA	2,723
Nickel ore[11]	metric tons	330	NA	5,523	NA	6,671	W
Sand and gravel (construction)	thousand short tons	15,785	60,928	e15,600	e62,800	16,488	69,536
Silver[4]	metric tons	W	W	—	—	(6)	1
Stone (crushed)[5]	thousand short tons	e18,000	e86,600	20,608	89,322	e16,800	e74,900
Talc and pyrophyllite	metric tons	105	10	63	67	64	67
Zinc[4]	do.	—	—	751	873	—	—
Combined value of cement (masonry), clays [bentonite (1992)], diatomite, emery, gold (1990, 1992), lime, pumice, silver (1990), stone [crushed dolomite and quartzite (1990), crushed slate (1991-92)], and values indicated by symbol W		XX	53,984	XX	22,347	XX	66,256
Total		XX	204,595	XX	197,928	XX	214,170

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
PENNSYLVANIA							
Cement:							
Masonry	thousand short tons	303	$22,594	e253	e$18,975	326	$21,924
Portland	do.	5,621	286,185	e4,881	e248,931	5,529	258,887
Clays	metric tons	2840,646	2,900	2701,399	2,890	649,257	3,455
Gemstones		NA	5	NA	5	NA	1
Lime	thousand short tons	1,626	92,557	1,695	95,328	1,660	94,543
Peat	do.	18	730	10	207	16	250
Sand and gravel (construction)	do.	r20,795	r97,068	e18,300	e87,800	19,334	94,643
Stone:							
Crushed[3]	do.	e95,800	e502,700	70,334	362,306	71,600	380,200
Dimension	short tons	r e46,788	r e10,894	r41,983	r10,459	41,728	10,822
Combined value of clays [fire (1990), kaolin (1990-91)], mica [scrap (1990-91)], sand and gravel (industrial), stone [crushed granite (1990), crushed limestone, dolomite, and quartzite (1991-92)], and tripoli		XX	15,125	XX	17,482	XX	14,655
Total		XX	r1,030,758	XX	r844,383	XX	879,380
RHODE ISLAND							
Gemstones		NA	2	NA	1	NA	1
Sand and gravel (construction)	thousand short tons	1,969	9,042	e1,300	e6,000	2,455	11,964
Stone (crushed)	do.	e 121,600	e8,800	1,187	7,262	e1,500	e9,500
Total[8]		XX	17,844	XX	13,263	XX	21,465
SOUTH CAROLINA							
Cement (portland)	thousand short tons	2,464	109,644	e2,215	e99,675	2,296	93,385
Clays	metric tons	2,062,824	44,486	1,709,205	25,662	1,608,338	27,694
Gemstones		NA	10	NA	10	NA	641
Gold[4]	kilograms	W	W	W	W	6,747	74,832
Sand and gravel:							
Construction	thousand short tons	r8,664	r24,998	e6,600	e18,900	6,896	19,923
Industrial	do.	844	15,972	822	16,348	849	17,316
Stone:							
Crushed[3]	do.	e26,200	e135,400	18,216	84,260	17,600	83,800
Dimension	short tons	e8,929	e848	8,829	854	W	W
Combined value of cement (masonry), manganiferous ore, mica (scrap), peat, silver, stone [crushed shell (1990), crushed dolomite (1991-92)], vermiculite, and values indicated by symbol W		XX	r118,475	XX	r94,364	XX	29,305
Total		XX	r449,833	XX	r340,073	XX	346,896
SOUTH DAKOTA							
Gemstones		NA	110	NA	W	NA	967
Gold[4]	kilograms	17,870	221,157	16,371	191,217	18,681	207,195
Sand and gravel (construction)	thousand short tons	r9,676	r23,513	e8,700	e20,800	8,279	22,187

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990 Quantity	1990 Value (thousands)	1991 Quantity	1991 Value (thousands)	1992 Quantity	1992 Value (thousands)
SOUTH DAKOTA—Continued							
Silver[4]	metric tons	10	$1,566	7	$944	6	$802
Stone (crushed)	thousand short tons	e4,800	e16,800	4,824	19,657	e4,500	e18,900
Combined value of cement, clays (common), feldspar, gypsum (crude), iron ore (usable), lime, mica (scrap), stone (dimension), and values indicated by symbol W		XX	r55,897	XX	57,304	XX	50,619
Total		XX	r319,043	XX	289,922	XX	300,670
TENNESSEE							
Clays[2]	metric tons	1,060,662	25,776	828,635	44,572	574,470	24,097
Gemstones		NA	W	NA	W	NA	23,347
Sand and gravel:							
Construction	thousand short tons	7,619	23,474	e6,700	e21,100	8,478	35,077
Industrial	do.	W	W	W	W	677	10,665
Stone:							
Crushed	do.	e54,600	e268,600	44,088	223,561	e46,700	e243,800
Dimension	short tons	r e3,460	r e292	3,460	260	e3,400	e320
Combined value of cement, clays [bentonite (1992), common (1991-92), fuller's earth (1990, 1992), kaolin (1991)], copper, lead, lime, phosphate rock (1990), silver, zinc, and values indicated by symbol W		XX	344,627	XX	258,294	XX	238,498
Total		XX	r662,769	XX	547,787	XX	575,804
TEXAS							
Cement:							
Masonry	thousand short tons	142	10,106	W	W	W	W
Portland	do.	7,678	296,680	e7,498	e289,341	7,540	308,749
Clays[2]	metric tons	2,162,095	14,652	2,265,746	13,247	2,237,093	12,610
Gemstones		NA	W	NA	W	NA	3,834
Gypsum (crude)	thousand short tons	1,868	10,166	1,609	9,240	1,790	9,920
Lime	do.	1,337	76,181	1,373	69,400	1,474	83,359
Salt	thousand metric tons	7,450	75,149	8,106	73,117	7,985	76,125
Sand and gravel:							
Construction	thousand short tons	46,083	158,080	e38,800	e135,800	45,640	166,362
Industrial	do.	1,849	40,880	1,557	27,002	1,511	26,141
Stone (crushed)	do.	e81,800	e285,700	65,813	226,836	e71,300	e253,100
Sulfur (Frasch)	thousand metric tons	2,340	W	2,056	W	1,495	W
Talc and pyrophyllite	metric tons	227,138	4,844	212,887	4,561	235,919	5,720
Combined value of clays [ball (1991-92), bentonite, fuller's earth, kaolin], helium (crude and Grade-A), iron ore (usable), magnesium compounds, magnesium metal, sodium sulfate (natural), stone (dimension), and values indicated by symbol W		XX	r486,092	XX	r417,067	XX	357,458
Total		XX	r1,458,530	XX	r1,265,611	XX	1,303,378
UTAH							
Beryllium concentrates	metric tons	4,548	5	r4,339	5	4,826	5
Clays[2]	do.	277,795	1,774	210,382	1,028	242,769	2,714
Gemstones		NA	713	NA	489	NA	634

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
UTAH—Continued							
Lime	thousand short tons	354	$18,878	325	$18,634	W	W
Salt	thousand metric tons	1,062	50,436	1,310	29,959	1,367	$44,498
Sand and gravel:							
Construction	thousand short tons	13,601	44,881	e14,400	e48,200	17,678	54,819
Industrial	do.	2	42	—	—	—	—
Silver[4]	metric tons	147	22,750	W	W	W	W
Stone:							
Crushed	thousand short tons	e4,600	e20,200	4,450	18,259	e5,300	e22,400
Dimension	do.	e17,559	e1,109	23,079	1,429	—	—
Combined value of cement, clays [bentonite, fuller's earth (1992)], copper, fluorspar (1990), gold, gypsum (crude), iron ore (usable), magnesium compounds, magnesium metal, mercury (1990, 1992), molybdenum, phosphate rock, potash, sodium sulfate (natural), vanadium ore (1990), and values indicated by symbol W		XX	1,174,213	XX	r1,067,184	XX	1,222,593
Total		XX	r1,335,001	XX	r1,185,187	XX	1,347,663
VERMONT							
Asbestos	metric tons	W	W	W	W	4,575	1,686
Gemstones		NA	10	NA	5	NA	1
Sand and gravel (construction)	thousand short tons	3,675	11,948	e3,000	e9,900	3,474	11,291
Stone:							
Crushed	do.	e3,700	e35,000	2,685	12,666	e2,500	e12,200
Dimension	short tons	r e106,265	r e33,522	r92,658	31,013	e125,000	e34,639
Combined value of other industrial minerals		XX	6,046	XX	6,236	XX	(10)
Total		XX	r86,526	XX	59,820	XX	e59,817
VIRGINIA							
Clays[2]	metric tons	882,383	3,741	723,495	3,248	753,504	3,367
Gemstones		NA	34	NA	70	NA	W
Lime	thousand short tons	846	39,784	825	39,612	842	40,271
Sand and gravel (construction)	do.	13,096	48,950	e9,700	e36,900	9,545	37,336
Stone:							
Crushed	do.	e59,400	e320,000	48,861	260,966	e47,500	e261,300
Dimension	short tons	W	W	11,046	3,061	W	W
Combined value of aplite[3] (1990-91), cement, clays [bentonite (1992), fuller's earth], feldspar,[3] gypsum (crude), iron oxide pigments (crude), kyanite, sand and gravel (industrial), talc and pyrophyllite, vermiculite, and values indicated by symbol W		XX	r94,057	XX	84,188	XX	119,589
Total		XX	r506,566	XX	428,045	XX	461,863
WASHINGTON							
Clays	metric tons	158,257	1,357	263,374	2,633	306,267	e1,889
Gemstones		NA	281	NA	85	NA	379
Gold[4]	kilograms	9,620	119,671	9,954	116,260	8,802	97,619

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1990 Quantity	1990 Value (thousands)	1991 Quantity	1991 Value (thousands)	1992 Quantity	1992 Value (thousands)
WASHINGTON—Continued							
Sand and gravel (construction)	thousand short tons	r40,032	r$132,921	40,200	$140,700	40,933	$140,994
Stone (crushed)	do.	e12,700	e41,900	13,126	59,588	e13,500	e63,200
Combined value of cement, clays [fire (1992)], diatomite, gypsum [crude (1990-91)], lead (1991-92), lime, magnesium metal, olivine, peat, sand and gravel (industrial), silver, stone (dimension), zinc (1991-92), and values indicated by symbol W		XX	r176,929	XX	r163,395	XX	164,958
Total		XX	r473,059	XX	r482,661	XX	469,039
WEST VIRGINIA							
Clays	metric tons	164,257	384	134,262	322	79,573	221
Gemstones		NA	1	NA	2	NA	1
Sand and gravel (construction)	thousand short tons	r2,456	r12,040	e3,100	e14,300	1,385	5,730
Stone (crushed)	do.	e [2]12,000	e [2]45,200	10,255	50,505	e11,400	e57,800
Combined value of cement, lime, peat, salt, sand and gravel (industrial), stone [crushed granite (1990)], and values indicated by symbol W		XX	75,803	XX	51,802	XX	47,846
Total		XX	r133,428	XX	116,931	XX	111,598
WISCONSIN							
Gemstones		NA	W	NA	542	NA	5
Lime	thousand short tons	461	24,608	536	23,225	521	26,579
Peat	do.	12	256	9	227	62	553
Sand and gravel:							
Construction	do.	r29,553	r73,676	e29,600	e77,500	29,118	77,066
Industrial	do.	W	W	W	W	1,374	24,639
Stone:							
Crushed	do.	e26,600	e91,000	[3]23,676	[3]80,475	e [3]25,500	e [3]89,300
Dimension	short tons	r e [3]57,525	r e [3]7,191	r [3]60,890	r [3]6,221	e36,166	e4,227
Combined value of other industrial minerals and values indicated by symbol W		XX	r18,727	XX	r27,534	XX	([10])
Total		XX	r215,458	XX	r215,724	XX	e222,369
WYOMING							
Cement (portland)	thousand short tons	W	W	W	W	483	30,182
Clays[2]	metric tons	2,523,573	76,082	2,496,361	81,573	2,534,550	83,094
Gemstones		NA	151	NA	61	NA	12
Lime	thousand short tons	W	W	37	2,729	W	W
Sand and gravel (construction)	do.	4,329	14,446	e3,500	e11,900	3,147	11,438
Stone (crushed)	do.	e2,200	e14,000	2,946	12,645	e4,500	e19,900
Combined value of cement (masonry), clay (common), gypsum (crude), helium (Grade-A), soda ash, and values indicated by symbol W		XX	806,169	XX	820,268	XX	806,131
Total		XX	910,848	XX	929,176	XX	950,757

See footnotes at end of table.

TABLE 6—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral	1990		1991		1992	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
UNDISTRIBUTED						
Delaware, Hawaii, New Hampshire, North Dakota (1991), Rhode Island, Vermont (1991-92), Wisconsin (1991-92), and undistributed (1991)	XX	$5,938	XX	r$13,870	XX	$25,797

eEstimated. rRevised. NA Not available. W Withheld to avoid disclosing company proprietary data; value included with "Combined value" figure. XX Not applicable.

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

[2]Excludes certain clays; kind and value included with "Combined value" figure.

[3]Excludes certain stones; kind and value included with "Combined value" figure.

[4]Recoverable content of ores, etc.

[5]Grindstones, pulpstones, and sharpening stones; excludes mill liners and grinding pebbles.

[6]Less than 1/2 unit.

[7]Revised data withheld to avoid disclosing company proprietary data; included with "Combined value" data.

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

[9]Excludes salt in brines; value included with "Combined value" figure.

[10]Value excluded to avoid disclosing company proprietary data.

[11]The Riddle nickel smelter uses lateritic ore mined on Nickel Mountain, lateritic ore imported from New Caledonia, and small tonnages of recycled Ni-bearing catalysts. In 1989, the Glenbrook Nickel Co. purchased the idled mining and smelting complex and restarted the operation. Since then, production of ferronickel on a contained Ni basis has been as follows: 1990—3,701 metric tons (mt) valued at $32.8 million; 1991—7,065 mt valued at $57.6 million; and 1992—8,962 mt valued at $62.7 million.

[12]Excludes traprock.

TABLE 7

NONFUEL MINERAL PRODUCTION[1] IN THE COMMONWEALTH OF PUERTO RICO AND ISLANDS ADMINISTERED BY THE UNITED STATES

Mineral		1990		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
PUERTO RICO							
Cement (portland)	thousand short tons	1,486	$122,027	e1,382	e$110,560	1,431	$119,643
Clays	metric tons	W	W	145,483	355	W	527
Lime	thousand short tons	29	3,483	30	4,440	30	3,717
Sand and gravel (industrial)	do.	55	825	55	825	W	W
Stone (crushed)	do.	NA	NA	8,828	49,839	NA	NA
Total		XX	[2]126,335	XX	166,019	XX	[2]123,887
ADMINISTERED ISLANDS							
American Samoa: Stone (crushed)	thousand short tons	—	—	69	756	—	—
Guam: Stone (crushed)	do.	—	—	2,201	18,038	—	—
Total		XX	—	XX	18,794	XX	—

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

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

[2]Total does not include value of items withheld.

TABLE 8

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

Mineral		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS					
Aluminum:					
Aluminum oxide (alumina, includes hydroxide [calcined equivalent])	thousand metric tons	1,351	r$412,109	1,143	$306,513
Crude and semicrude	metric tons	1,762,287	3,356,065	1,452,695	2,680,202
Manufactures	do.	r62,181	r201,005	7,475	231,190
Scrap (remelt ingot, used beverage containers, other waste and scrap)	do.	460,820	541,702	295,239	299,598
Speciality compounds (aluminum sulfate, aluminum oxide abrasives, and various fluorine-based compounds)	do.	39,200	45,630	NA	NA
Antimony:					
Metal, alloys, waste and scrap	do.	694	1,138	947	1,619
Oxide (antimony content)	do.	3,752	7,404	4,817	10,443
Arsenic metal	do.	233	528	94	783
Bauxite (dried and calcined)	thousand metric tons	44	9,148	NA	NA
Beryllium (alloys, wrought or unwrought, and waste and scrap)	kilograms	33,122	2,690	41,109	5,277
Bismuth (metal, alloys, waste and scrap)	do.	74,597	641	90,320	577
Cadmium (alloys, dross, flue dust, metal, residues, and scrap)	metric tons	158	218	178	244
Chromium:					
Chemicals	do.	23,237	30,514	22,820	29,325
Chromite ore and concentrate	do.	8,759	2,041	7,042	1,602
Metal and alloys	do.	11,073	16,398	11,122	14,909
Pigments	do.	1,969	7,423	2,554	10,413
Cobalt:					
Metal (unwrought, powders, waste and scrap, and mattes and other intermediate products of metallurgy)	do.	543	13,963	485	20,180
Metal (wrought and cobalt articles)	do.	323	13,400	405	13,200
Ores and concentrates	do.	9	231	6	83
Oxides and hydroxides	do.	1,102	10,623	999	11,797
Other forms (acetates and chlorides)	do.	822	5,866	897	7,729
Columbium:					
Ferrocolumbium	thousand kilograms	741	6,952	902	8,254
Ores and concentrates	do.	8	55	—	—
Copper:					
Scrap (alloyed and unalloyed)	metric tons	306,593	446,363	246,636	281,882
Semimanufactures [bare wire (includes wire rod), bars, cable (stranded), foil, hydroxides, oxides, pipes, plates, sheets, tubing, and wire (stranded)]	do.	77,438	306,873	108,734	400,522
Sulfate	do.	827	2,361	1,049	NA
Unmanufactured (anodes, ash, blister, ore, concentrate, matte, precipitates, and refined)	do.	r548,356	r1,033,971	472,571	791,697
Gold:					
Bullion (refined)	kilograms	174,377	2,038,850	256,845	2,877,377
Doré and precipitates	do.	45,536	486,266	51,008	518,661
Ores and concentrates	do.	10	98	30	221
Waste and scrap	do.	64,204	653,748	60,968	548,873
Indium	do.	NA	NA	NA	NA
Iron ore [usable, agglomerates, byproduct ore, concentrates, and direct-shipping ore, (less than 5% manganese)]	thousand metric tons	4,045	156,242	5,055	186,864

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Iron and steel:					
Direct-reduced iron	thousand metric tons	22	$33,845	NA	NA
Ferroalloys not elsewhere listed:					
Ferrophosphorous	metric tons	2,872	1,822	2,142	$1,470
Ferrozirconium	do.	95	138	88	130
Ferroalloys (n.e.c.)	do.	2,800	4,112	2,217	3,497
Pig iron	thousand metric tons	15	1,700	NA	NA
Products:					
Cast (granules-shot, grinding balls, grit, fittings, pipe, rolls, and other)	do.	165	338,944	201	403,831
Fabricated	do.	645	1,742,491	609	1,938,148
Steel mill	do.	5,757	3,671,704	3,890	3,032,072
Scrap:					
Borings, bundles, heavy melting, iron, shredded, shovelings, stainless, turnings, and other steel	do.	9,345	1,232,845	9,262	1,099,802
Ships, boats, and other vessels for scrapping	do.	114	8,158	92	7,622
Used rails for rerolling and other uses (contains used plus new rails)	do.	48	12,422	22	5,998
Lead:					
Ash and residues (lead content)	metric tons	11,828	4,106	2,141	1,031
Ore and concentrate (lead content)	do.	87,953	25,159	72,323	22,202
Scrap	do.	93,262	26,574	63,212	15,165
Unwrought metal and alloys (lead content)	do.	94,428	69,982	64,340	44,624
Wrought metal and alloys (lead content)	do.	7,615	20,614	5,251	19,637
Magnesium:					
Alloys	do.	3,233	10,132	1,473	5,365
Metal	do.	42,859	119,848	35,824	96,221
Powder, sheets, tubing, ribbons, wire, and other forms	do.	8,149	18,046	12,158	24,367
Waste and scrap	do.	919	2,304	2,496	5,907
Manganese:					
Ferromanganese (all grades)	do.	14,573	15,414	13,404	12,996
Metal (including alloys, waste, and scrap)	do.	5,272	12,658	5,005	11,946
Ore and concentrates	do.	66,292	8,523	13,086	2,295
Silicomanganese	do.	2,873	2,802	9,171	6,500
Mercury	do.	786	3,144	977	2,760
Molybdenum (molybdenum content):					
Ferromolybdenum	do.	r225	3,058	319	4,403
Ore and concentrates	do.	33,424	r113,714	33,438	125,405
Oxides and hydroxides	do.	1,571	9,678	556	2,889
Molybdates (all)	do.	740	3,965	1,030	4,976
Powder	do.	230	4,907	350	5,811
Unwrought	do.	88	1,204	74	640
Wire	do.	360	r12,057	355	14,972
Wrought	do.	110	5,570	144	5,772
Nickel (nickel content):					
Alloyed [bars, foil, ingot (unwrought), pipes, profiles, rods, sheets, strip, tubes, wire, and other articles]	do.	16,058	227,384	15,184	208,105

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Nickel (nickel content)—Continued:					
Unwrought:					
Primary [briquets, cathodes, chemicals (catalysts and salts), ferronickel, flakes, oxide (metallurgical grade), pellets, powder, and shot]	metric tons	9,104	$91,359	8,560	$84,175
Secondary [scrap (stainless steel and waste)]	do.	27,798	243,405	25,307	187,797
Wrought (bars, foil, pipes, profiles, rods, sheets, strips, tubes, and wire)	do.	354	5,756	447	7,955
Platinum-group metals (concentrates, iridium, ores, osmium, palladium, platinum, rhodium, ruthenium, and waste and scrap)	kilograms	39,624	461,588	57,829	382,016
Rare-earth metals (rare-earth oxide content):					
Cerium compounds	do.	1,368,535	8,195	1,935,021	10,089
Compounds (inorganic and organic)	do.	1,793,092	20,954	1,306,463	12,771
Ferrocerium and pyrophoric alloys	do.	r2,113,169	9,343	2,737,342	15,842
Metals (includes scandium and yttrium)	do.	59,035	2,683	36,452	1,098
Ores and concentrates	metric tons	459	NA	NA	NA
Selenium (metal, waste and scrap, selenium content)	kilograms	210,495	1,939	174,788	1,658
Silicon:					
Ferrosilicon	metric tons	50,393	43,008	55,996	45,825
Metal	do.	8,246	112,323	8,531	93,813
Silver:					
Bullion (refined)	kilograms	r787,475	115,224	910,587	125,531
Doré and precipitates	do.	r53,127	8,486	88,894	16,104
Ores and concentrates	do.	299	49	8,505	1,503
Waste and scrap	do.	r840,228	124,015	745,221	110,381
Tantalum:					
Ores and concentrates (includes synthetic)	thousand kilograms	11	248	19	50
Unwrought (alloys, metal, powders, and waste and scrap)	do.	208	27,646	131	24,329
Wrought	do.	77	26,580	66	22,668
Thorium:					
Compounds	kilograms	2,649	154	93	12
Ore and monazite concentrate	do.	—	—	5,000	11
Tin:					
Ingots and pigs	metric tons	970	5,455	1,888	8,957
Tin scrap and other tin bearing material (except tinplate scrap, includes bars, rods, profiles, wire, powders, flakes, tubes, and pipes)	do.	121,359	r85,708	127,191	89,298
Tinplate and terneplate	do.	150,187	89,677	272,549	162,302
Titanium:					
Metal:					
Scrap	do.	4,568	10,706	2,770	7,201
Sponge	do.	418	2,604	178	1,102
Other unwrought (billet, blooms and sheet bars, ingots, etc.)	do.	3,845	47,833	2,640	43,372
Wrought (bars, rods, etc.)	do.	3,300	113,060	2,431	111,027
Ores and concentrates	do.	26,912	10,167	34,665	10,566
Pigments (dioxides and oxides)	do.	r211,854	r352,912	270,422	420,372
Tungsten (tungsten content):					
Ammonium paratungstate	do.	770	4,114	470	3,354
Carbide powder	do.	839	18,880	715	18,098
Metal and alloy powder	do.	689	13,947	316	8,380

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1991 Quantity	1991 Value (thousands)	1992 Quantity	1992 Value (thousands)
METALS—Continued					
Tungsten—Continued:					
Miscellaneous tungsten-bearing materials [(ferrotungsten and ferrosilicon tungsten, unwrought, wire (metal and alloy), wrought, other compounds (other tungstates), and other metal)]	metric tons	822	$40,037	684	$28,332
Ore and concentrate	do.	21	165	38	284
Vanadium:					
Aluminum-vanadium master alloy	kilograms	170,392	4,344	545,198	9,564
Compounds [(pentoxide (anhydride), and other (excludes vanadates), vanadium content)]	do.	1,810,150	10,957	1,138,653	4,921
Ferrovanadium	do.	178,027	2,454	325,656	3,727
Zinc:					
Blocks, pigs, anodes, etc. (unwrought and unwrought alloys)	metric tons	5,477	8,680	NA	NA
Compounds (chloride, lithopone, oxide, sulfate, sulfide, and compounds n.s.p.f.)	do.	16,312	51,102	16,081	59,593
Dust and flakes	do.	5,737	8,247	NA	NA
Ore and concentrates	do.	r381,818	r220,927	387,918	239,343
Waste and scrap (zinc content)	do.	96,314	61,706	NA	NA
Wrought zinc and zinc alloys (angles, bars, pipes, plates, rods, strips, etc.)	do.	16,536	22,466	NA	NA
Zirconium:					
Ore and concentrates	do.	31,333	20,607	27,853	14,323
Unwrought and waste and scrap	do.	238	5,785	389	13,070
Metal totals[1]		XX	r20,095,000	XX	18,797,000
INDUSTRIAL MINERALS					
Abrasive materials (includes reexports):					
Natural		XX	158,518	XX	177,542
Manufactured		XX	161,433	XX	205,732
Asbestos (includes reexports):					
Manufactured		XX	116,015	XX	134,102
Unmanufactured	metric tons	25,636	7,424	24,860	6,724
Barite: Natural barium sulfate	do.	43,296	3,304	12,469	1,806
Boron:					
Boric acid	thousand metric tons	47	35,457	80	53,652
Sodium borates	do.	554	205,722	489	159,492
Bromine:					
Compounds (contained bromine)	thousand kilograms	14,555	21,280	16,946	26,445
Elemental	do.	2,563	7,665	5,320	5,542
Calcium chloride	metric tons	30,568	8,030	38,365	8,808
Cement: Hydraulic and clinker	thousand metric tons	633	r45,774	747	48,720
Clays:					
Ball	do.	58	2,924	49	3,120
Bentonite	do.	660	63,571	591	53,652
Fire	do.	119	19,000	228	23,537
Fuller's earth	do.	27	4,440	27	4,022
Kaolin	do.	2,855	430,287	3,000	490,869
Other (includes chamotte or dinas earth, activated clays and earths, and artificially activated clays)	do.	197	69,952	262	88,278
Diatomite	do.	152	45,187	163	50,704
Feldspar	metric tons	8,425	1,334	17,700	2,212
Fluorspar	do.	73,943	16,424	13,646	1,983

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
INDUSTRIAL MINERALS—Continued					
Gemstones (includes reexports):					
Diamonds (excludes industrial diamond)	carats	r3,710,416	r$1,521,600	3,950,390	$1,449,500
Graphite:					
Artifical (includes artifical, and colloidal or semicolloidal)[3]	metric tons	37,662	29,876	34,487	32,689
Natural (amorphous, crystalline flake, lump or chip, and natural n.e.c.)	do.	19,374	11,345	20,217	12,244
Gypsum:					
Boards	thousand short tons	105	36,943	151	39,177
Crude	do.	74	3,720	108	3,946
Plasters	do.	96	19,872	151	22,303
Other	do.	XX	25,077	XX	31,557
Helium (Grade-A)	million cubic meters	27	36,504	31	72,108
Iodine:					
Crude/resublimed	thousand kilograms	r1,213	r15,751	1,625	15,139
Potassium iodide	do.	105	398	182	402
Iron oxide pigments:					
Pigment grade	metric tons	20,606	33,816	21,117	32,173
Other grade	do.	164,084	109,463	172,162	115,935
Lime	short tons	r51,688	r6,058	64,500	7,540
Lithium compounds:					
Carbonate	kilograms	9,564,674	31,273	8,225,957	27,008
Hydroxide	do.	3,078,922	12,998	2,911,116	13,183
Metal	do.	57,373	NA	62,232	NA
Magnesium:					
Calcined dolomite	metric tons	16,702	3,349	19,584	3,314
Caustic-calcined magnesia	do.	3,640	2,289	5,262	2,404
Compounds (chlorides, hydroxide and peroxide, and sulfates)	do.	8,913	8,022	9,586	8,253
Dead-burned and fused magnesia	do.	66,292	25,038	56,758	22,257
Magnesite (crude)	do.	7,961	5,567	5,926	4,214
Other magnesia	do.	25,149	13,985	19,075	11,540
Mica:					
Scrap and flake:					
Powder	do.	3,420	1,717	3,954	2,054
Waste	do.	874	331	475	204
Sheet:					
Unworked	do.	205	309	170	307
Worked	do.	411	7,454	436	7,180
Nitrogen compounds (major):					
Anhydrous ammonia	thousand metric tons	r705	NA	431	NA
Fertilizer materials	do.	13,768	NA	12,205	NA
Industrial chemicals	do.	135	110,131	142	120,731
Peat	thousand short tons	14	NA	24	NA
Perlite (crude)	metric tons	r29,030	r852	r29,000	r825
Phosphorus:					
Diammonium and monoammonium phosphates	thousand metric tons	r10,508	1,847,926	9,161	NA
Elemental phosphorous	metric tons	17,018	30,421	17,880	32,784
Phosphate rock:					
Ground	thousand metric tons	219	13,078	288	NA

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
INDUSTRIAL MINERALS—Continued					
Phosphorus—Continued:					
Phosphate rock—Continued:					
Unground	thousand metric tons	5,530	$246,755	3,689	NA
Phosphoric acid	do.	440	76,342	602	NA
Superphosphates	do.	r911	r120,809	1,114	NA
Potash:					
Potassium chloride, all grades	metric tons	730,600	NA	708,500	NA
Potassium magnesium sulfate	do.	306,400	NA	292,600	NA
Potassium nitrate	do.	r16,000	NA	18,600	NA
Potassium sulfate	do.	203,300	NA	309,800	NA
Pumice and pumicite	thousand metric tons	13	290	NA	NA
Quartz crystal:					
Cultured	thousand kilograms	53	2,620	15	$1,278
Natural	do.	NA	NA	NA	NA
Salt	thousand metric tons	1,777	29,875	992	32,193
Sand and gravel:					
Construction:					
Gravel	do.	635	6,043	550	5,364
Sand	do.	398	1,301	870	12,599
Industrial	do.	1,485	106,606	1,337	90,403
Sodium compounds:					
Soda ash	do.	2,734	409,088	2,955	433,606
Sodium sulfate	do.	103	11,495	155	11,403
Stone:					
Crushed	metric tons	2,190,672	33,003	3,656,800	43,400
Dimension	thousand short tons	NA	64,947	NA	54,904
Strontium compounds (precipitated carbonate, oxide, hydroxide, and peroxide)	kilograms	1,800,221	1,765	1,186,259	2,193
Sulfur:					
Elemental	thousand metric tons	1,196	119,713	966	69,662
Sulfuric acid (100% H_2SO_4)	metric tons	148,872	11,806	139,456	11,822
Talc (excludes talcum in packages, face, and compact)	thousand metric tons	178	30,050	175	30,070
Vermiculite	do.	e10	NA	e8	NA
Industrial minerals totals[1]		XX	r6,661,000	XX	4,437,000
Total[1]		XX	r26,756,000	XX	23,234,000

rRevised. NA Not available. XX Not applicable.

[1]Rounded.

[2]Artificial 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		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS					
Aluminum:					
Aluminum oxide (alumina)	thousand metric tons	4,592	$1,102,008	4,701	$886,613
Crude and semicrude	metric tons	1,489,600	2,268,296	1,724,624	2,462,070
Manufactures	do.	r43,287	r142,973	47,204	147,566
Scrap (remelt ingot, used beverage containers, and other waste and scrap)	do.	208,384	219,558	265,306	267,372
Antimony:					
Metal	do.	13,502	23,841	15,100	26,077
Ore and concentrate (antimony content)	do.	3,381	5,250	1,923	3,710
Oxides (antimony content)	do.	11,950	18,941	14,181	22,619
Arsenic:					
Acid	do.	374	427	40	34
Metal	do.	1,008	2,899	740	2,550
Sulfides	do.	(1)	31	(1)	31
Trioxide	do.	27,142	14,320	30,671	16,342
Bauxite:					
Calcined	thousand metric tons	r298	r21,620	346	23,289
Crude and dried	do.	r11,871	NA	10,939	NA
Beryllium:					
Beryl	metric tons	288	394	61	NA
Metal and compounds	kilograms	118,343	822	108,392	1,237
Bismuth metals and alloys	do.	1,411,394	7,876	1,620,534	7,681
Cadmium metal	metric tons	2,039	7,928	1,958	3,842
Chromium:					
Chemicals	do.	11,987	r21,143	9,948	20,278
Chromite ore	do.	212,139	14,963	219,474	15,299
Ferrochromium (all grades)	do.	400,536	231,659	410,798	235,140
Metals and alloys [metal (waste and scrap and other), and ferrochromium-silicon]	do.	11,066	47,238	14,830	44,027
Pigments and preparations based chromium	do.	4,939	13,453	6,943	15,308
Cobalt:					
Metal (alloys, articles, matte, wrought, and waste and scrap)	do.	574	13,019	805	19,200
Metal (unwrought, excluding alloys and waste and scrap)	do.	6,375	157,711	5,274	246,393
Oxide and hydroxides	do.	583	12,941	431	18,651
Other forms (acetates, carbonates, chlorides, and sulfates)	do.	448	r3,481	629	7,779
Columbium:					
Ferrocolumbium	thousand kilograms	3,282	27,415	3,767	31,075
Ores and concentrates	do.	2,515	8,445	2,428	8,764
Oxide	do.	603	10,210	792	13,473
Unwrought (alloys, metals, and powders)	do.	1	103	1	101
Copper:					
Scrap (alloyed and unalloyed)	metric tons	125,928	216,305	168,750	284,144
Semimanufactures [bare wire (includes wire rod), bars, cable (stranded), foil, hydroxides, oxides, pipes, plates, tubing, sheets, and wire (stranded)]	do.	69,467	294,825	67,507	275,504
Sulfate	do.	10,309	NA	8,290	NA

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Copper—Continued:					
Unmanufactured (anode, ash, blister, concentrates, matte, ore, precipitates, and refined, copper content)	kilograms	413,276	$907,438	457,233	$923,815
Gallium (unwrought, waste and scrap)	do.	11,271	3,829	8,479	3,126
Germanium materials	do.	26,834	11,999	13,229	4,871
Gold:					
Bullion (refined)	do.	147,491	1,721,576	141,251	1,568,186
Doré and precipitates	do.	5,597	66,735	17,092	175,542
Ore and concentrates	do.	992	10,874	351	3,877
Waste and scrap	do.	24,668	126,264	15,649	66,376
Hafnium (unwrought, and waste and scrap)	metric tons	3	489	2	431
Indium (unwrought, and waste and scrap)	kilograms	36,288	7,867	54,417	10,824
Iron ore:					
Pellets	thousand metric tons	9,317	338,493	8,880	314,372
Usable [agglomerates, byproduct ore, concentrates, and direct-shipping ore, (less than 5% manganese)]	do.	13,335	436,777	12,504	395,791
Iron and steel:					
Direct-reduced iron	do.	423	97,897	NA	NA
Ferroalloys not elsewhere listed:					
Ferrophosphorus	metric tons	6,713	1,835	7,492	1,920
Ferrotitanium and ferrosilicon-titanium	do.	1,166	3,819	1,357	3,202
Ferrozirconium	do.	288	483	1	2
Ferroalloys (n.e.c.)	do.	16,485	24,749	16,518	23,830
Pig iron	do.	434,318	75,261	496,547	196,428
Products:					
Cast	thousand metric tons	187	195,644	191	196,428
Fabricated	do.	1,709	2,705,856	1,762	2,887,517
Steel mill	do.	r14,375	9,060,231	15,490	7,892,621
Scrap:					
Iron and steel	do.	1,073	142,552	1,316	147,616
Ships, boats, and other vessels for scrapping	do.	2	60	(1)	31
Used rails for rerolling and other uses	do.	93	16,173	78	15,583
Stainless steel (bars, pipe, plate, semifinished, shapes, sheet, strip, tube, wire and wire rods)	metric tons	340,015	NA	400,077	NA
Lead:					
Base bullion (lead content)	do.	419	283	218	94
Miscellaneous products (lead content)	do.	1,154	4,133	NA	NA
Ore and concentrates (lead content)	do.	12,437	4,466	5,310	3,422
Pigments and compounds	do.	23,946	29,967	30,239	36,197
Pigs and bars (lead content)	do.	116,473	69,351	190,723	106,433
Scrap (reclaimed, includes ash and residues, lead content)	do.	117	28	236	65
Wrought (all forms, including wire and powders, gross weight)	do.	r5,962	8,460	7,094	10,548
Magnesium:					
Alloys (magnesium content)	do.	4,596	15,903	3,839	14,545
Metal	do.	21,758	52,186	4,244	11,030

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Magnesium—Continued:					
Powder, sheets, tubing, ribbons, wire, and other forms (magnesium content)	metric tons	1,359	$4,866	1,336	$4,281
Waste and scrap	do.	4,150	4,653	2,425	2,821
Manganese:					
Chemicals (manganese dioxide and potassium permanganate)	do.	r20,990	30,724	22,193	33,024
Metal	do.	r15,791	24,509	13,952	21,991
Ore and concentrates (manganese content)	do.	r234,511	80,664	240,800	59,934
Ferromanganese (all grades, manganese content)	do.	r500,946	378,324	476,940	333,631
Silicomanganese (manganese content)	do.	r169,784	130,677	169,047	118,464
Mercury (metal, mercury-bearing waste and scrap)	do.	56	301	92	403
Molybdenum (molybdenum content):					
Ferromolybdenum	do.	953	7,304	1,096	6,974
Molybdates (all)	do.	77	772	86	763
Ore and concentrates	do.	161	882	831	4,081
Oxides and hydroxides (gross weight)	do.	948	5,013	1,032	3,928
Powder	do.	r27	r788	52	1,784
Unwrought	do.	45	r1,703	46	1,437
Wire (gross weight)	do.	2	211	1	177
Wrought (gross weight)	do.	53	3,275	46	3,004
Other (inorganic compounds, orange, waste and scrap, and other, gross weight)	do.	1,186	6,237	1,029	4,476
Nickel (nickel content):					
Alloyed (bars, foil, ingot [unwrought], pipes, profiles, rods, sheets, strips, tubes, wires, and other articles)	do.	7,794	119,466	5,944	72,517
Unwrought:					
Primary (briquets, cathodes, chemicals [catalysts and salts], ferronickel, flakes, oxide [metallurgical grade], pellets, powder and shot)	do.	r132,446	1,123,536	118,760	871,086
Secondary (scrap [stainless steel and waste])	do.	r6,212	r58,638	9,506	47,791
Wrought (bars, foil, pipes, profiles, rods, sheets, strips, tubes, and wire)	do.	1,131	16,880	951	15,319
Platinum-group metals (iridium, ores, osmium, palladium, platinum, rhodium, ruthenium, ores, and waste and scrap)	kilograms	125,661	1,742,866	132,006	1,483,680
Rare-earth metals (rare-earth oxide content):					
Cerium compounds (includes chlorides, hydroxides, nitrates, oxides, oxilate, and sulfates)	do.	544,962	4,913	808,688	8,034
Compounds (includes hydroxides, nitrates, oxides, and others, except chlorides)	do.	3,693,163	34,079	4,148,289	34,711
Chloride mixtures (except cerium chloride)	do.	3,377,242	8,890	1,583,402	7,692
Ferrocerium and other pyrophoric alloy	do.	92,997	r1,424	105,630	1,613
Oxide mixtures (except cerium oxides)	do.	892,277	13,138	294,971	14,853
Rare-earth metals (whether intermixed or alloyed)	do.	225,820	3,329	280,593	3,101
Rhenium:					
Ammonium perrhenate	do.	3,513	2,815	5,694	2,833
Metal	do.	10,847	13,316	6,385	7,522
Selenium: (selenium content)					
Selenium dioxide	do.	r10,252	208	9,484	196

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Selenium—Continued: (selenium content)					
Unwrought, and waste and scrap	kilograms	333,289	$7,815	361,043	$6,776
Silicon:					
Ferrosilicon	metric tons	183,214	93,455	247,601	113,911
Metal	do.	43,386	100,373	32,716	92,734
Silver:					
Bullion (refined)	kilograms	r2,525,134	338,514	2,661,622	340,898
Doré and precipitates	do.	151,836	25,740	528,715	102,118
Ore and concentrates	do.	21,422	3,659	25,352	3,885
Waste and scrap	do.	1,452,501	153,299	1,774,085	54,492
Tantalum:					
Ores and concentrates (includes synthetic)	thousand kilograms	1,000	20,609	1,367	35,600
Unwrought (alloys, metal, powders, and waste and scrap)	do.	137	11,462	103	5,757
Wrought	do.	2	765	2	768
Tellurium (unwrought, and waste and scrap)	kilograms	29,255	3,073	48,384	3,700
Thallium (unwrought waste and scrap)	do.	1,013	184	NA	NA
Thorium:					
Compounds	do.	42,609	1,270	13,505	526
Ore metal (excludes monazite)	do.	205,100	31	186,803	36
Tin:					
Compounds	metric tons	r340	r2,698	510	3,883
Concentrates (tin content)	do.	1	6	—	—
Dross, skimmings, residues, scrap, tin alloys, n.s.p.f.	do.	5,855	33,132	NA	NA
Metal (unwrought)	do.	29,102	161,725	27,314	163,023
Miscellaneous tin and tin manufactures (alloys [n.s.p.f.], dross, flitters, foil, metallics, powder, residues, scrap, skimmings, and manufactures [n.s.p.f.])	do.	XX	r35,648	XX	60,208
Tinplate and terneplate	do.	r284,783	195,659	295,321	200,534
Tinplate scrap	do.	10,109	2,240	28,500	7,070
Titanium:					
Concentrates:					
Ilmenite	do.	213,886	24,071	294,585	20,414
Rutile (natural and synthetic)	do.	r240,120	r121,631	317,399	129,758
Titaniferous iron ore	do.	27,012	1,593	32,381	1,564
Titanium slag	do.	408,302	105,792	537,118	155,943
Metal:					
Ingots and billets	do.	24	1,095	241	2,062
Powder	do.	34	697	50	886
Unwrought	do.	612	5,451	684	5,363
Waste and scrap	do.	2,666	8,503	6,257	19,436
Wrought (bars, castings, foil, pipes, plates, profiles, rods, sheet, strip, tubes, wire, and other)	do.	914	24,014	456	12,830
Other (includes bars, blooms, sheet, slabs, and other unwrought)	do.	141	1,561	78	491
Pigments (dioxides and oxides)	do.	166,094	285,290	169,260	284,843
Tungsten (tungsten content):					
Ammonium tungstate	do.	842	6,756	378	2,647

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Tungsten (tungsten content)—Continued:					
Ferrotungsten	metric tons	525	$3,128	414	$2,194
Miscellaneous tungsten-bearing materials [carbide, chlorides, oxides, unwrought, tungstates (calcium and sodium), waste and scrap, wrought, and other tungsten-bearing material]	do.	6,246	71,114	3,375	50,152
Ore and concentrates	do.	7,837	43,269	2,477	16,265
Vanadium:					
Ferrovanadium (vanadium content)	kilograms	419,573	5,367	592,490	7,038
Pentoxide (anhydride, vanadium content)	do.	132,904	943	205,956	1,364
Vanadium-bearing materials [ash, residues, slag, other (includes spent catalyst), pentoxide content]	do.	r1,574,007	r4,853	1,495,199	3,500
Zinc:					
Blocks, pigs, slabs	metric tons	549,137	619,880	NA	NA
Compounds (chloride, lithopone, oxide, sulfate, sulfide, and compounds n.s.p.f.)	do.	r48,106	r53,265	49,072	59,594
Dross, ashes, and fume (zinc content)	do.	6,483	4,658	NA	NA
Dust, powder, flakes	do.	15,424	26,169	NA	NA
Ore and concentrates (zinc content)	do.	45,419	22,110	NA	NA
Sheets, plates, strips, and other forms	do.	539	877	NA	NA
Waste and scrap	do.	31,596	14,185	NA	NA
Oxide	do.	38,215	43,712	NA	NA
Other (anodes, manufactures, and unwrought alloys)	do.	XX	22,765	XX	NA
Zirconium:					
Ore and concentrates	do.	35,706	13,772	37,439	6,906
Unwrought and waste and scrap	do.	197	1,347	115	821
Metal totals[2]		XX	27,605,000	XX	25,273,000
INDUSTRIAL MINERALS					
Abrasive materials (natural and artificial)		XX	r450,880	XX	482,134
Asbestos (unmanufactured)	metric tons	34,765	8,900	31,602	7,210
Barite:					
Barium chemicals	do.	29,382	22,551	32,173	24,322
Crude and ground	do.	887,205	41,304	353,665	17,324
Witherite	do.	18	8	NA	NA
Boron (contained boric oxide):					
Borax	thousand metric tons	10	3,260	16	5,328
Boric acid	do.	5	3,784	6	4,337
Colemanite	do.	18	4,389	30	8,408
Ulexite	do.	16	4,060	42	10,306
Bromine:					
Compounds (contained bromine)	thousand kilograms	r23,727	r41,952	14,646	32,559
Elemental	do.	r142	r91	851	522
Calcium:					
Metal	kilograms	821,457	5,238	815,264	4,452
Chloride (crude)	metric tons	124,094	18,610	128,253	17,653
Other compounds	do.	r84,130	r40,843	69,818	32,825
Cement: Hydraulic and clinker	thousand metric tons	7,893	r402,577	6,168	297,174

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
INDUSTRIAL MINERALS—Continued					
Clays:					
Kaolin (China clay)	thousand metric tons	3,373	$1,607	4,221	$2,122
Fire	do.	425	80	8,089	937
Fuller's earth and decolorizing earths	do.	82	47	160	31
Bentonite	do.	2,224	1,272	2,527	1,257
Ball and common blue clay	do.	699	230	753	262
Other (chamotte or dina's earth, artifically activated clay and activated earth)	do.	28,467	9,952	25,553	10,926
Diatomite	metric tons	436	162	182	128
Feldspar	do.	17,876	1,124	12,965	923
Fluorspar:					
Aluminum fluoride	do.	33,326	33,424	32,274	29,268
Cryolite	do.	3,359	3,448	4,067	3,897
Fluorspar	do.	r437,081	r53,483	407,169	42,502
Hydrofluoric acid	do.	r82,388	r89,085	67,135	67,051
Gemstones:					
Coral and similar materials (unworked)	thousand carats	r2,554	r6,741	2,787	6,115
Diamonds	do.	8,482	3,992,023	9,352	4,143,629
Emeralds (cut but unset)	do.	3,939	165,508	2,956	213,497
Pearls (natural, cultured, and imitation)		NA	r23,949	NA	25,919
Rubies and sapphires (cut but unset)	thousand carats	5,880	r152,484	7,246	152,886
Other precious or semiprecious stones		NA	r294,297	NA	297,388
Graphite:					
Natural [amorphous, crystalline flake, lump or chippy dust, and other natural (crude and refined)]	metric tons	33,544	21,662	49,744	25,538
Electrodes (electric furnace)	do.	26,871	45,635	27,388	43,740
Gypsum:					
Boards	thousand short tons	88	7,842	106	8,803
Crude	do.	7,633	52,070	7,915	52,972
Plasters	do.	11	258	7	660
Other	do.	XX	27,971	XX	33,600
Iodine:					
Crude	thousand kilograms	3,503	r35,516	3,652	32,911
Potassium iodide	do.	52	502	93	891
Iron oxide pigments:					
Natural	metric tons	3,288	1,624	3,428	1,382
Synthetic	do.	31,437	37,736	41,648	48,487
Kyanite (andalucite)	do.	5,140	933	6,380	1,126
Lime:					
Hydrated	short tons	r52,248	r3,841	45,059	3,661
Quicklime	do.	121,678	7,227	167,461	11,322
Lithium:					
Carbonate	kilograms	r3,109,834	r7,419	4,052,048	10,617
Hydroxide	do.	20,375	128	36,430	294
Magnesium compounds:					
Calcined dolomite	metric tons	27,852	r3,371	23,904	3,244

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
INDUSTRIAL MINERALS—Continued					
Magnesium compounds—Continued:					
Caustic-calcined magnesia	metric tons	107,848	$15,891	83,051	$12,309
Compounds (chlorides, hydroxide, peroxide, and sulfates)	do.	34,384	9,921	28,475	5,817
Dead-burned and fused magnesia	do.	r146,528	30,209	210,415	37,928
Magnesite (crude)	do.	1,956	r713	3,407	623
Other magnesia	do.	4,109	7,712	3,284	6,160
Mica:					
Scrap and flake:					
Powder	do.	9,725	5,219	11,568	7,479
Waste	do.	3,630	996	3,786	974
Sheet:					
Unworked	do.	1,422	1,608	2,054	2,011
Worked	do.	918	6,835	1,407	9,011
Nepheline syenite (crushed and ground)	do.	289,000	13,069	335,000	14,749
Nitrogen compounds:					
Anhydrous ammonia	thousand metric tons	r3,336	r392,463	3,271	365,826
Fertilizer materials	do.	6,495	822,102	6,505	818,978
Industrial chemicals	do.	58	59,444	49	47,321
Peat moss (poultry and fertilizer grade)	do.	573,200	96,132	638,670	110,749
Perlite (crude)	metric tons	e54,431	e1,597	e65,000	e1,900
Phosphate rock and phosphate materials	thousand metric tons	574	50,620	1,560	74,582
Potash:					
Potassium chloride	metric tons	r6,745,000	528,500	6,836,000	549,100
Potassium nitrate	do.	22,300	6,000	39,100	11,300
Potassium sodium nitrate mixtures	do.	r39,100	5,000	36,900	5,600
Potassium sulfate	do.	r55,700	10,100	67,700	11,800
Pumice:					
Crude or unmanufactured	do.	r115,458	10,047	254,112	10,464
Wholly or partially manufactured	do.	2,850	1,382	2,676	1,605
Quartz crystal (lacas)	thousand kilograms	NA	NA	NA	NA
Salt	thousand metric tons	6,188	87,380	5,394	87,714
Sand and gravel:					
Construction	do.	1,329	16,638	1,311	15,463
Industrial	do.	83	932	164	2,454
Sodium compounds:					
Soda ash	do.	134	21,299	72	12,772
Sodium sulfate	do.	157	13,807	158	13,444
Stone:					
Crushed and calcium carbonate fines	thousand metric tons	r5,200	r38,600	7,000	60,700
Dimension		NA	r474,914	NA	403,922
Strontium:					
Celestite (strontium sulfate)	metric tons	33,204	2,577	44,810	3,026
Compounds (carbonate and nitrate)	kilograms	16,629,319	10,803	22,370,558	13,877

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
INDUSTRIAL MINERALS—Continued					
Sulfur:					
Elemental	thousand metric tons	3,020	$241,749	2,725	$129,894
Sulfuric acid (100% H_2SO_4)	metric tons	1,845,255	57,727	1,985,414	68,496
Talc (unmanufactured)	do.	66,791	11,925	79,560	12,408
Vermiculite	thousand metric tons	38	NA	e40	NA
Industrial minerals totals[2]		XX	r9,185,000	XX	9,153,000
Total[2]		XX	r36,790,000	XX	34,426,000

rRevised. NA Not available. XX Not applicable.
[1]Less than 1/2 unit.
[2]Rounded.

TABLE 10

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

(Metric tons unless otherwise specified)

Mineral		1991			1992		
		World production[r,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]		80,379	W	NA	75,659	W	NA
Arsenic trioxide		43,638	—	—	47,600	—	—
Bauxite[3]	thousand tons	108,157	W	NA	103,625	W	NA
Beryl		6,611	[4]4,399	67	7,002	[4]4,826	69
Bismuth		3,225	W	NA	2,998	W	NA
Chromite	thousand tons	13,445	—	—	10,896	—	—
Cobalt[2]		26,803	—	—	21,924	—	—
Columbium-tantalum concentrate (gross weight)		38,358	—	—	35,193	—	—
Copper[2]	thousand tons	9,187	1,631	18	9,290	1,761	19
Gold[2]	kilograms	2,148,743	[r]296,805	14	2,247,840	329,124	15
Iron ore (gross weight)	thousand tons	956,224	[r]56,596	6	929,754	55,593	6
Lead[2]	do.	3,276	477	15	3,242	408	13
Manganese ore (gross weight)	do.	21,213	—	—	19,929	—	—
Mercury		3,213	58	2	3,014	64	2
Molybdenum[2]		117,732	53,364	45	111,667	49,725	45
Nickel[2]		948,796	[4]5,523	1	921,929	[4]6,671	1
Platinum-group metals	kilograms	288,338	[r]7,780	3	280,889	[r]8,310	3
Silver[2]		15,692	[r]1,855	12	15,345	1,804	12
Tin[2]		202,723	W	NA	179,466	W	NA
Titanium concentrates (gross weight):							
Ilmenite (including leucoxene)	thousand tons	3,411	W	NA	3,581	W	NA
Rutile	do.	458	W	NA	442	W	NA
Tungsten[2]		41,880	W	NA	30,755	W	NA
Vanadium[2]		28,477	W	NA	19,700	W	NA
Zinc[2]	thousand tons	7,170	547	8	7,137	552	8
METALS, SMELTER BASIS							
Aluminum	do.	19,528	4,121	21	19,219	4,042	21
Cadmium		20,221	1,676	8	18,750	1,620	9
Cobalt		24,243	—	—	19,991	—	—
Copper (primary and secondary)[5]	thousand tons	9,217	1,487	16	9,496	1,742	18
Iron, pig	do.	525,579	44,533	8	518,566	47,767	9
Lead (primary and secondary)[6]	do.	5,480	1,229	22	5,426	1,193	22
Magnesium (primary)		339,596	131,288	39	303,619	136,947	45
Nickel[7]		894,282	7,065	1	852,952	8,962	1
Selenium[8]	kilograms	1,631,118	259,522	16	1,723,854	242,797	14
Steel, raw	thousand tons	736,007	79,738	11	721,315	84,322	12
Tellurium[8]	kilograms	83,582	W	NA	90,800	W	NA
Tin[9]		205,948	W	NA	198,023	W	NA
Zinc (primary and secondary)	thousand tons	7,175	[r]376	5	6,354	400	6
INDUSTRIAL MINERALS							
Asbestos	do.	3,533	[10]20	1	3,121	[10]16	1
Barite	do.	5,685	[10]448	8	5,436	[10]316	6
Boron minerals	do.	2,965	[10]1,240	42	2,608	[10]1,009	39
Bromine		380,023	[10]170,000	45	378,800	[10]171,000	45
Cement, hydraulic[11]	thousand tons	1,190,275	[r]66,753	6	1,231,627	71,426	6

See footnotes at end of table.

TABLE 10—Continued

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

(Metric tons unless otherwise specified)

Mineral		1991			1992		
		World production[r 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[12]	thousand tons	9,008	[e]3,432	38	8,524	3,354	39
Fuller's earth[8]	do.	3,953	[10]2,740	69	3,624	[10]2,413	67
Kaolin[12]	do.	23,891	[10]9,575	40	21,502	[10]8,064	38
Diamond, natural	thousand carats	105,855	—	—	107,771	—	—
Diatomite	thousand tons	1,626	610	38	1,581	595	38
Feldspar	do.	5,544	580	10	5,771	725	13
Fluorspar	do.	4,077	[e 4]58	1	3,846	[e 4]51	1
Graphite, natural		596,036	—	—	567,390	—	—
Gypsum	thousand tons	97,792	[r]14,021	14	97,791	14,759	15
Iodine, crude		17,537	1,999	11	16,930	1,995	12
Lime[11]	thousand tons	132,215	[10]15,694	12	128,730	[10]16,227	13
Magnesite, crude	do.	11,166	W	NA	11,129	W	NA
Mica (including scrap and flake)		210,488	102,830	49	186,046	85,338	46
Nitrogen: N content of ammonia	thousand tons	93,995	[r]12,801	14	92,532	13,404	14
Peat[13]	do.	165,243	[r]632	4	147,950	599	4
Perlite		1,510,784	[10]514,036	34	1,396,665	[10]511,768	37
Phosphate rock (gross weight)	thousand tons	149,665	48,096	32	143,753	46,965	33
Potash (K_2O equivalent)	do.	15,323	1,749	11	22,172	1,705	8
Pumice[8]	do.	11,603	[10]401	3	11,142	[10]481	4
Salt[11]	do.	192,281	[r]35,943	19	184,854	34,829	19
Sand, industrial (silica)	do.	112,102	23,223	21	106,308	24,464	23
Sodium compounds, n.e.s. (natural and manufactured):							
Soda ash	do.	31,053	9,005	29	31,067	9,379	30
Sulfate	do.	4,611	696	15	4,297	609	14
Strontium[8]		193,752	—	—	217,100	—	—
Sulfur, all forms	thousand tons	55,041	[r]10,820	20	52,409	10,663	20
Talc and pyrophyllite[14]	do.	9,001	1,037	12	8,864	997	11
Vermiculite		534,693	[r 10]180,000	34	474,649	[10]190,000	40

[e]Estimated. [r]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.

[1]The world production totals on commodities for which U.S. data are withheld exclude U.S. production; therefore, percent of world production cannot be reported.

[2]Content of ore and concentrate.

[3]U.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 basis, but for some countries available data are insufficent to permit this adjustment.

[4]Shipments.

[5]Primary and secondary anode and blister copper, including electrowon refined copper that is not included as blister or anode.

[6]Includes bullion.

[7]Refined nickel plus nickel content of ferronickel, nickel oxide, and other nickel salts.

[8]World total does not include estimates for output in the former U.S.S.R. or China.

[9]Includes tin content of alloys made directly from ore.

[10]Quantity sold or used by producers.

[11]Data for the United States include Puerto Rico.

[12]World total does not include an estimate for output in China.

[13]Data for the United States exclude proprietary amounts of fuel peat.

[14]Data for the United States exclude 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) Long tons (4)	Metric tons (6)	Physical inventory Adjustment only (3)	Beginning stocks (4)	Production (5)	Shipments (6)	Ending stocks (7)
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? ☐ (1) Yes ☐ (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 more than 25 years. Mr. Chekan is a mining engineer who has been with the U.S. Bureau of Mines, Pittsburgh Research Center, for 14 years and has extensive research experience in coal mine ground control in multiple-seam mining operations. Mr. Jude is a mining engineer at the Denver Research Center who has extensive industrial and research experience in block caving mining operations.

MINING HIGHLIGHTS

Summary

The year 1992 recorded unimpressive economic growth and uncertainties over what changes would occur for the financial market. Falling interest rates in the United States and elsewhere tended to exert a number of positive influences on financial markets and, indirectly, the mining and quarrying industry. The interest rate declines during 1992 were no exception. Lower rates prompted many investors to turn their attention to long-term investments such as stocks that offer potentially greater rates of return, causing large cash inflows into the equity market. Lower rates made it easier for businesses to finance growth and for consumers to finance the purchase of products businesses made. Also the rates enabled many companies to increase their health and profitability by refinancing their existing loans at lower rates.

Falling interest rates were not confined to the United States. With Japan and Western Europe in the midst of economic slumps, marketing authorities in many countries overseas lowered rates in an effort to stimulate business activity. True to form, that contributed to stock market rallies abroad. Stabilizing inflation and lower interests stimulated the industry during 1992 and will likely influence favorably the industry for the next few years.

Worldwide minerals exploration slipped in 1992 from 1991 levels. Although industrial production figures showed the U.S. economy emerging from recession in early 1992, it was not until February 1993 that the lagging indicator of unemployment dropped to 7%. Most other industrialized countries are still in recession.

Preliminary data for 1992 showed industrial production dropping in Japan (5%), Germany (1.4%), the United Kingdom (0.5%), and France (1.48%). The slowdown in industrial production led to reduced mineral demand. This resulted in lean cash-flows from mining operations, which squeezed exploration funding. Although mineral prices were steady during most of 1992, some mineral commodity prices began falling in late 1992 and early 1993.

Exploration 1991-92.—According to Metals Economies Group (MEG), planned 1992 exploration expenditures were down by about 5%. Geographically, the leading exploration target was the United States with 21% of the expenditures, followed by Australia (19%), Canada (18%), Latin America (15%), the Republic of South Africa (9%), and the western Pacific (7.5%). The remaining 10% was split between Europe and Africa.

There were absolute increases in exploration expenditures in the United States and Latin America. Latin America showed the largest increase. The change in the Mexican mining law allowing foreign ownership of mines should result in the inflow of direct foreign investment in Mexico's mining industry.

Unresolved issues of property rights in Eastern Europe and the former U.S.S.R. are a deterrent to grassroots exploration by western companies in these areas. Projects, such as those of Newmont at Muruntau, Uzbekistan, and by Goldbelt Resources in Kazakhstan, apply new technology to established mining projects in return for a share of production.

The 1992 increase in domestic exploration spending reported by a MEG study is reflected in the increase in new claims on Federal land recorded by the Bureau of Land Management (BLM). Nevada accounted for nearly all of the increase.

During 1992, Congress considered proposals to impose new fees and regulations on exploration and mining on Federal lands. A new BLM claims fee of $100 for fiscal years 1992 and 1993 was imposed on all claims of record. The intent of the fee was to raise revenue. However, the law's effect also will be to concentrate acreage into fewer independent entities.

The Society of Economic Geologists (SEG) annual survey showed a slight decline in 1991 exploration expenditures by domestic firms in the United States when adjusted for survey coverage. This

survey of U.S. and Canadian firms showed an overall increase for exploration in Latin America from 1990 to 1991.

Respondents were asked to allocate exploration spending by product category. U.S. respondents spent about 71% on gold and 25% on base metals and Canadian respondents spent 27% on gold and 64% on base metals. When exploring in the United States, the Canadian respondents spent about the same percentage of gold as U.S. firms. The increase in base metals exploration relative to gold was reflected by the 1991 increase in the share of core drilling relative to rotary drilling.

In Canada, 1992 exploration expenditures appeared to be down by about 15% from those of 1991. Canada's mining industry is particularly vulnerable to worldwide recession because it is an export-based industry.

The BHP-Dia Met discovery of diamond-bearing kimberlites in the Northwest Territories (NWT) caused a diamond rush that has spilled over to northern Alberta. The massive claimstaking that followed, however, has foreclosed millions of acres to exploration for other minerals.

Gold exploration still accounted for more than one-half of the exploration expenditures in 1992. Newly reported North American gold discoveries included Pipeline (Gold Acres South), NV, by Cortez, and Gold Ridge, NV, by Atlas. New gold zones, ore bodies, and extensions of identified gold properties included the following:

- a new zone at Sunbeam, UT, by Centurion Mines,
- a new zone at Casa Berardi, Quebec, by TYX Gold and Golden Knight,
- a new ore body at Gold Ridge, NV, by Atlas,
- an extension at Jerritt Canyon and Gracie, NV, by Minorco,
- an extension at Amalgamated Kirkland property, Ontario, by Battle Mountain Gold,
- an extension at the New World, MT, by Crown Butte, and
- an extension at the Kendall Mine, MT, by Canyon Resources.

Other North American discoveries include Pointe Lake (diamonds, NWT) by BHP-Dia Met, Inushshuk (copper-zinc, NWT) by Minnova and Metall Mining, Prairie Creek (lead-zinc-silver, NWT) by San Andreas Resources, and Bell Alard South (copper-zinc-silver, Quebec) by Noranda.

New zones, ore bodies, or extensions were reported at Izok Lake (copper-zinc, NWT) by Minnova and Metall Mining, Gibraltar (copper, British Columbia) by Placer Dome and Newcoast, LaReyna (copper, Mexico) by Aurizon, and Piedras Verdes (copper, Mexico) by Azco.

Outside of North America, gold discoveries include Mount Constantine (Australia) by Hunter Resources and Western Minerals, Nalung (Greenland) by Nunoil, and Big Gossen (Indonesia) by Freeport-McMoRan.

New gold zones and extensions were announced for Macuelaizo (Honduras) by Melinga, El Higo (Dominican Republic) by Canyon Resources and Battle Mountain Gold, Carbine North (Australia) by Samantha Gold, Afema (Ivory Coast) by Eden Roc, Penjom (Malaysia) by Avocet Ventures, Minas de Oro (Honduras) by Kennecott and Fisher-Watt Gold, Kanowna Bell (Australia) by Delta Gold, and Orient Well (Australia) by Melita Mining.

Other reported discoveries include Mount Moss (zinc, Australia), by Jervois, Chacobamba and Ferrobamba (copper, Peru) by Minero, Cannington (polymetallic, Australia) by BHP, Naberru (diamond, Australia) by Great Central Mine, and Bamuigui (diamonds, Central African Republic) by United Reef.

Significant extensions were reported at Grasberg (copper-gold, Indonesia) by Freeport-McMoRan, Broken Hill (lead-zinc, Australia) by Pasminco, Golmay (lead-zinc, Ireland) by Arcon, Lisheen (lead-zinc, Ireland) by Ivernia and Chevron, and Cerratappe (copper, Turkey) by Cominco.

The Portugese Directorate of Geology and Mines announced the discovery of base and precious metals in the Iberian Pyrite Belt in Portugal. Indian and Argentine Atomic Energy Agencies announced uranium discoveries in those countries.

Trends and Outlook.—Forces have already appeared that promise changes for the U.S. mining industry. Proposed revisions to the Mining Law of 1872 would change the current patent system for assignment of minerals rights ownership on Federal lands.

Potential liability under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 (Superfund legislation) makes it risky to rework domestic mining properties as well as to develop new projects that have any potential of damaging the environment. This law reserves the right to assign liability to firms currently using best management practices for pollution mitigation in the event that emissions standards are tightened in the future. Potentially responsible parties (PRP's) are held joint and severally liable—one PRP could be held totally responsible for a site, even though several parties were involved in ownership and operation.

The emergence of the world economy from recession will fuel base metal demand. For countries seeking loans, the World Bank has been fostering mining laws reform to promote direct foreign investment. Perhaps the mining industry will find those countries making the reforms and having good prospects and stable political regime as attractive areas for future exploration.

In 1992, the U.S. economy grew at a rate of 2%. The gross domestic product rose to $5,946 billion. With 257 million people—635,000 in mining, including petroleum—the United States has more than 100 million dwelling units and more than 190 million licensed motor vehicles.

New private housing starts rose 11% to 1.2 million units. New car production rose 4% to 5.7 million units. Truck and bus production rose 20% to 4 million units.

The rate of inflation was 3.5%, and the prime rate of interest was 6.25%. The Producer Price Index (1982 = 100)

was relatively unchanged from that of 1991 as follows: fuels and related products and power, 80; metals and metal products, 119; chemicals and allied products, 126; and nonmetallic mineral products, 117.

Energy.—Imports of crude and refined petroleum, costing $50 billion, rose 3% to 455 million cubic meters (Mm^3) [2.9 billion barrels (bbl)]. Domestic petroleum production fell 1% to 582 Mm^3 (3.5 billion bbl). Petroleum supplied about 41% of U.S. energy; natural gas, 24%; and coal, 23%.

Coal production, 60% from surface operations, rose 1% to 914 million metric tons (m/t) [1 billion short tons (st)]. About 78% was used to generate electricity and 3% was coked. Exports valued at $4 billion included 57 Mmt (63 million st) of metallurgical coal and 39 Mmt (43 million st) of steam coal. Uranium mining, including recovery from phosphates, fell 18% to 3 thousand metric tons (kmt) (3,300 st) U_3O_8.

Nonfuel Minerals.—Processed nonfuel mineral materials were valued at $310 billion. Metals from U.S. ores fell 1% to $11.1 billion. Industrial minerals rose 6% to $20.7 billion. Recycled scrap, largely steel and aluminum, fell 30% to $10 billion.

Imports of nonfuel, mineral-based materials were valued at $43 billion and exports at $37 billion. Canada, with which the United States has a free trade agreement and is a partner in the North American Defense Industrial Base, was a major supplier of many minerals. The North American Free Trade Agreement (NAFTA) was signed in October 1993. The United States, Canada, and Mexico are part of the agreement. The treaty, however, still requires ratification by each country's legislature.

Major Metals.—Steel production rose 5% to 84 Mmt (93 million st). Iron ore mining rose 1% to 56 Mmt (62 million st), nearly all pelletized. Net ore imports fell 20% to 7.5 Mmt (8.3 million st). Steel capacity was 103 Mmt (114 million st). Voluntary agreements limiting imports terminated in March 1992. Net imports of steel totaled 10.5 Mmt (11.6 million st).

There was no domestic mining of chromium, cobalt, or manganese. The Glenbrook Mine, in Riddle, OR, produced 5.5 kmt (6,100 st) of nickel in concentrates and 9.1 kmt (10,000 st) of ferronickel.

Some tungsten and vanadium were mined. Upgrading of Government-stockpiled ores to ferrochromium and ferromanganese continued. This helped maintain some domestic ferroalloy production capacity.

Primary aluminum smelters ran close to capacity, producing 4 Mmt (4.4 million st). Some bauxite was mined but most came from imports of 12 Mmt (13 million st). That was supplemented by net imports of 4 Mmt (4.4 million st) of alumina.

Magnesium production totaled 135 kmt (149,000 st). Titanium mill shipments totaled 16 kmt (18,000 st). Copper production rose 5% to 1.7 Mmt (1.9 million st), and refinery production of 2.1 Mmt (2.3 million st) treated four-fifths primary material and one-fifth scrap.

Lead mining fell 14% to 410 kmt (450,000 st), and zinc mining rose slightly to 520 kmt (570,000 st). Primary refined lead of 300 kmt (330,000 st) was supplemented by 830 kmt (915,000 st) refined from old scrap. About 255 kmt (280,000 st) of primary slab zinc was supplemented by 125 kmt (140,000 st) of secondary plus net imports of 320 kmt (350,000 st).

According to *Metals Week*, yearly lows and highs were as follows:

- copper—98 cents to $1.21/pound (lb),
- aluminum—51 cents to 65 cents/lb,
- lead—32 cents to 39 cents/lb, and
- zinc—48 cents to 69 cents/lb.

Precious Metals.—In 1992, mines in the United States yielded 320 mt [10.3 million ounces (oz)] of gold and 1.8 kilograms (kg) (58 million oz) of silver. About 10% of the gold and 60% of the silver were a byproduct of base metal mining.

The Stillwater Complex in Montana produced 1.7 tons (55,000 oz) of platinum and 6.1 tons (195,000 oz) of palladium last year.

Nonmetallics.—Cement production rose 7% to 69 Mmt (76 million st). Four thousand quarries produced 1.1 billion mt (1.2 billion st) of crushed stone, and 4,200 sand and gravel pits produced 750 Mmt (8.30 million st). One thousand clay pits produced 38 Mmt (42 million st), and 61 gypsum mines produced 15 Mmt (16 million st).

About 460 kmt (510,000 st) of magnesium compounds was produced from brines and seawater. An estimated 1.1 Mmt (1.2 million st) of titanium dioxide pigments was produced from domestic and imported minerals.

Sulfur production totaled 10.6 Mmt (11.7 million st), 22% by the Frasch process. Production of other major nonmetallics included 36 Mmt (40 million st) of salt, 16 Mmt (18 million st) of lime, 9.5 Mmt (10.5 million st) of soda ash, and 520 kmt (570,000 st) of B_2O_3.

Fertilizers.—Mining of fertilizer minerals was essentially unchanged from 1991. Phosphate rock totaled 47 Mmt (52 million st) and potash 1.8 Mmt (2 million st) of K_2O. To that were added 13 Mmt (14 million st) of ammonia. Significant quantities of ammonia and potash are also imported.

Outlook.—The breakup of the U.S.S.R. and the lessening of cold war tensions led to reexaminations of the U.S. strategic posture. This included the roles of the United States-Canada North American Defense Industrial Base and the U.S. stockpile of strategic and critical materials.

The U.S. Department of Defense (DOD) reported to Congress that substantial reduction of stockpile goals and major disposals of stockpile inventories might be possible. In October 1992, Congress authorized the disposal of some stockpiled materials, largely minerals, valued at $4 billion. To ensure that such disposals (and possibly some acquisitions of new high-technology

materials) did not unduly interfere with the normal markets, Congress specified two major levels of review—one at the DOD level and one at the Presidential level.

In early 1993, the DOD Defense Logistics Agency (DLA) and its Market Impact Committee met frequently. The DLA then held several open meetings with industry to develop acceptable disposal methods.

Meanwhile, economic disorder in the Commonwealth of Independent States (C.I.S.) (the former U.S.S.R.) led to substantial dumping of former Soviet stockpiles of strategic metals, forcing metal prices to soften in a period of general worldwide economic malaise.

Foreign ownership of domestic mines and quarries is increasing, and there is excess world productive capacity for many minerals and metals. Traditional metals and alloys are being replaced by newer engineered materials based on geologically abundant elements, such as carbon, silicon, oxygen, and nitrogen, but costly sophisticated processing is required. For example, the United States' production of plastics totaled 30 Mmt (33 million st)—nearly double all metals on a volume basis.

Concerns about global climate change, acid rain, and industrial hazards are leading to more stringent regulations by Federal, State, and local governments. Land use and air and water issues concern the citizens of many lands. The venerable Mining Law of 1872 is scheduled for review and updating by Congress in 1993.

To ameliorate environmental and health and safety problems and to better meet global competitiveness challenges, the U.S. Bureau of Mines (USBM), with its seven Generic Mineral Technology Centers and 30 Mineral Institutes, continues collaborative government-industry-university innovative research in mineral science and technology.

Production Overview

The mineral industry experienced little growth in 1992. The value of processed materials of mineral origin was estimated at approximately $310 billion in 1992. The value of U.S. raw nonfuel mineral production in 1992 was estimated at approximately $32 billion, a 3% increase over that of 1991.

U.S. raw mineral trade declined moderately in 1992. Imports of metal ores and concentrates decreased by almost 5% to $1.2 billion, while raw industrial mineral imports declined nearly 14% to $700 million. Similarly, metal ore and concentrate exports fell almost 12% to $900 million. Raw industrial mineral exports departed from this trend, managing a modest increase of about 1% to $1.1 billion.

Both metals and industrial mineral mining employment showed modest decreases in 1992. Together, that resulted in a decline of 4.2% for the sector. Considered separately, total employment in industrial mineral mining declined 4.7% to 100,000 workers. Production workers decreased 5.4% to 74,000. Such declines continued to reflect the weak construction industry leading to relatively flat production of stone, sand, and gravel. Metals mining experienced smaller declines, with total employment falling 3.2% to 54,400, and the number of production workers declining 3.0% to 42,400.

Industrial Minerals

The industrial mineral industry has been slowed in recent years by reduced commercial building construction, which prevailed throughout much of 1992 due to a glut of office buildings, hotels, and other commercial properties. This glut helped dull the performance of crushed stone and sand and gravel industries. Overall, industrial mineral production gained 2% in 1992, and the results were mixed for sand and gravel and crushed stone. The value of production rose about 3% for construction sand and gravel and 4.5% for crushed stone.

U.S. demand for cement (excluding Puerto Rico) increased by 7.6% to 81 Mmt (87 million st). This was the first year cement demand increased since 1987. The cement production increase was due to growth in residential, nonresidential, and highway construction spending. Plans to stimulate the economy, through Federal, State, and local investments, were under discussion in early 1993.

Agricultural Minerals

Mining of fertilizer minerals was essentially unchanged from 1991. Phosphate rock totaled 47 Mmt (52 million st) and potash 1.8 Mmt (2 million st) K_2O. To that was added 13 Mmt (14 million st) of ammonia. Significant quantities of ammonia and potash also were imported.

The past decade has not been good to the fertilizer industry for many reasons, including plenty of supply coupled with depressed farm prices that stifled demand, closures of mines in Florida, and recent events in Eastern Europe and the C.I.S. In 1992, some activity was noted that may signal the beginning of a slow recovery. Increased demand should gradually occur for sulfates, phosphates, and potash on a worldwide basis, particularly in developing Far East countries where agricultural activity is expected to grow.

Metals

Aluminum.—Throughout 1992, the United States remained almost totally dependent on foreign sources of bauxite for production of primary aluminum metal. U.S. primary aluminum smelters ran close to capacity, producing 4 Mmt (4.4 million st). Some bauxite was mined but most came from imports of 12 Mmt (13 million st) of alumina. Approximately 93% of the domestic and imported bauxite consumed in 1992 was refined into alumina. Primary aluminum smelters received 85% of the alumina supply. Annual alumina capacity was 5 Mmt (5.6 million st), with five Bayer refineries in operation at yearend.

On a global basis, increases in primary aluminum consumption have not kept pace with increases in production capacity. World primary aluminum consumption has stayed relatively constant since 1988. Large inventories of

primary aluminum continue to have a dampening effect on prices, according to the Commerce Department, but producers did not cut back, largely because they have been successful in lowering costs. Commerce estimates the use of aluminum in autos will increase in the next decade as automakers strive to meet future fuel efficiency standards.

Iron and Steel.—In many respects, 1992 was an improvement over the steel industry performance of 1991. Steel production rose 5% to 84 Mmt (93 million st). Iron ore mining rose 1% to 56 Mmt (62 million st), nearly all pelletized. Net ore imports fell 20% to 7.5 Mmt (8.3 million st). Steel capacity was 103 Mmt (114 million st).

Voluntary Restraint Agreements (VRA's) expired in March 1992, and it was hoped they would be replaced with a multilateral steel agreement binding all nations that trade in steel. This agreement had not yet been reached as of early 1993. In mid-1992, about 12 U.S. steel companies filed countervailing duty and antidumping petitions with the Department of Commerce and International Trade Commission. The petitions charged 21 foreign countries with market-distorting subsidization and dumping practices. The procedure on these cases continued into 1993.

Copper.—Domestic mine production in 1992 was about 1.5 Mmt (1.7 million st), valued at $4.1 billion. As in previous years, copper managed to defy recessionary conditions. Copper prices, having fallen far less precipitously than those of other base metals in the previous couple of years, dropped no more steeply than the average in 1992. That allowed most producers to continue to record respectable profits. Copper consumption improved in the United States and was estimated to be about 8% higher than that in 1991. U.S. exports of copper materials and semifabricates continued to be high, prompted by the demand from Canada, the Far East, and Mexico.

Lead.—After considerable growth in domestic refinery production and consumption during 1987-89 and a leveling out in 1990, all sectors in 1992 continued to reflect recessionary conditions. World demand declined for the third year in a row, with supply ahead of demand. An increase in mine output was most noticeable in Canada, while declines were most apparent in the United States and Europe. U.S. lead mining fell 14% to 410 kmt (450,000 st). Primary refined lead of 300 kmt (330,000 st) was supplemented by 830 kmt (915,000 st) refined from old scrap.

Zinc.—Domestic zinc mine production was only marginally higher than in the previous year but, nonetheless, was the highest since 1965. Zinc mining rose slightly to 520 kmt (570,000 st). About 255 kmt (280,000 st) of primary slab zinc was supplemented by 125 kmt (140,000 st) of secondary plus net imports of 320 kmt (350,000 st). Two zinc-producing mines, one in Oregon and the other in Tennessee, opened in 1992. Alaska again accounted for about one-half of the U.S. total output, even though the Red Dog Mine in northwestern Alaska continued to produce below rated capacity.

Galvanizing represents the largest end use of zinc in the United States, and an increase in demand by the two largest users—autos and construction—accounted for a 7.2% increase in consumption in 1992. By 1996, almost all cars and light-duty trucks with steel bodies sold domestically will be made from two-sided galvanized steel.

Precious Metals

Gold.—U.S. gold production yielded 320 tons (10.3 million oz of gold). Despite continuing weak gold prices, the United States maintained its position as the world's second largest gold-producing nation, after the Republic of South Africa. Nevada and California were again the Nation's dominant gold-producing states, together accounting for about 70% of the U.S. total. U.S. gold exploration activity, having peaked about 1988, continued to trend downward. Estimated uses in 1992 were as follows: jewelry and arts, 70%; industrial (mainly electronic), 23%; and dental, 7%. Environmental pollution abatement continued to be of concern to domestic gold producers, especially in Alaska, where there are many small placer mines.

Silver.—U.S. silver recovery yielded 1.8 kmt (58 million oz) silver. About 60% of the silver was a byproduct of base metal mining. U.S. silver production declined for the second consecutive year. During 1991, operating levels at a number of silver-producing mines were reduced or the mines were temporarily idled. In 1992, operations at these mines generally remined unchanged. The low silver price was cited most often by company officials when announcing mine closures or reduced production rates. Approximately 50% of the refined silver consumed domestically during 1992 was used in the manufacture of photographic products; 21% in electrical and electronic products; 9% in electroplated ware, sterlingware, and jewelry; and 20% in other uses.

Platinum-Group Metals.—U.S. production of platinum and palladium in 1992 was held at about the same level as that in 1991. Ore containing the platinum-group metals (PGM) was mined, concentrated, and smelted by the Stillwater Mining Co. (SMC), in Nye, MT. The resultant PGM matte was exported to Belgium for refining and separation of the individual PGM. The Stillwater operation produced 1.7 tons (55,000 oz) of platinum and 6.1 tons (195,000 oz) of palladium in 1992. Refined PGM products were distributed among using industries as follows: automative, 38%; electrical and electronic, 29%; dental and medical, 9%; chemical, 4%; petroleum refining, 5%; and other, 15%. The automotive, chemical, and petroleum-refining industries used PGM mainly as catalysts. Mine production of PGM was valued at $38 million in 1992.

Second National Minerals Education

Conference

USBM personnel participated in the second National Minerals Conference, held in Salt Lake City, UT, in June 1993. The National Energy Foundation (NEF) coordinated the conference, with cosponsors including the USBM, American Mining Congress, National Coal Association, and mining associations from Arizona, California, Idaho, Nevada, and Utah. Participating organizations and corporate cosponsors included Caterpillar Inc., Freeport McMoRan, Kennecott Corp., American Coal Foundation, Mineral Information Institute, and the NEF. The NEF conference provided a forum to share ideas, learn what programs are working for others, review educational initiatives underway, and support educational reform.

Incentive Bonus Systems

Mining companies continue to use incentive bonus plans as part of their wage systems in 1992. As an example, after a strike was narrowly averted in 1989, Magma Copper Co. of Arizona realized that its future depended on a major improvement in labor relations. The company began applying innovative human resources programs that directly involved the employee in building a future for the company. The result of 2 1/2 years and 400,000 management and employee hours was a historic 15-year labor agreement and a highly participative work culture.

Instilling this participative culture is ongoing and, in 1992, each of Magma's divisions designed and initiated programs aimed at involving all employees in the running of the operations.

Gainsharing programs were adopted by Magma in 1991. Each division has its own specific gainsharing plan that focuses on performance objectives within the control of employees.

In 1992, Magma and its employees reduced costs by $0.05 per pound and improved productivity by 12 % over 1991 levels. Employees eligible for gainsharing were paid an average of $4,750 per person in gainsharing awards.

Mexico Adopts New Mining Law

The Mexican Government published a new Mining Law in July 1992 that regulates Article 27 of the 1917 Mexican Constitution and will be enforced by the Federal Executive Branch through the Secretaria de Energia, Minas e Industria Paraestatal (SEMIP). In terms of the effect on foreign participation in the mining industry, the new Mining Law is much more important than NAFTA, which has little effect on the mining industry.

The new Mining Law allows the private sector to play a much larger role in the mining industry as the Government of Mexico continues to privatize State-owned companies, divest its mining reserves, and encourage domestic investment and foreign participation in the mining industry. The law allows direct investment, with up to 100% ownership of the capital stock, in exploration works and activities. Through a 30-year trust mechanism, it allows up to 100% of the capital stock that is renewable indefinitely for foreign participation in mining works and activities. The new Mining Law clearly spells out the ores or substances covered by the law and provides greater legal security for holders of exploration and exploitation concessions. The law allows private-sector participation in the exploitation of mineral deposits previously considered as priority and strategic within the domain of Government ownership, such as coal, iron ore, phosphate rock, potassium, and sulfur. The law extends the term of exploitation concessions from 25 to 50 years, renewable for a similar period, while exploration concessions will be for nonrenewable 6-year periods. Through competitive bidding, it allows exploration and mining for minerals on the continental shelf and underwater shelves of islands, as well as the seabed and the subsoil of the exclusive economic zone. A limiting factor of these concessions is that they are nontransferable.

Some examples of substances not covered by the 1992 Mining Law are as follows:

- petroleum and solid, liquid, or gaseous hydrogen carbides;
- radioactive minerals;
- substances contained in suspension or dissolution by subterranean waters; and
- salt that comes from salt pits formed in basins.

The Mining Law eliminates the need for concessions for ore preparation plants, and the system of substances incorporated in the national mining reserves is eliminated. The individuals engaged in processing minerals subject to this law will be obliged to inform SEMIP when their operations begin, submit the relevant reports, and comply with the general regulations and specific technical standards in the area of environmental balance.

The law brings greater flexibility to the management of mining affairs; eliminates excessive, repetitive obligations and red tape; stimulates small- and medium-scale mining production; and promotes private-sector investment in exploration and mining activities. The beneficial aspects of the 1992 Mining Law, combined with the reduction of corporate income tax to 35% in 1989 and the elimination of the mineral production tax in 1991, have led to an increase in large mining projects being launched with the participation of domestic and international private capital. During 1990 and 1991, almost $1 billion was invested in the Mexican mining sector, twice the rate of investment in 1989. To date, about 3.9 million hectares of national mining reserves has been divested. In addition, to encourage the exploitation of mineral deposits, the number of mining titles issued has doubled from 2,000 annually to more than 4,200, and the land area covered by concessions has increased from 2.8 million hectares.

LEGISLATION AND GOVERNMENT ACTIONS

Revision of the U.S. Mining Law of 1872

The Mining Law of 1872 established a policy of "self-initiation," whereby a

prospector could file an unpatented mining claim if he made a discovery of a valuable mineral. 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. A typical claimant may invest $250,000 in development prior to being issued a patent according to mining industry estimates.

In an effort to restructure the Mining Law of 1872, both Senator Bumpers (S. 433) and Congressmen Rahall (H.R. 918) and Defazio (H.R. 2614) introduced and later modified bills in the 102d Congress to provide comprehensive changes. Key arguments against the current law included (1) inadequate control of environmental damage, (2) patenting of surface ownership for less than fair market value, (3) lack of financial return to the Government (royalties), and (4) nonmining abuses of claims.

On June 24, 1992, the House Committee on Interior and Insular Affairs approved, with amendments, a substitute to H.R. 918 offered by Mining Subcommittee Chairman Rahall. As in the original bill, the substitute gave jurisdiction over U.S. Forest Service lands to the Secretary of Agriculture; withdrew "common variety" materials and some "environmentally sensitive" areas from operation of the law; eliminated extralateral rights and patents, as well as the requirements for discovery; afforded claimants' exclusive rights of possession for mineral activities; and specified claim location and maintenance requirements, including a graduated per acre annual rental fee. It also required that mineral activities be compatible with land use planning and be covered by an approved plan of operation, including a reclamation plan and bonding for the full cost of reclamation. The bill established and funded an Abandoned Minerals Mine Reclamation Fund. Current claimants would be required to convert their claims within 3 years.

The substitute to H.R. 918 did, however, contain some significant changes from the original bill. It changed the original diligence requirements to allow an offset in rental fees for the amount of diligent development expended and it established detailed reclamation standards. Instead of identifying all mineral lands on public domain lands as part of the land planning process, it required that land use plans be amended for all areas unsuitable for mineral activities and the criteria that could be used to determine unsuitability were greatly expanded. Amendments to the substitute added an 8% gross income royalty on production on mining claims located under the act and a small miner exemption to waive or reduce rentals and diligence expenditures. H.R. 918 was not considered by the full House in 1992.

Also during 1992, Senator Bumpers considered a significant amendment to his original bill S. 433. Although the original bill represented a complete restructuring of the law, the substitute preserved many of the current principles, including mining claim location, recordation, and patenting. Jurisdiction over Forest Service lands would have transferred to the Secretary of Agriculture. The substitute, however, would have established a graduated per acre annual holding fee, to be split between the States and Federal Treasury, and imposed a term limit on mining claims of 15 years, with a possible 5-year extension. Reclamation plans and financial guarantees were required, and some reclamation criteria were specified. Neither S. 433, in its original nor proposed substitute, received further consideration by the Senate Energy Committee in 1992.

In his June 23, 1992, letter to House Interior Committee Chairman Miller, Secretary Lujan expressed his strong opposition to the Rahall substitute to H.R. 918, a position consistent with earlier Department comments on the text of H.R. 918 and S. 433. Although the Bush administration supported possible changes in the areas of annual labor, distinction between "common varieties" of mineral materials subject to sale and "uncommon varieties" subject to location under the Mining Law, and the matter of obtaining a fair return to the Government for surface use and for issuance of a patent, it felt that any change had to support four principles of the current Mining Law: (1) self-initiation of mineral rights, (2) free access across public lands, (3) security of tenure to mineral deposits, and (4) diligence that is self-policing.

As in fiscal year 1992, the President's fiscal year 1993 budget request included a $100 annual holding fee per unpatented mining claim, mill site, and tunnel site previously estimated to generate revenues of $97.5 million in 1992. Of this amount, $17.3 million would be retained by BLM to cover administrative costs and the remaining $80.2 million would be deposited in the General Fund of the Treasury. H.R. 5503, providing appropriations for the Department of the Interior for fiscal year 1993, passed the House on July 23, 1992, and included the $100 holding fee supported by the administration. It also contained a 1-year patent moratorium. When the Senate passed H.R. 5503 on August 6, 1992, the holding fee provision was retained, but a patent moratorium amendment offered by Senator Bumpers was replaced by an amendment providing Mining Law structural reforms sponsored by Senators Reid, Dominici, DeConcini, and Bryan.

The Reid reforms replace the extant $2.50 and $5 per acre patent fees with a requirement to pay fair market value for the surface estate. Patented claims would revert to Federal ownership if used for unauthorized or unapproved purposes. Surface reclamation requirements would be codified within the structure of the Mining Law. Following the failure of a motion to table the Reid amendment on August 5, 1992, by a vote of 45 to 52, the amendment was accepted to H.R. 5503 by voice vote. In addition, on August 6, 1992, an amendment to H.R. 5503 offered by Senators Reid and Bumpers to require reclamation bonding at the outset of mining operations was adopted by voice vote.

The Reid-sponsored, Senate-passed provisions did not survive the House/Senate Conference. The $100

holding fee, however, adopted by both bodies, was nonconferenceable. Under this provision, a mining claimant must pay the fee unless (1) he or she is producing $1,500 to $800,000 per year of minerals on less than 10 claims, (2) he or she is exploring 10 or fewer claims, or (3) he or she has 10 acres or less of unreclaimed land, either in production or in exploration.

In the fall of 1992, the BLM developed regulations covering the payment of the $100 holding fee. Existing claimants still were required to file the old affidavit of $100 assessment work for the September 1, 1991, through September 1, 1992, mining year by December 30, 1992. Because Congress made the holding fee a 2-year requirement, claimants also are required to pay the fee for the September 1, 1992, through August 31, 1993, mining year and September 1, 1993, through August 31, 1994, mining year at the same time. Thus, many miners were required to make a double payment in August 1993. For claims staked after October, 5, 1992, claimants must (1) file the usual certificate of location with BLM with a $10 payment, plus (2) pay immediately the $100 rental for the mining year that runs through August 31, 1993.

Resource Conservation and Recovery Act

During 1992, considerable Environmental Protection Agency (EPA) activities focused on attempts to reissue its "mixture and derived-from" rules under the Resource Conservation and Recovery Act (RCRA). These rules were adjudicated invalid on procedural grounds by the U.S. Court of Appeals for the District of Columbia in late 1991. The court indicated that EPA had not elicited sufficient public comment on the rules prior to its finalization and remanded to the Agency for repromulgation. The rules had required that any wastes mixed with or derived from a hazardous substance must be treated as hazardous wastes under RCRA. After the refusal of the District of Columbia Court to rule on whether or not its decision was retroactive, the Eighth Circuit overturned a RCRA conviction because of the invalidation of the EPA rules. Sources have commented that these developments could lead to relitigation of many cases by EPA.

Although RCRA was not reauthorized in 1992, significant congressional activity centered on consideration of relevant issues. Topics debated included toxic use reduction, enhanced chemical production reporting, and possible limitation of the statute to municipal solid waste concerns. H.R. 3865, the RCRA package of Representative Al Swift, Chairman of the House subcommittee on Transportation and Hazardous Materials and of the House committee on Energy and Commerce, was a major bill considered. Prior to markup by full committee, there were no provisions directly relating to mine waste management. During the markup, the subcommittee rejected an amendment that would have required EPA to consider the "practicable capabilities" of Senate Environment & Public Works Committee, chaired by Senator Quentin Burdick, and passed its RCRA reauthorization bill, S. 976, on May 20, 1992. This bill did not contain provisions directly impacting management of mine waste. However, sources have said that the bill faces an uncertain future because of industry's opposition to recycling requirements and to the bill's reporting demands for facilities that use toxic chemicals. The environmentalists contend that the demands of the bill are too weak.

Clean Water Act Reauthorization

Efforts to reauthorize the Clean Water Act (CWA) took a back seat to RCRA bills during 1992 and also encountered a divided Senate in approaches to reauthorization. The issue of how to reform wetlands provisions of the CWA became the critical hurdle that prevented progress in the Senate on reauthorization. The House did not take up comprehensive clean water reauthorization. When the 103d Congress convenes, CWA reauthorization is expected to be at the top of the legislative agenda. Reauthorization proposals are likely to focus on watershed planning with pollution prevention and pollution from nonpoint sources receiving much attention. This focus may potentially have a significant impact on mining activities, especially for the control of wet weather runoff.

Stormwater Permits.—The 1987 amendments to the CWA mandated a two-phase program to control stormwater runoff. Under the program, municipalities and various industries must apply for permits. Phase 1 covers large municipalities and stormwater discharges associated with industrial activity. The industrial activity category covers about 31 sectors, including metal mining, coal mining, and mining and quarrying of nonmetallic minerals. In April, the EPA issued a final rule for the submission of individual permit applications by October 1, 1992. A permit model for individual industrial permits, outlining the classes of dischargers and data that must be reported, was issued in late September. Under the model, all facilities must develop a site-specific stormwater pollution prevention plan that describes on-site pollution sources and identifies pollution prevention measures and controls. The number of pollutants to be monitored and amount of monitoring data needed have been subjects of controversy between industry and the EPA in developing the monitoring group criteria for the permits. It is expected that EPA will issue its final group application requirements in October 1993.

Wetlands.—The controversy over Federal wetlands regulatory reform continued during 1992. Several divergent wetland bills were given attention in Congress. The Wetlands Reform Act of 1992, H.R. 4255, had the backing of environmentalists seeking to boost wetlands protection by strengthening the EPA permitting role and expanding the number of activities requiring a permit. Another bill, the Comprehensive Wetlands Conservation and Management Act of 1991, H.R. 1330, was an industry

supported bill reintroduced in the 102d Congress that would limit the EPA wetlands permit veto authority. The bill also would classify wetlands into high, medium, and low value wetlands and would allow development to occur in the low value wetlands without a permit. Also at issue were which of several existing manuals to use for identifying wetlands. This issue may be resolved by a National Academy of Sciences study funded by Congress in the fall of 1992. The study will be completed by the fall of 1994 and will cover wetlands delineation.

In another wetlands development, EPA has developed a proposal as part of the settlement in the "Tulloch" case. The proposal should expand Federal authority to regulate a variety of wetland activities, including ditching, draining, excavation, and other development-related actions. This could significantly affect mining and other earth disturbing projects conducted in wetland areas.

Ecosystems and Endangered Species

Concern with the effects of economic activity on the environment continued, as reflected in the controversy over the Northwest Spotted Owl. Although most agreed with the objective of protecting the old growth forests that host the owl and other species, the high cost in jobs and incomes for northwest logging communities seemed high. The controversy illustrated what the Secretary of the Interior Bruce Babbitt referred to as a "train wreck"—the inevitable conflict and collision of environmental and economic interests under the current approach that focuses on a single specie (the owl, the desert tortoise, or limestone endemic plants in the California desert). During recent years, recognition of this problem has resulted in an "ecosystems" approach to the management of public lands and, increasingly, to other environmental issues. In this approach, the interactions of plants, animals, and their physical environment are considered in the development of environmental policy. The U.S. Forest Service, the BLM, the EPA, the Corps of Engineers, and the U.S. Fish and Wildlife Service are all involved in the development of this new approach and are currently working on definitions and guidelines. The evolution of policies awaiting reauthorization such as the CWA, and the Endangered Species, and any new environmental legislation are likely to be heavily influenced by the ecosystems approach.

Clean Air Act Amendments 1990

Passage of the Clean Air Act Amendments has significant and long-term consequences for U.S. minerals industry competitiveness. The act applies directly to metallurgical processing through the control of emissions of toxic substances. Indirectly, the act affects the cost of energy for the minerals industry as powerplants pass through higher compliance costs for acid rain reduction regulations requiring scrubbing or the use of higher cost low-sulfur coal. "Bureau studies have revealed that the average cost increase could be 2.5 to 4 cents per pound of aluminum metal, 2.5 to 4.5 cents per pound silicon metal, and 2 to 3 cents for ore-grade ferrosilicon, as a consequence of the acid rain provisions of the Clean Air Act."[1]

Section 169B of the Clean Air Act Amendments of 1990 authorized the creation of visibility commissions to study regional impacts of emissions on visibility. The Grand Canyon Visibility Transport Commission (GCVTC) was created to study visibility issues in the so-called Golden Circle class I area encompassing large areas of Arizona, Colorado, New Mexico, and Utah, and is the prototype for future commissions. The work of the GCVTC continues. "The scope of the class I area of concern and the transport region shows that [GCVTC] findings will have potential to affect major portions of the western minerals industry."[2]

Title III of the Clean Air Act Amendments of 1990 requires the establishment of maximum achievable control technology (MACT) standards for major and area sources of hazardous air pollutants. For the smelters, EPA has initiated the MACT process with a study of copper smelters. EPA is also gathering information related to potential revisions to the primary National Ambient Air Quality Standard (NAAQS) for sulfur dioxide (SO_2). Of primary concern is EPA's focus on a short-term SO_2 standard protective of exercising asthmatics. These two developments have potential to increase costs to nonferrous smelters.

Off-road diesel emissions is another potential cost raiser for mines, especially if the "construction equipment" category is extended to mining vehicles.

The EPA is developing new rules for prevention of significant deterioration (PSD) and nonattainment that pertain to construction and modification of major sources. Revisions to attainment and nonattainment areas for criteria pollutants such as SO_2 and PM-10 are being reported to EPA by States. These changes could impact minerals-related activities within these changing boundaries.

The EPA will issue a notice of proposed rulemaking in November 1993 regarding standards for secondary lead smelters under its hazardous air pollutant authorities.

Summarizing, new regulations will continue to add cost to minerals-related activities in the United States, and U.S. relative competitiveness will continue to be a concern.

NAFTA

On August 12, 1992, 14 months after the formal start of negotiations, the United States, Canada, and Mexico announced completion of the NAFTA. The NAFTA is a regionwide trade agreement that will progressively eliminate tariffs and nontariff barriers to trade in goods, improve access for service trade, establish fair rules for investment, strengthen protection of intellectual property rights, and create an effective dispute settlement mechanism.

The United States negotiated NAFTA under the "fast track" procedures of the Trade Act of 1974 and the rules set forth in the 1988 Trade Act governing the application of fast track procedures to bills implementing certain types of trade

agreements. Pursuant to those rules, the President notified Congress on September 18, 1992, of his intent to sign the NAFTA. The NAFTA text was initiated by Ministers at a meeting of the three heads of state on October 7, 1992, in San Antonio, TX. The three heads of state signed the NAFTA in their respective capitals on December 17, 1992. The next step will be consideration by the Congress of NAFTA implementing legislation.

Proposed Multilateral Steel Trade Agreement

On July 25, 1989, the administration established the Steel Trade Liberalization Program. The program's ultimate goal was to ensure that market forces, not governments, determine prices and the level and pattern in international steel markets.

The first phase of the program included the negotiation of 10 bilateral consensus agreements to eliminate trade-distorting practices in the steel sector and the extension of the steel VRA's. These agreements were terminated as scheduled in March 1992.

Under the terms of the program, after March 31, 1992, domestic producers would have to rely on domestic trade laws to remedy foreign trade distorting practices. On June 30, U.S. producers filed 84 antidumping and countervailing duty investigation reports against imports of certain flat-rolled steel from 20 countries. These petitions, and others on certain other steel imports, were investigated by the U.S. Department of Commerce and the International Trade Commission.

Anticipating the expiration of the VRA's and bilateral consensus agreements on March 31, 1992, the United States has concentrated its efforts on incorporating the obligations and disciplines of the bilateral agreements into a multilateral accord within the General Agreement on Trade and Tariffs (GATT). This multilateral effort builds upon the rules established in the bilateral consensus agreements.

More than 30 countries have been participating in the multilateral steel negotiations, including the bilateral consensus counties and others, such as Argentina, Canada, and Sweden. The principal U.S. objectives for a multilateral agreement include prohibitions against most subsidies and the establishment of an effective mechanism to resolve disputes. Negotiations toward a multilateral steel agreement are expected to continue into 1993.

Lead-Acid Battery Recycling

Lead-acid batteries are the Nation's most recycled commodity. Lead-acid battery recycling has generally been increasing in recent years, reaching 97% in 1991. Fifteen companies operated 20 battery-breaking plants and 22 smelter-refineries in 1992.

Plant capacities ranged from 10,000 to more than 100,000 tons annually. Two such plants in Ohio and Tennessee remained temporarily shut down, and some others had curtailed operations. A major battery recycling plant in Alabama was permanently closed by the EPA early in the year. Operations were indefinitely suspended at a smaller battery recycler at midyear in Tennessee, but this was offset by Refined Metal's Memphis, TN, plant coming back on-stream. A new, small battery recycler came partially on-stream in Ohio, but was not producing at yearend owing to financial and technical problems.

The Doe Run Co.'s new $38 million lead-acid battery recycling center in Boss, MO, (100 miles south of its headquarters) was in its first full year of operation and produced at full capacity. The facility is designed to produce up to 60,000 tons of refined lead from 120,000 tons of used batteries. It was designed to produce one-third the volume of hazardous waste normally associated with battery recycling operations.

Several bills relating to recycling of lead-acid batteries were introduced in Congress in 1991, but had not been acted upon. Most were not reintroduced in Congress in 1992. One bill, H.R. 2479 (essentially a revamping of H.R. 2922 introduced in 1991), was introduced in June 1993 by Representative Carden (Maryland). It was titled "The Lead-Acid Paint Hazard Abatement Trust Fund Act of 1993" and intended to tax all (both primary and secondary) lead production at $0.045 per pound to pay for a $1 billion trust fund for a lead abatement project. A parallel bill was introduced in the Senate by Senator Bradley (New Jersey).

A major reason for such a high recycling rate is the enactment of mandatory battery collection and recycling laws in 42 States. These States account for more than 85% of the Nation's population. These State laws are substantially based on a lead-acid battery collection and recycling reverse distribution system. Under this system, retailers, wholesalers, manufacturers, and automotive dismantlers accept used lead-acid batteries from customers for delivery to secondary lead smelters, collection, or recycling facilities regulated by the States or subject to regulation by EPA under Federal law.

Basel Convention

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal "Basel Convention" is an international agreement dealing with the export and import of hazardous wastes. The United States signed the Basel Convention on March 1990. However, to implement the Convention in the United States, Senate ratification is required, and legislation must be passed to provide the necessary statutory authority.

The Basel Convention requires that hazardous wastes be disposed in an environmentally sound manner, regardless of the nation in which the disposal takes place, and requires that governments prohibit exports of hazardous wastes unless they can be sure that the hazardous wastes will be properly handled and disposed in the receiving nation. Although most scrap metal is nonhazardous, almost all scrap metal still will be subject to the Convention, even when they are being transported for the

purpose of recycling. If all metal wastes and scrap were subject to the Basel Convention procedures, it would be costly and disruptive to trade in the minerals and metals industries. Transactions would be unnecessarily delayed at best. Some transactions would be aborted because of delay, and added cost would alter the economics of the transaction.

The Basel Convention allows nations to make bilateral or multilateral agreements, as long as the underlying requirements are not compromised. Such agreements could modify the "notification," "consent," and "document" requirements. The United States already has agreements in place with Canada and Mexico. The United States also entered into an agreement to regulate the transboundary movement of hazardous recyclable materials among the Organization for Economic Cooperation and Development (OECD) nations. The negotiation of additional agreements with every nation with whom the U.S. trades may prove to be burdensome to the agencies involved; i.e., State and EPA. Much of U.S. trade in metal scrap is with other nations such as China, India, the Republic of Korea, and Taiwan.

The Convention entered into force on May 5, 1992, 90 days after ratification by Australia, the 20th nation to ratify. The first meeting of the Conference of the Parties (COP) to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal was held November 30 to December 4, 1992, at Piriapolis, Uruguay. The United States participated at the Initial Conference of the Parties as an observer. The second meeting of the COP to the Basel Convention will be scheduled for February or March 1994.

As of September 1993, 46 nations have ratified the Convention, but the United States is still not one of these. During the 102d Congress, none of the numerous draft bills continuing Basel Convention-implementing language was passed. In July 1993, the Clinton administration began the process of drafting new Basel-implementing legislation. This task will be completed as an interagency process lead by the EPA, and the EPA will be negotiating with both houses of Congress to avoid conflicts as much as possible. The U.S. Senate ratified the Basel Convention on August 11, 1992, but the State Department is not delivering the instrument of ratification to the United Nations until implementing legislation is passed by Congress. After the instrument of ratification is delivered to the United Nations, a 90-day period must pass before the United States will be recognized as a party of the Convention.

Trade Issues

NAFTA.—The United States, Canada and Mexico on December 17, 1992, signed the NAFTA, a regionwide trade agreement that will progressively eliminate tariffs and nontariff barriers to trade in goods; improve access for services trade; establish rules for investment; strengthen protection of intellectual property rights; and create an effective dispute settlement mechanism. The three countries on August 13, 1993, completed negotiation of supplemental agreements concerning labor, the environment, and import surges. NAFTA is scheduled to enter into force on January 1, 1994, subject to domestic approval and implementation procedures in the respective countries.

The 1917 Mexican Constitution makes subsoil resources and minerals the property of the Nation, and companies wishing to open mining operations must obtain concessions from the Government. Such concessions are only granted to Mexican nationals or majority-owned Mexican firms.

In September 1990, Mexico issued new mining regulations that included permission for foreigners to control up to 100% of mining properties through trusts for up to 12 years. In 1992, a new Mining Law was promulgated (published) under which the private sector, including foreigners, will be able to exploit coal, iron, potassium, phosphorous rock, and sulfur. The State will retain total or majority control over oil and hydrocarbons, salt, radioactive minerals, deepsea suspended particles, and construction-grade stone. The law also sets the stage for the privatization of several State-owned mining companies.

Five years after the NAFTA takes effect, U.S. companies will be given national treatment and may obtain concessions on the same basis as Mexican companies.

GATT.—GATT market access talks continued in 1992 in Geneva. Australia, Canada, and the United States continued to pursue zero-for-zero in nonferrous metals. Zero-for-zero means the mutual elimination of tariffs among key trading partners. France continued to oppose tariff elimination in aluminum, but Japan's position on copper appeared to be softening.

In July 1993, the Quad countries (Canada, the European Community, Japan, and United States) reached agreement on the minimum elements necessary for a Uruguay Round market access package. This package included zero-for-zero in eight sectors. The Quad countries will continue to seek a solution in nonferrous metals and harmonization of other tariffs at a rate higher than zero.

In July 1993, Congress extended the fast track authority for the Uruguay Round for 10 months. Under the new authority, the President must notify Congress by December 15, 1993, of his intention to enter into a trade agreement. This means that all negotiations must be completed by December 15.

Public Land Use

A proposal by preservationists to establish the Emigrant Trail National Conservation Area in northwestern Nevada would prohibit mineral development on the pioneer-wagon Applegate-Lassen and Nobles trails and surrounding BLM lands. The USBM responded with a mineral assessment of the 1.7-million-acre region (MLA 7-93) to assist the BLM in its land use planning process.

In response to proposed legislation, H.R. 4370, "Bodie Protection Act of 1992," the USBM conducted a mineral

resource evaluation and a study of the social and economic impacts of proposed gold mining adjacent to the Bodie State Historic Park in east-central California (MLA 5-93). The legislation would prohibit mining on about 6,000 acres of public lands to the east of and adjacent to the park.

The USBM published an evaluation of potential impacts on known and undiscovered metallic mineral development on 1.5 million acres of the California Desert by the land use bills H.R. 2929, S. 21 and H.R. 3066/S. 2393 entitled: Economic Analysis of the Minerals Potential of the East Mojave Scenic Area, CA (OFR 55-92 and 56-92).

National Defense Stockpile

In prior years defense spending was in the vicinity of $300 billion per year, but significant cuts in defense spending are lowering current demand for many defense-related mineral-based materials. Further, the DOD informed Congress that the threat of major global war had diminished and that several previously vulnerable offshore sources of materials could now be considered more reliable.

For more than three decades stockpile goals estimated deficits—where reliable supplies fell short of military, industrial, and essential civilian requirements in a 3-year major conventional war. Ever since World War II Canada has cooperated, culminating in the North American Defense Industrial Base Organization in which Canadian and U.S. military and atomic energy production are accorded parallel priorities and allocations treatment. At yearend, stockpile inventories were valued at about $6 billion and stockpiles became obvious candidates for reduction. In the 1993 Defense Authorization Act, October 23, 1992, reductions of stockpile inventories approaching $4 billion were authorized. To ensure that contemplated disposals would not unduly interfere with normal markets of producers, processors, and consumers, the act mandated two levels of review, each to consult with affected interests. The DLA manages the stockpile. The DLA longstanding Market Impact Committee was formalized by the act to include representatives of DOD; the Departments of State, Treasury, Commerce, Interior, Energy, and Agriculture; and the Federal Emergency Management Agency. A second committee to advise the President was mandated to include those agencies plus interested persons from the private sector.

At a time of general malaise in the world economy, these authorized disposals caused domestic and foreign mineral producers, individually and through trade associations and embassies, to deluge DLA with statements advocating caution lest the defense industrial base be imperilled and the economies of friendly foreign nations be undermined. Accordingly, in early 1993, DLA initiated a series of individual commodity meetings with interested producers, processors, and consumers to devise initial pilot disposals that would develop mutual understanding of pricing, timing, specifications, packaging, shipping, and hazardous materials precautions.

Despite stockpile disposals, most of the materials classified as 'strategic and critical' will continue to be so classified because the United States is still counting in large measure on existing productive capacity for those same materials in the United States, Canada, and other reliable sources. The USBM provides DOD with detailed information on world production capacity, country by country, for the next decade, as well as basic information on consumption in the United States and in most other industrialized nations.

Industrialized nations cannot have viable economies without some assurances of continued availability of essential materials. Further, as military material becomes increasingly reliant upon new or advanced materials, some of them will undoubtedly be designated as strategic and critical, not necessarily to be stockpiled but rather to be covered by other measures to create and maintain reliable productive capacity. Carbon fiber, currently displacing metals and alloys in aerospace applications, is an example: the 1993 DOD Appropriations Act, October 6, 1992, specified that DOD shall ensure that a minimum of 75% of the coal and petroleum pitch carbon fiber requirement be procured from domestic sources by 1994. The Defense Production Act (DPAct), which authorizes priorities, allocations, and exemptions from the Antitrust Acts and maintains the Defense Industrial Base, was extended to September 30, 1995. The DPAct specifies that "energy" is a strategic and critical material. Under the DPAct the USBM maintains the Emergency Minerals Administration covering nonfuel mines, concentrators, smelters, and refineries. The Department of Energy covers fuel minerals and energy and it stockpiles fissionable materials and petroleum.

UNDERGROUND MINING

Mechanical Mining—Extraction

In 1992, the U.S. mining industry continued its efforts to increase production while reducing costs to maintain its position in an increasingly competitive world. Mechanical mining methods have received much attention because of the potential to increase production and reduce costs. Although in mechanical mining tend toward evolution rather than revolution, increasingly competitive markets mandate consideration of mechanical methods in more and more operations. Equipment manufacturers have responded to this interest with programs to design and produce more efficient and more robust mechanical mining machines. This included improving existing designs, improving cutting tools, and developing machines that represent new directions in excavation technology.

The trend in mechanical mining equipment is toward more massive and powerful machines. The Voest-Alpine AM 105 roadheader design is one example. It features low speed, high torque cutterheads that use variable frequency electric motors. Low speed, high torque machines maintain better rock contact in harder rock and they reduce machine vibration due to cutter bounce that occurs in older systems.

Consequently, these designs transfer more of the machine's power to cutting the rock. In addition, some of the more powerful machines feature gripping devices that allow more thrust.[3]

The new Jarva MK27 is the most powerful TBM ever built and the only machine of its kind that can be modified for tunnel diameters varying from 6.4 to 12.4 meters (m) [21 to 40.7 (ft)]. The machine is powered by either six or eight 560-kilowatt (kW) [750-horsepower (hp)] electric motors, giving an installed power of 4,480 kW (6,000 hp) for the upper diameter range.

Innovations include double thrust bearings at the drive section in the rear and a single front bearing; stepless, variable-speed drive control combined with automatic thrust control for optimum penetration in all rock types; and a unique overbore system. The latter allows tunnel bore diameter to be temporarily increased where necessary by up to 0.45 m (1.47 ft) to provide room for extra rock support such as shotcrete and steel arches. This makes it possible to walk the TBM back through supported areas and minimizes lining costs.[4]

The new SR-700 miner redefines performance and durability standards for continuous miners and is manufactured by the Simmons-Rand Co. The unit features a 52,617-kg (116,000-lb) operating weight for stability in mining tough seams. The SR-700 was designed with a 711-millimeter (mm) [28-inch (in)] chassis and a 3,048-mm (120-in) cutting height for operation in all midseam mines. The unit's 2.74-m-wide (9-ft-wide) chassis with its 914-mm (36-in) conveyor offers the maneuverability of narrower-conveyor machines and the increased production of wider models. Routine maintenance aids include independent left and right cutterhead gear cases, access to all major components from the side of the unit, traction drives separated by function in left and right components, and pump motor and gathering motors that are interchangeable.[5]

The Jeffrey Div. of Indresco Inc. has introduced a new model 1024 low-seam continuous miner. It has a specially engineered low profile, making it ideal for mining low coal seams down to 762 mm (30 in) high. Significant features include a gear-driven ripper chain cutterhead, a dual-drive arm-type gathering head, and an all-gear traction system. A 914-mm-wide (36-in-wide) conveyor provides high loading rates for low-seam operations.

A major factor is the 50,000-kg (110,230-lb) gross weight. With 508-mm (20-in) crawler pads to maintain a reasonable ground pressure, this heavyweight machine gives good mining rates and can mine hard top when necessary. The low profile unit has no operator's pit and is operated by radio or cable remote control. A dust collector system is available and can be built within the right or left side of the miner's low profile chassis.[6]

The 2048HPMB was developed by Dresser Industries and was designed especially for longwall development in Australia's poor roof conditions. It can install roof bolts as close as 1.2 m (3.94 ft) from the face. Features include: a specially designed lateral gathering chain that replaces the normal gathering arm or CLA-type gathering head, thus enabling roof drills to be located immediately behind the cutting drum; a lateral array of four roof drills, each mounted on pivots to allow variation of lateral roof bolt position; and incorporation of two separate rib drills to allow installation of rib bolts as the machine advances. The miner/bolter can cut seam thicknesses ranging from 2 to 4 m (6.6 to 13.2 ft).[7]

To meet the miner bolter challenge, Joy has introduced the 12ED18. It is a double-pass mining machine fitted with two bolting drills, located immediately behind the cutter drum to enable roof and rib bolts to be installed as close to the cut face as possible. According to Joy, the unique drill configuration permits the installation of more horizontal and vertical roof bolts than any other machine currently on the market. Like the 12CM18, it is fully certified for use in United Kingdom and European gassy environments and should be capable of 12 m (39.4 ft) advance per shift.

To permit the installation of bolts as close to the face as possible, the 12ED18 does not use a gathering arm system. Coal is forced onto the conveyor by the scrolling action of the cutter drum. It also features a rear conveyor drive, which is more efficient than the conventional way of running the conveyor drive off the gathering arm system.

For multientry development or room-and-pillar production sections, Jeffrey offers the 1026HH and 1038HH continuous miners for seams 1 to 4 m (4.28 to 13.1 ft) thick. Each is equipped with AC-DC all-gear traction drive, a dual-drive gathering head with arms or CLA's, and can be configured with a chainless or ripper chain cutterhead. Options include radio control and an integral dust collector.

In more competent roofs, the Jeffrey 1038HCRB wide-head miner carries two onboard roof drills in fixed positions approximately 3 m (9.84 ft) behind the face. These roof drills carry separate timber jacks for erecting steel W-straps along with the roof bolts. It is also equipped with four hydraulic roof jacks that provide temporary roof support for the drill operators while they are drilling the roof and installing bolts.

Jeffrey's 1040HPSRB carries the onboard roof drill concept a step further by mounting the roof drills on an inverted "U" frame that straddles the miner and can traverse a distance of about 1.5 m (4.92 ft) atop the miner. Once the miner is in position for a new cut at the face, the frame is hydraulically raised off the miner's chassis and locked between the roof and floor. Thus, roof drilling and bolting can be accomplished from the U frame while the miner continues cutting up to two full sump-shear cycles, at which time the frame is lowered and repositioned on the chassis for the next mine and bolt cycle. The 1038HCRB and 1040HPSRB are typical of miners used successfully for longwall development in the Pittsburgh No. 8 seam in the eastern United States.[8]

The Earth Mechanics Institute (EMI) of the Colorado School of Mines has conducted research on the development of mechanical excavation technologies for hard-rock mining. Several types of

excavating systems, including short-radius tunnel boring machines and mobile continuous miners, are being investigated for use in mine development and production.

Hard-rock miners require large amounts of power. That problem has been a major impediment to the successful development of a miner that can provide acceptable production rates at costs competitive to drill-and-blast techniques. The large machine mass, to generate the high cutting loads necessary for efficient hard-rock excavation, results in reduced machine mobility and versatility. This limits the machine's usefulness in underground mining. The solution is to develop more efficient cutting tools that can break hard rock at lower machine thrust and power requirements. EMI has focused its research on such a tool.

Following computer modeling and testing, EMI developed a mini disk cutter, 127 mm (5 in) in diameter, with the ability to penetrate hard rock at load levels much lower than the current disk cutters. This means the new cutter can provide the same production rate as current cutters at much lower machine mass and power requirements. The new cutter also has a self-sharpening feature that prevents machine performance degradation as cutter wear occurs. It is believed that the mini cutter will find application in the development of hard-rock mobile miners and narrow vein miners.[9]

Roof Bolting

Resin-grouted roof bolts, the most common form of ground support in U.S. underground coal mines, form a passive support system. An alternative to this system is an active support system—the mechanically anchored, tensioned roof bolt system. This system is designed to load the support during installation by using a mechanical anchor, coupling, or threaded nut after the resin has properly cured.

Bolt loads are checked by using a torque wrench to ensure active bolts have been properly installed. Unfortunately, this practice presents potential safety hazards and has limited accuracy. Laboratory and field experiments also reveal that the torque-to-tension ratio developed on active support systems can vary by 50% among various bolts, which can induce stress concentrations that lead to roof failure.

The USBM has developed a support system that is independent of mechanical tensioning devices subject to frictional losses and system bleed-off. This support system offers predetermined uniform-installation load and reduces support costs by 30%. The support system uses resin-grouted rebar bolts installed in such a manner that the system becomes "active" immediately upon insertion. The system requires minor bolter modifications, special bolt installation stingers, and a calibrated load cell.

The bolter is modified by installing a valve that permits 44.5 kilonewton (kN) (10,000 lb) of upward force to be developed at the installation head, on demand, through the operation console. The stingers were designed to withstand enormous repetitive axial and bending loads generated between the installation head and the roof bolt. The load cell is used to calibrate the upward thrust to any desired level prior to support installation. Laboratory testing and massive underground tests at sites in room-and-pillar and longwall gate roads have demonstrated that this method is capable of installing bolts under uniform tensions equivalent to levels as high as 406.8 Newtonmeter (Nm) [300 foot pounds (ft-lb)] of torque.[10]

A new JM-Truss system for controlling uneven and severely potted out roof has been developed by Jennmar Corp. The truss system features a unique shoe and U-bolt assembly. Made of cast, ductile iron, the shoe has a radial design with hammerhead configuration and is used with the U-bolt having an attached bearing block. Each truss accommodates four diameters—19.1 mm, 22.2 mm, 25.4 mm, and 28.6 mm (3/4 in, 7/8 in, 1 in, and 1 1/8 in). The headed U-bolt eliminates threads, thus reinforcing the assembly. The JM-Truss system is easy and fast to install under extremely severe roof conditions. The system is adjustable to varying entry widths and has the fewest components of any system on the market. JM-Truss is a dynamic tension system providing an uplifting force to reduce or eliminate roof sag. The system can be installed during the mining cycle as primary support or installed later for additional support. It utilizes tensioned point anchor resin with angle bolts. The tie rod is adjustable to any entry width.[11]

Cable bolt supports have been widely accepted as an effective ground control technique in hard-rock mines. They can be used as passive or active supports. They can behave as stiff or yieldable reinforcement, depending on their configuration, and can be placed at any angle in the rock. The use of cable supports contributes to safe, productive mining without the need to make changes in existing mining methods.

USBM engineers began evaluating the application of these supports in soft-rock mines, such as coal and trona, with an emphasis on using resin cartridges for grouting the cables. In longwall gate road applications, for example, cable bolt supports offer several advantages over traditional secondary support. They enhance stress redistribution to pillars and gob areas, minimize or eliminate timber posts and cribs that complicate ventilation, reduce material handling injuries related to the placement of crib supports, and reduce ground control costs.

More research into the mechanics of cable reinforcement continued with the implementation of equivalent materials models in finite element models developed at the University of Utah. Use of computer models to simulate development opening excavation, bolt installation, and subsequent mining provides valuable guidance to mine planning.

One full-scale test stope study was completed at the Homestake Mine. A second application of cable bolting for pillar recover at the Magmont Mine is underway. Both involve rock mass monitoring and large-scale computer simulation of the mining sequence. Understanding the fundamentals of

reinforcement interaction may lead to more efficient and reliable procedures.[12]

J. H. Fletcher & Co. has introduced two new low-profile, man-up roof drills that are designed to bolt in heights from 2 to 7.6 m (7 to 25 ft). The Model AR-D features dual tram-power systems. A diesel engine is used over long distances and trams up to 16 kilometers per hour (km/h) [10 miles per hour (mph)] with no trailing cable. An electric motor is used for inch tramming in the work area. It offers pinpoint positioning with little noise and no emissions. It is controlled from the operator's basket. An all-diesel version also is available. When drilling, the operator stands in the basket under a canopy. The telescoping boom raises to 45° and swings 45° either side of center. In tram configuration, the unit's overall length is 8.2 m (27 ft), its wheel base is 3 m (10 ft), and tram height is 1.8 m (6 ft). Turning radius is 5.8 m (19 ft).[13]

Fletcher's HDDR roof bolter is a dual-head unit with walk-through chassis. Optional independent, elevating operator platforms raise to allow the insertion of resin cartridges and checking of bolt torques. The booms separate from 1.2 to 6.1 m to enable several bolt installations from a single position. Heavy-duty booms allow operators to drill over rubble, near ribs, and over otherwise loose bottom areas. The bolting pattern is established relative to the roof, not the floor (for angled hole drilling). The HDDR can operate in seam heights from 1.5 to 6.1 m (4.92 to 20 ft).[14]

Simmons-Rand SR-250 is a hydraulically operated, planetary-drive roof bolter. It incorporates a dual boom arm with outfront automated temporary roof support (ATRS) that allows efficient and quick installation of roof bolts. The unit offers variable drilling torque up to 542.5 Nm (310 ft-lb) and bolt tightening torque up to 332.5 Nm (190 ft-lb). The SR-250 is 0.9 m (36 in) high and features a 228-mm (9-in) ground clearance. Vertical articulation incorporated in the chassis and steering design enables the unit to maneuver efficiently over uneven terrain. In addition, a 60-kilowatt (kW) [80-horsepower (hp)] AC motor and dual-speed settings allow the SR-250 roof bolter to tram up to 39.6 meters per minute (m/min) [130 feet per minute (ft/min)] in the fast mode and up to 19.8 m/min (65 ft/min) in the slow mode.[15]

Conveyor Advances

Sensor technology for nondestructive testing of conveyor belt reinforcement has expanded the capabilities of conveyor belt monitoring equipment.

Instrumentation for measuring the condition of a conveyor belt's reinforcing layer has been in operation for a number of years. Recent advances, however, have enabled new high-gain sensors to be used to detect damage and defects, which previously had been difficult to measure. In particular, cord plane deviations have proven almost undetectable in all but ideal measurement conditions. These new sensors, developed at the University of Newcastle, New South Wales, in association with Winders, Barlow and Morrison Inc. (WBM) of Denver, CO, demonstrated very high sensitivity to small changes in the magnetic field surrounding steel cord conveyor reinforcement.

The new equipment is in modular form and is extremely lightweight. This has significant advantages for both transportation and installation of the equipment on-site. Suitable for either permanent installation or temporary mounting, the system can detect damage and defects to the reinforcing layer in steel cord, fabric, and woven fabric conveyor belts.[16]

Continental Conveyor has devoted considerable research to improving intermediate booster drives for conveyors clearing coal from longwalls. Because the conveyors have to be constantly moved, components must be as compact and light as possible, and the design must be flexible enough to be modified as new terrain and conditions are met.

In the past, when drive powers or belt tensions were exceeded due to conveyor length, a new flight would be added. In some cases, this led to as many as three flights installed in a single panel. As the face retreated through each flight, mining was halted while drives and storage units were removed. This sometimes meant several days of lost production.

Intermediate drive technology was developed to eliminate this excessive downtime and still keep conveyor belts, motors, pulleys, and other components as small as possible. With intermediate drives placed along the carrying side of the conveyor, belt and motor sizes are kept as small as possible, and only one storage unit is needed. Most importantly, as the longwall retreats through a booster drive station, it can generally be removed in a regular planned downtime period and no additional production time is lost.[17]

Mine Design

Mine design research at the USBM recognizes that many advances in mine ground control and mining methods arose from cooperation with the natural characteristics of the rock mass. Two examples are rock bolts that mobilize the strength of intact rock while at the same time immobilizing weak discontinuities, and the use of rock mass weakness in block caving. The term "geoconformal mining" is being used to describe a concerted effort to examine new ways in which mining can take advantage of the natural characteristics of a rock mass to improve the efficiency of mining.

One area being investigated is the natural variation of in situ stress before mining. USBM research, as well as case studies from throughout the world, has demonstrated that rock mass structures create a wide range of stress conditions that could increase mining efficiency if integrated into mining plans. For instance, high-stress conditions that can result in localized rockbursts should be avoided or mined with special precautions. On the other hand, relatively destressed areas could be mined more aggressively, with larger extraction ratios and less support.

USBM researchers are developing computer programs to calculate stress in coal mines. One recently available program, MULSIM/NL, is a three-dimensional, boundary-element method program for stress and displacement analysis of coal mines. The program has

nonlinear material models that enable it to simulate yielding and crushing of coal pillars and the ensuing load transfer to other parts of the mine. The program also includes preprocessors and postprocessors that help the user generate a model and examine the output.

IC 9513, Proceedings of the Workshop on Coal Pillar Mechanics and Design, cosponsored by the USBM, expounds further on USBM research and presents the ideas of coal pillar design experts from around the world.[18]

A new system called GUIDE (Graphical User Interface for the DATAMINE Environment), is a fully interactive three-dimensional (3-D) graphical display into which drill holes, geological block models, wireframe models (triangulated surface lattices), and string data can be read and manipulated in a number of ways. GUIDE runs alongside the DATAMINE system, using the same data base structures, providing a 3-D environment with processing directed to solving mining and geological problems. The package operates in the same way on PC's and workstations. On workstations an extra 3-D visualization program GVP (GUIDE Visualization Program) also is available, which provides 3-D dynamic graphics with full-color surface rendering.

Because GUIDE has a data base structure underlying it, it is able to provide a great deal of flexibility to the user. For example, new design data can have constant or variable attributes assigned to string or wireframe data, providing considerable flexibility in identification of mining units, and allowing users to set up their own convention for identification of existing or designed underground features. The general graphics capabilities built in include many useful functions in such areas as string editing, smoothing, translation, conditioning, gridding, and string combination. To these general capabilities have been added the features required in underground mine design.[19]

The decision on how best to control the roof often is made arbitrarily or is based upon previous experience. As a result, when roof failure occurs, questions arise about the contributing factors and how such failures can be prevented. The inherent stability of the rock comprising an entry's roof is recognized as a major factor in its stability. Other factors include abutment loads, horizontal stress, span width, pillar strength, and floor strength. The USBM's Practical Roof Stability Classification system will provide a stability rating for the roof, which then can be used to help design longwall gate roads and aid in primary support selection. It also can be used as a guideline in decisions about wide or deep cuts. This system uses common geotechnical observation and simple field tests to gather data. The necessary rock properties are rock strength, bedding plane resistance, fracture spacing, cohesion, and geometry. Properties of the rock are then fed through an equation that considers several factors to arrive at the final roof rating from 0 to 100.[20]

Trends in Truck Haulage

Truck haulage has grown considerably owing to its versatility. Trucks of all sizes are used in underground haulage, from standard highway vehicles to small articulated vehicles for the narrowest, trackless mines. Articulated trucks are the most versatile of underground transport media. Their low loading height, narrow bodies, hydraulic power steering, and up to 45° articulation left and right permit tight turning circles. They also can cope with extreme grades. Manufacturers can be divided into those who make standard offroad vehicles, such as Caterpillar and Volvo, and those specializing in vehicles for underground transport such as Kiruna Truck, John Clark Inc. (JCI), Tamrock Toro, and Wagner.

Variations on standard end-dumping include side-dumping, arrangements for dumping in low ceiling heights, and detachable containers where one prime mover operates with two or more containers. In the latter and depending on distance, one truck can work with up to eight rock boxes, hauling a full one out while the others are being filled. The concept gives major savings in the number of trucks required. Other advantages are that small loaders can be used and there is less wear and tear on the truck because the rock is loaded into stationary boxes resting on the ground.

Kiruna Truck AB was founded with the sole purpose of manufacturing low-profile container trucks for the Kiruna iron ore mine in Sweden. Today, the company builds two basic models: the 35-mt (38.6-st) payload K250 and the 50-mt (55.1-st) payload K501/503. The U-frame K501 "Combi" is the container version of the K503 and can accommodate a 60-mt (66.1-st) payload in containers custom-built to match the rock density.

JCI produces four articulated haulers with payloads from 6 to 24 mt (66 to 24.5 st). The larger 1504 and 2604 trucks come in two versions, standard end-dump trucks and container trucks (designated the C1504 and C2604). In contrast to the U-frame Kiruna "Combi" that has a split rear section to allow the truck to back over the container, JCI units use a "J" hook to pull the box off the ground into the forward hauling position. Separate hoist cylinders control dumping, simultaneously raising the container box and tailgate, thus allowing the container to be dumped like a normal end-dump truck.

Both Tamrock Toro and Wagner have patented arrangements for dumping in restricted height areas. Tamrock Toro manufactures two diesel articulated underground dump trucks, the 31.8-mt (35-st) capacity 35D and 37.3-mt (41.1-st) capacity 40D. The latter is offered with an ejector tray option for dumping where height clearance is too limited for conventional dump trucks. The ejector tray is an integral part of the truck's rear body with a push plate at one end that is used to eject the load off the back of the truck. The push plate is mounted on a carriage, which is guided by rails on either side of the truck body and driven by three hydraulic cylinders. The plate has exchangeable wear pieces and the tailgate lowers over the rear axle and wheels to protect them while dumping. A full 16-cubic meter (m^3) [565-cubic

foot (ft^3)] payload can be dumped in 30 seconds. Wagner's special dump box for low ceiling areas is known as a Teledump and uses a telescoping feature to push the load out the rear.[21]

Mine Waste-Disposal Technology

A new technology, designed to dispose of mineral production waste (MPW), including mine tailings, back into surface and subsurface mine excavations, was announced by two companies who have filed for a process patent on the technology with the U.S. Patent Office.

The two companies, Hunter Environmental Services, Inc., an environmental services company, and PB-KBB, Inc., an engineering and operational service company for underground storage and technology, have agreed to form a joint venture to develop the technology for commercial application. The technology employs viscosity modified fluids to convey mineral production waste back into the geologic formations from which they were originally mined. The technology will aid in the reclamation of mine and processing facilities; eliminate emissions to air, surface water, and ground water; and assist in mitigation of surface subsidence. Returning the wastes to their original location is an environmentally sound practice.

In applying this technology, the waste is suspended in a liquid that is conveyed into the excavation. Phase separation of the suspension begins to occur after conveyance flow ceases. As settling by gravity progresses, the waste is dewatered and compacts, allowing the liquid to be recycled and leaving the MPW emplaced in its original formation. The mechanisms of particle suspension, colloidal flow, and gravity dewatering provides the basis for handling mineral wastes where the volumes are significantly large and the location for waste emplacement may be an inconvenient distance from the stockpile. Tests of the process have demonstrated that the technology is highly effective, economical, and environmentally superior when compared with current practices.[22]

SURFACE MINING

In 1992, copper's fortunes continued to be exceptional. The expansions and new projects initiated by copper's high price started to come on-stream last year. Gold is no longer the most sought after commodity. This is due to the 30% reduction in its price in the past 2 years that has considerably lowered profit margins for gold.

Phelps Dodge's $300 million, 3-year expansion program at its Morenci complex increased the company's copper production to 340,000 metric tons per year (mt/yr) [375,000 short tons per year (st/yr)]. About 154,000 mt (170,000 st) of that is from solvent extraction-electrowinning (SX-EW).

In Montana, the Seven Up-Pete Joint Venture (72.5% Phelps Dodge and 27.5% Canyon Resources) began the permitting process for the McDonald property near Lincoln. The property contains 188 Mmt (208 million st) of minable reserves grading at 0.7 grams per metric tons (g/mt) [0.02 ounces per short ton (oz/st)] gold. The projected capital costs for the proposed 27,000-metric-ton-per-day (mt/d) [30,000-short-ton-per-day (st/d)] heap-leach operation is about $125 million. Operating costs are estimated at $227/mt ($250/st).

Phelps Dodge announced plans to develop the La Candelaria copper-gold deposit in northern Chile. The property contains about 350 Mmt (385 million st) of ore grading 1.14% copper, with 93.3 tons (102.8 st) of gold. The $350 million project is expected to produce about 109,000 mt/a (120,000 st/yr) of copper and 2.48 mt/a (2.73 st/yr) of gold.

Production began at the $62 million Lince Mine and SX-EW facility. It is 25% owned by Cia Minera Carolina de Michilla, 60% by Chemical Bank of New York, and 15% by Outokumpu Oy of Finland. Production is expected to be 18,000 mt/a (19,840 st/yr) of copper. The deposit contains 16 Mmt (17.6 million st) of 1.6% copper.

Cluff Resources announced plans to develop Ayanfuri gold mine in Ghana. The project is expected to produce 1.5 mt/a (1.65 st/yr) from 700,000 mt (771,600 st). Total reserves are 4,300 mt (4,740 st) grading 1.7 g/mt (0.05 oz/st). Capital costs are estimated to be $22 million.[23]

ASARCO Incorporated reported its Ray copper mine now contains more than 1,000 Mmt (1,102 million st) of ore grading 0.63% copper, making it one of only three U.S. properties to contain that much ore. The company just completed the ore reserve calculation at Ray, the first time since acquiring the property in 1986. When Asarco acquired the complex, reserves were 614 Mmt (677 million st) of ore grading 0.7% copper.[24]

Cia Vale do Rio Doce (CVRD) and Anglo American Corp. approved a $765 million joint-venture agreement to develop the Salobo copper-gold mine in Brazil's Amazon region. The 50-50 joint venture is through Mineracao Morro Velho, a Brazilian gold mining company 60% owned by Anglo American and state-owned CVRD. The mine is due into production by 1998 and will have a capacity of 150,000 mt/a (165,000 st/yr) of copper and 7.8 mt/a (8.6 st/yr) of gold. Ore reserves are estimated to be 1,200 Mmt (1.323 million st) grading 0.86% copper.[25]

Minera Escondida Ltda. is to expand copper production at its Escondida Mine by 50%. Escondida was brought on-stream at the end of 1990 with a design capacity of 320,000 mt/a (352,700 st/yr) copper in concentrate. Contained-copper production at Escondida, already the world's second largest copper mine, will rise to 390,000 mt (429,800 st) in 1993, to 420,000 mt (463,000 st) in 1994, and to 480,000 mt (529,100 st) in 1995. Very importantly, the extra production will be processed to copper in Chile. Up to date, all Escondida's production is exported as concentrate, most of it to smelters in Europe and Japan.[26]

The Phosphorus Chemicals Div. (PCD) of FMC Corp. has opened a new phosphate rock mine at Dry Valley, ID, to supply the company's future phosphate needs. The new Dry Valley Mine highlights the continued investment being made by FMC, the largest producer of industrial phosphorus in North America,

to ensure the availability of phosphate for a wide range of industrial and consumer applications.[27]

New Equipment

Shovels and Excavators.—The use of hydraulic shovels continues to increase in surface mines. This is primarily because the fast response of a hydraulic system can reduce swing time by up to 30% over rope shovels.

Caterpillar introduced several new lines of excavators. The 235 and 245 series is equipped with a 4.4-m^3 [5.7-cubic-yards (yd^3)] bucket capable of loading 1,400 metric tons per hour (mt/h) [1,540 short tons per hour (st/h)], a 23% increase over the 245B it replaced. The new 320 and 325 excavators are available in 20 to 30 tons (22 to 33 st). Design efficiencies are improved by the Maestro system, which converts 98% of engine power to hydraulic power. Also, the new 130-tons (143-st) class hydraulic excavator machine delivers 535 kW (717 hp) and features the vehicle management and information system (VMIS). Four different buckets are offered.[28]

Komatsu's PC1000-1 excavator has state-of-the-art electronics that maximizes fuel economy and provides continuous fault monitoring. The unit is available in a front-shovel or backhoe configuration. It has bucket capacities ranging from 3.1 to 7 m^3 (4.1 to 9.2 yd^3). As a front shovel, the PC1000-1 can be equipped with buckets in three sizes: 5.5, 6.1, and 7 m^3 (7.2, 8, and 9.2 yd^3).

The PC1000-1 comes in three backhoe configurations. The PC1000-1 is the standard version. It is used for general purpose excavation and trenching. The PC1000LC-1, or long-track version, features extended track frames and wider track pads for improved flotation and lifting capacity. The PC1000SE (Super Earthmover) features a reinforced arm and shortened boom for maximum production. The three operating modes on the PC1000-1 permit the operator to select the match of engine speed to hydraulic power that will most efficiently accomplish the job. To support the three modes, the PC1000-1 is fitted with an electronic open-center load sensing system (OLSS). This system automatically controls hydraulic fluid flow from three variable capacity piston pumps to eliminate unnecessary flow and save fuel.[29]

Andrew Golightly Ltd. has taken delivery of a Liebherr R992 face shovel, the first such model in the United Kingdom. This is the second largest machine in the Liebherr range, weighing slightly less than 140-mt (154-st) and fitted with a 7-m^3 (9.2-yd^3) bottom dump bucket. The new R992 is working at the Meadowdale opencast coal site, Bedlington, Northumberland, where Golightly is the main contractor. This site is scheduled to produce about 220,000 tons (242,500 st) of high-calorific value coal, destined for power stations. Work at the site started in April last year, with an overburden removal and rehandling expectation in the region of 6 million m^3 (7.85 million yd^3). On completion of coal extraction at the end of the 2 1/2-year contract, the ground will be restored, including 2 million m^3 (2.62 million yd^3) of compacted overburden.[30]

The new Litronic series of excavators that Liebherr introduced in 1992 provides an illustration of larger equipment to tackle heavy mining jobs. The new R 964 Litronic has an engine output of 268 kW (364 hp). Its performance has been raised by about 30% compared to that of its predecessor. The delivery rate of the hydraulic pumps also has been increased by 27%. The R 974 with an engine output of 321 kW (436 hp) is now 14% more powerful than its predecessor. The R 984 Litronic is now 15% more powerful than its previous model with an output of 431 kW (586 hp).

At the beginning of this year, Demag introduced its second-generation models of the 485 series, already the largest hydraulic shovel in the world with a service weight of 625 tons (690 st). The original 485 series was introduced in 1986. The new generation of 485's are heavier, more powerful, and can be equipped with large buckets than their predecessors. Some of the first of the new machines are already working at CVRD iron ore mines in Brazil. CVRD already operates a number of 485 shovels loading iron ore and overburden into a fleet of 172-mt (190-st) trucks. Shovels like the 485 can easily maintain a production loading rate of about 3,500 mt/h (3,860 st/h) while peak loading rates of 5,000 mt/h (5,510 st/h) have been demonstrated.

According to Demag, one factor limiting shovel capacity is the size of hydraulic pumps available. Bigger, more powerful shovels would need bigger, more powerful pumps. Increasing the number of pumps on the largest size available is not an attractive solution. Demag's giant H 485 uses just six main pumps. Increasing this number to 10 or 12 would be undesirable.[31]

The P&H 2250 hydraulic mining excavator features Harnischfeger's latest technology in large hydraulic components, computer controls, and single-engine proficiency. Nominal capacity is 17.6 m^3 (23 yd^3). The excavator's working weight is 338 mt (372.5 st). Features of the 2250 include in-line power train for optimum efficiency and reliability, a closed-loop hydraulic swing system that provides 30% faster swing cycle, and a separate cooling compartment for the heat exchanger. Other features include the P&H hydraulic viscosity conditioning system for automatic maintenance of proper oil temperature, a triple filtration system for the high-pressure circuit, mining shovel crawlers, and a walk-inside machinery house. Dipper capacity ranges between 11 to 24.6 m^3 (15 to 33 yd^3).

Harnischfeger also introduced its 2800XP Series B electric mining shovel. This shovel combines the basic features of the company's 2800XP/A model with improvements meant to simplify maintenance and increase productivity and durability. Several of the key features on 2800XP/B included an enlarged and redesigned machinery house for easier maintenance and a modernized operator compartment that adds greater visibility and ease of operation. An improved dipper handle and boom shipper shaft accommodates the industry's larger dippers. The shovel offers improved

crawler shoes and larger lower rollers and front idlers in the crawler frame, as well as hoist cable with ferrule beckets and heavier, galvanized structural strand suspension cables.

Harnischfeger's 9020 walking dragline incorporates an improved A-frame and front-end geometry, precision gathering and planetary swing, and propel transmissions. The dragline's design uses finite element analysis to ensure structural integrity while increasing digging capability, dump height, operating radius, and bucket capacity. The 9020 handles bucket capacities of about 76.5 m^3 (100 yd^3). Boom lengths exceed 122 m (400 ft). Maximum suspended load ratings are more than 227 tons (250 st). The walking dragline features a large-diameter roller circle for reduced loading on the rollers, rail, tub, and revolving frame. To maximize the availability of the dragline, an integrated diagnostic system monitors more than 200 critical control points.[32]

The "S" designation on Black Thunder mine's Bucyrus-Erie 2570-WS dragline stands for super. With its 110-m (360-ft) boom length, 122-m^3 (160-yd^3) capacity HPS bucket, and a load of technical innovations, this machine is definitely in a class by itself. Its bucket size and suspended-load rating of 306,180 kg (675,000 lb) provide a 33% increase in a capacity over the standard 2570-Ws with 92-m^3 (120-yd^3) buckets.

Erection of the dragline got under way in March 1991, and the machine was placed in service early in February 1993. It is conducting two-pass stripping on the southern portion of Black Thunder's property and is expected to move more than 30.5 million cubic meters per year (m^3/yr) [40 million cubic yards per year (yd^3/yr)]. Running on 22,000 volts, the 14,720-kW (20,000-hp) machine is the first of its kind to incorporate static AC drives.[33]

An S-100 compact bucket wheel excavator manufactured by Krupp Fordertechnik GmbH is being used to cut Teutonia Marl at a rate of 800 mt/h (880 st/h). The new bucket wheel effectively mills the rock rather than excavating it by using buckets and precutters integrated into the bucket wheel. This allows digging forces to be transmitted directly from the teeth to the wheel axis. There is also a larger number of precutters. The S-100 is the smallest standard version in the range with a bucket volume of 0.1 m^3 (0.13 yd^3), weight of 50 mt (55 st), and capacity of 420 m^3/h (550 yd^3/h).[34]

Blasthole Drills.—Since acquiring the Gardner-Denver line of large rotary blasthole drills in 1991, Harnischfeger has updated the five models to the latest technology. Modifications includes the following:

- Upgrading of gearing to current Harnischfeger standards for hardness, dimensions, and geometry to increase impact strength, reduce wear, and extend service life.
- Increasing weld sizes to improve fatigue resistance in the main frame, side frames, and throughout the machines.
- Installing heavier-duty AC and DC motors with higher outputs and higher torques for longer life and enhanced performance.
- Redesigning main and auxiliary hydraulic systems to improve reliability and reduce maintenance.
- Increasing drill rotary torque at the higher speed ranges to provide up to 50% more torque at some portions of the speed-torque range.

These modifications are now standard on the P&H 70A, 70XHA, 70HA, 100A, and 120A models, as well as the new P&H 160, scheduled for the market in September 1993.

Ingersoll-Rand Co.'s Rotary Drill Div. has introduced the new DM-M3, a large rotary blasthole drill featuring advancements in drilling and nondrilling systems that maximize productivity and reduce overall drilling costs. With a rotary driven by dual-hydraulic motors, the DM-M3 delivers 13,560 Nm (10,000 ft-lb) of torque and rotation speeds to 200 rev/min, while its hydraulic cylinder feed system provides bit loading forces to 40,820 kg (90,000 lb).

These features mean that the drill can penetrate hard rock more rapidly and easily than competing models. To enhance nondrilling productivity, it incorporates a highly efficient "inside-the-tower" drill changing carousel that minimizes the downtime associated with changing drill pipes. The handling system can hold four pipes each 273.1 mm (10.75 in) diameter and 12.19 m (40 ft) long. With one pipe under the rotary tophead, the rig offers onboard depth capability to 61 m (200 ft). The DM-M3 also has been designed to simplify angle drilling operations as the tower can be positioned and held at angles up to 30° in 5° increments from the operator's console.[35]

The Bohler TC 118 all-hydraulic crawler drill with the HS 464 drifter is designed for blasthole drilling in pits, quarries, and benches. It is equipped with an automatic drill-rod rack and hydraulic wrench for high-performance one-worker operation. The onboard compressor provides 8 cubic meters per minute (m^3/min) [282.5 cubic feet per minute (ft^3/min)] at 9 bar for adequate chip flushing in holes from 64 to 127 mm (2.5 to 5 in) diameter. Bohler says low fuel consumption is achieved by direct linking of the high-efficiency 125-kW (167.5-hp) KHD diesel engine to the hydraulic pump and compressor. Tramming speed is 0.85 meters per second (m/sec) [2.8 feet per second (ft/sec)] and grade climbing ability is 65%.[36]

The DK100B, a versatile new, crawler-mounted hydraulic drill, is recommended by Davey Drill Div. of Davey Kent, Inc. for a wide range of mining and quarrying applications. The new unit features improved tramming on a caterpillar undercarriage and an excavatorlike, turret-bearing drive that allow 360° rotation of the drill body about its crawler base. Powered by a 74.6-kW (100-hp) diesel engine, the DK100B utilizes a versatile universal boom for mast positioning to facilitate setup. The DK100B can be equipped for rotary, rotary-percussion, down-the-hole hammer, and double head drilling. As a result, it can be used for coring, site investigation, onshore and offshore blastholes, mine-shaft filling, dewatering

holes, micropiles, and for work involving tie-back anchors. When equipped with optional rotators and grout pumps, the DK100B is ideal for geotechnical drilling applications needing ground stabilization and grouting of all types. With its crawler mounting, the machine can be moved to virtually any location regardless of conditions or terrain.[37]

Bucyrus-Erie's (B-E) blasthole drills feature a Panelview console option that provides a full range of information ranging from machine status reporting to programmed drill-control settings. The Panelview system works in conjunction with an onboard, expandable PLC that handles lubrication system fault alarms, startup logic, motion limits, automatic leveling, and other functions. The PLC/Panelview feature first appeared on B-E's 49-R drill introduced in 1985. The original 49-R product line was recently upgraded by B-E with the addition of three new variants: the 49-RII-75, -100, and -120. The 49-R-75, with 333.6 kN (75,000 lb) of pulldown force, is intended for high-speed drilling in relatively soft material such as that typically found in coalfields. According to B-E, the new 49-R drill can outperform B-E's older 60-R models by as much as 50%.

The 49-R-120 is a heavy-duty version developed primarily for use in taconite mining, capable of drilling 250- to 381-mm-diameter (9 7/8- to 15-in-diameter) holes with bit loading forces up to 533.8 kN (120,000 lb). The 49-R-100 model, available in diesel or electric versions, as are the others in the series, is designed for drilling 250- to 311-mm-diameter (9 7/8- to 12 1/4-in-diameter) holes and has single-pass depth capacity of 18.3 m (60 ft). The drill's DC-driven rack and pinion pulldown gear provides bit loading up to 444.8 kN (100,000 lb).

The 49-RII series drills feature an automatic leveling system also available on the 59-R, a more powerful model that drills holes up to 444.5 mm (17 1/2 in) dia. The leveling system consists of four hydraulic jacks activated by a single raise/lower switch in the cab. A preprogrammed sequence allows front-to-rear then side-to-side leveling that can accommodate most terrain and avoids excessive torsional stresses on the drill's frame during the leveling process.[38]

Trucks.—The Titan 3320 Mine-Haul truck from Marathon LeTourneau takes a new step in haul truck history as the largest mine-haul truck in the world. Its 290-mt (320-st) payload could allow greater production efficiency levels than any truck currently available. The eight-tire, three-axle concept truck is designed to utilize proven component technology while affording vehicle balance during operation. The unique two-axle, four-tire steering and four-tire, single-axle drive are claimed to provide the optimum design configuration. A new Marathon TeTourneau "F-series" traction motor, designed specifically for the Titan 3320 and rated at 1,492 kW (2,000 hp), makes this single-drive axle concept a reality.

The Titan 3320 will be available with a choice of twin Cummins diesels rated at 1,194 kW (1,600 hp) each, twin Detroit Diesels rated at 1,194 kW (1,600 hp) each, or a single MTU diesel engine rated at up to 2,387 kW (3,200 hp), and a choice of gear ratios to allow power application to be matched to mine requirements. The truck is 17.56 m (56.6 ft) long and will use eight 44.00R57-size tires. The Titan 3320 mine-haul truck can be equipped with the Marathon LeTourneau Vital Signs Monitor and Digital Diagnostic systems.[39]

The Caterpillar 86.2-mt (95-st) capacity 777C truck introduces a new electronically controlled Cat 3508 diesel engine that delivers 687 kW (920 hp). Electronic fuel injection and control module replace the mechanical system, providing precise timing, reliability, and coordinated engine and transmission control. Other benefits include simplified engine controls and elimination of mechanical governor adjustment; reduced smoke; and ability to recognize problems and stop operation. A second-generation electronically controlled power-shift transmission communicates electronically with the engine for high performance, including improved drivetrain service life, smoother shifting, and electronic control of driveline torque during forward and reverse shifts. The truck's cab now features the Caterpillar Contour Series Seat with eight adjustments, including lumbar support, operator's crank-up window, and tilt steering wheel.[40]

Wagner Mining and Construction Equipment Co. introduced its Fullback 645 articulated dump truck for the mining and quarrying industries. The Fullback has a carrying capacity of 41-mt (45-st), a 72° dump angle, low-maintenance braking system, and an ergonomic cab. The 41-mt (45-st) capacity bed is designed with low sides for easy loading. The 72° dump angle is reached in 15 seconds for rapid discharge. Its fully enclosed, liquid-cooled brakes eliminate brake fade and wear. The Fullback's cab is fully climate controlled. Noise in the cab is suppressed and is pressurized for dust control. Safety features include centerline seating, full visibility to the front and sides, and heated convex mirrors.[41]

VME launched a new vehicle in its range of rigid haulers, the Euclid R60. The powerful 522-kW (700-hp) R60 has a 57-mt (63-st) payload capacity. The vehicle features a robotically welded, flat floor, sloped tail chute design and a body continuously heated by the engine exhaust. The new body is wider and the loading height lower than in previous models to ensure easier loading. The new Euclid is equipped with an advanced hoisting circuitry that reduces the body raise time considerably, thus, reducing dump cycle time and improving hauler productivity.[42]

Wheel Loader Advances

During the past 5 to 10 years, the coal mining industry has seen large wheel loaders grow from 11.5 m^3 (15 yd^3) to 21.4 m^3 (28 yd^3). The change, however, has not been limited entirely to capacity; the role of the loader in mining operations has changed as well. Once thought to be a backup for primary loading equipment and a cleanup tool, it now is being found more in primary loading situations because of its mobility and versatility.

The design techniques for large wheel loaders have evolved from yesterday's

basic applied stress mechanics with calculators to today's computer-generated finite element analysis and solid-state analysis. Correlating computer models with physical testing has provided a high degree of accuracy in the final design stages.

Electronics is also an ever-changing aspect as technology advances. Onboard computers soon will become the standard, controlling most of the machine's functions and monitoring the rest. The loader of the future will have auto-load, auto-service, and auto-troubleshoot. Electronically controlled engines will become a must for fuel economy, noise control, and emissions. Onboard computers will control the engine at times other than starting and shutting down. The brakes of the future will be electronically controlled by monitoring axle loads and determining torque requirements.

Auto-load systems, where the computer controls the lift linkages, will determine the tractive effort, lift, and tilt requirements. Bucket loads will be measured, cycle times will be rated, and overloading errors will be lessened. Joystick controls are being used primarily with smaller sizes; eventually they could make a move into the larger wheel loader market.

Manufacturers claim that large wheel loader use in the mining industry is growing faster than had been anticipated. Most of the large wheel loaders are exceeding surface miner's expectations, especially in productivity, and have become an economic alternative to shovels in certain situations.[43]

New Designs for Blasthole Drills

The past 5 years or so have brought a gradual change in the landscape of the drill manufacturing industry. Some well-known lines have disappeared, others have been taken over in whole or in part, and yet others endure on the market fringe where equipment that was originally developed for nonmining applications, such as water-well drilling. There have been a few new twists in drill development recently. These workhorse rigs, capable of sinking 152.4- to 558.8-mm-diameter (6- to 22-in-diameter) holes to depths exceeding 70 m (200 ft), are big-ticket items in a small market. Worldwide, only about 350 large rotary drills are sold in any given year, and the competition among manufacturers is intense.

The trend toward larger earthmoving equipment in surface mining has contributed toward a new interest in drill purchases. Mine operators want units that can drill quicker, move faster, and withstand the rigors of higher production schedules. Customer demand for performance and reliability improvements, coupled with competitive pressure, drives most manufacturers to maintain a steady schedule of feature enhancements and new model introductions across their complete product lines.

Although progress in rotary drill-rig design tends to be incremental, recent technical advances have not been insignificant. Mechanical innovations such as independent track propel, elimination of propel chains in favor of planetary gearboxes, replacement of pipe-feed pulldown chains with rack-and-pinion drives, and the introduction of electric rotary-drive options have resulted in drills that are more maneuverable, reliable, and thus, more productive.

Features that stimulate buyer interest certainly include the availability of field-proven electronics to improve drill performance, but customer preferences are primarily focused on improved mechanical systems that offer screw-type air compressors capable of maintaining high continuous air pressure levels; hydraulics that provide longer intervals between maintenance and that can be quickly repaired and restored to service in dirty mine environments; and convenient access to vital components for maintenance and replacement tasks.

Manufacturers are paying more attention to design elements that keep the operator safe and away from moving equipment. Pipehandling features on recent models allow the operator to make and break pipe connections, break stuck joints with a hydraulic wrench, and automatically grease pipe threads without leaving the cab. Telescoping mast braces and hydraulically actuated pins enable the operator to raise, secure, and lower the mast, also from inside the cab.

The range of drill improvements covers a spectrum that starts with increased mobility and extends to the high-tech areas of machine automation and remote data transfer. The next step in drill development seems to be aimed at eliminating a significant amount of the guesswork involved in drilling and blast-pattern design. Drills of the not-too-distant future will carry an arsenal of technologically advanced tools that will provide an increasing amount of information about the drilling process. In addition to increasingly sophisticated drill-control systems, future models will be equipped with data collection systems that will allow material-recognition information to be recorded during drilling operations. With the physical characteristics of the overburden known beforehand, blasting and stripping operations can be fine-tuned for optimum cost-effectiveness.[44]

Trends for Hydraulic Excavators

Among all manufacturers of hydraulic excavators for the mining industry, a clear trend to larger machines to match larger trucks has been observed in recent years. The consensus is that hydraulic shovels are not going to go on getting bigger—yet. Instead, they are becoming tougher, more powerful, smarter (electronics), more available, and very importantly, are now able to claim that they can have service lives comparable to those of rope shovels. Technology is being used for higher performance and greater operating economy.

In the late seventies and eighties, hydraulic excavators started competing seriously with rope shovels in the 10- to 13-m^3-size (13- to 17-yd^3-size) range. They were so successful that they became the machines of choice for this size range, performing such tasks as loading 77.1-ton (85-st) trucks in three to four passes. In the nineties, the hydraulic excavator is strongly entrenched in the market for machines with 20-m^3 (26.2-

yd³) buckets. That is, machines designed to load 154.2-mt (170-st) trucks in an economical and efficient three to four passes.

Among manufacturers is a trend to develop machines that are stronger and more powerful than their predecessors for increased life, durability, and reliability. Most big, new hydraulic excavators are delivered equipped with some form of electronic control and monitoring system. Effective job planning depends to a great extent on reliable equipment availability. All hydraulic shovel manufacturers emphasize how their various electronic control systems are the key to higher productivity and lower operating costs through reductions of unscheduled downtime and faster and more efficient servicing and repair. In the larger classes of excavator, there is a clear trend to electric drive instead of diesel for mining machines.

In the past, a large number of analog and illuminated displays had to be checked. Now the operator can read the same information at a glance on a single monitor screen. The engine speed, fuel level, water, and oil temperatures are displayed in the form of bar diagrams. The date, time of operating hours, outside temperature, engine oil pressure, and generator charging rate are given in digital display. Such systems greatly facilitate maintenance and service operations because the service personnel can call up and print out all default messages that have occurred since the last service. This saves lengthy troubleshooting and permits immediate recognition and elimination of operating problems. It is commonly held that hydraulic excavators have a shorter working life than rope shovels. The truth is that hydraulic shovels are being designed for long life. Furthermore, in the case of the largest machines, there is an element of "custom" building in each case, so that mines can select features that will suit the machine to cope with conditions that prevail at a particular operation.[45]

REMOTE MINING

Solution Mining

The term solution mining is commonly used to refer to heap leaching, dump leaching, slope leaching, in situ mining, and borehole slurry mining technologies. The USBM is continuing with research in these areas. Commercial application of these technologies is progressing.

There is an ongoing cooperative research project between the USBM and the Santa Cruz Joint Venture to evaluate in situ copper mining at a field site near Casa Grande, AZ. The project is currently in the environmental permitting stage. The USBM is preparing an environmental assessment for the project as part of the National Environmental Policy Act. The USBM is also continuing with laboratory experiments to study the leaching characteristics of atacamite ore from the field test site, as well as various aspects of the SX-EW process.[46]

The USBM is also investigating the possible use of stope leaching as an underground mining method. In stope leaching, a stope is filled with fragmented ore by blasting ore from the surrounding wall rock or transporting it from other parts of the mine. A dilute chemical solution is then used to leach metals from the fragmented ore within the underground stope. The leaching solution is collected, pumped to the surface, and processed to recover the target metal.

The USBM believes several advantages may result from incorporating the stope leaching method. First, ore would be processed underground, minimizing costs associated with transporting it to the surface. Second, lower production costs would allow the company to mine lower grade ores in the deposit, increasing recovery of the in-place reserves, and surface disturbance would be minimized because most of the waste would remain underground in isolated regions within the mine workings.

The USBM is addressing two areas critical to the successful development of stope leaching: the chemistry of leaching run-of-mine ore and solution control. The first area deals with the feasibility of leaching large fragments that make up run-of-mine ore. Previous research focused predominately on ore that had been finely ground. The USBM is evaluating different leaching methods, including bioleaching, to extract metals from run-of-mine ore. The second critical area being addressed is solution control. Loss of escaping metal-bearing solution results in loss of the target metal, as well as possible contamination of the surrounding ground water.

The USBM is testing different methods to prevent solution loss in a simulated leaching stope at the Colorado School of Mines' Experimental Mine west of Denver, CO. This project will use only water and environmentally acceptable tracers to simulate leach solutions. Research is being conducted on techniques to detect solutions escaping from the simulated leaching stope as well as developing control measures to block escaping solutions after detection. The USBM is also evaluating U.S. deposits as possible test sites for a future full-scale leaching stope. Results from current leaching chemistry and solution control research will be incorporated into engineering designs for a future full-scale stope leaching demonstration.[47]

In a related study, engineers at the USBM are researching in situ leaching of gob-filled stopes to determine the feasibility of recovering ore that might otherwise be lost. There are numerous gob-filled stopes in mines throughout the Western United States. In many, the ore and waste occurred in alternating bands.

Miners would blast both at the same time and then rely on hand sorting to extract the higher grade ore. Lighting in these stopes was often very poor, and miners would often have difficulty selecting good ore from bad. The rejected ore was used to backfill the stope. Consequently, many of these stopes contain rock that, at today's standards, is considered high-grade ore. In situ leaching of gob stopes would make it possible to recover this ore that might otherwise be lost.

Advantages associated with leaching

gob-filled stopes include high permeability, no fragmentation required, low capital investments, low work force requirements, short lead times for production, and low energy consumption. Major disadvantages include potential loss of lixiviants because of natural rock joints and blast damage to the stope walls, difficulty in determining the size and shape of the stope, and recovering core samples of the gob material to determine ore content.[48]

Most heap-leach pads require agglomeration. The most common agglomerating agent is cement, which also provides protective alkalinity for the cyanide solutions. However, the amount of cement needed for pH control is usually more than that needed for agglomeration. Therefore, excess cement often is added, which can lead to reduced gold recovery. There is an ongoing search for improved agglomerating agents. Two that have recently come to attention are Leach-It and polymers.

The Chemstar Lime Co. of Phoenix, AZ, recently introduced Leach-It, which according to independent tests by McClelland Laboratories, offers the following advantages compared with cement:

- Increased gold recovery of up to 20% compared with that achieved by the use of cement.
- The area under leach could be reduced, possibly by one-half.
- Pregnant solution volume would be less, and at a higher grade.
- Potentially one-half the volume at twice the grade. This in turn would reduce the size of the solution recovery circuit and pumping and storage requirements.
- Cyanide consumption and water evaporation should decrease due to less solution exposure to the environment.

Leach-It is a lime-based combination of minerals that provides alkalinity for the necessary ion-exchange reactions and for the development of cementitious materials such as tobermorite and ettringite. These minerals have a dendritic structure that provides innumerable passageways for leach solutions to penetrate and allows oxygen to circulate freely.

Betz Industrial has been pursuing polymers as substitutes for cement, an approach based on pioneering work in agriculture on their use to maintain the permeability of high-clay soils. Betz's tests show that polymer-agglomerated gold ores have leach rates and ultimate recoveries equal to those of cement.

Drain-rate tests showed that acrylamide acrylic acid (AM/AA) copolymers were the most effective. Efficiency depends on the AM/AA ratio, molecular weight, and dosage. For a given ratio, effectiveness increases with molecular weight, the best agents being those with 70:30 to 90:10 ratios. The most effective combination is also ore dependent. Field trials for both Leach-It and polymers are currently being conducted, and their effectiveness will ultimately depend on relative costs and recoveries.[49]

Borehole Surveying and Detection Systems

For the first time, a miniature television is providing accurate and detailed visual information that allows engineers to perform analyses essential to maintaining ore production. Inco Ltd. is using the RC93 camera, designed by Rees Instruments, for a range of rock inspection tasks in Manitoba, Canada.

Effective mining relies on the correct location, identification, and efficient extraction of high-quality ore. To optimize the planning process, mine engineers use numerical models to plot ore location and simulated mine excavations. Creation of these complex models requires detailed logging of data collected by feeding the camera into exploration boreholes or production holes and recording the inspections for later review. The resulting video recordings yield data that allow the models to be calibrated and new workings simulated.

Once located, ore quality must be assessed. This is made possible by using the enhanced color definition of the RC93 system to examine the lithology of the rock. Precise color reproduction is used to determine the mineral content. Visual observation of joint densities allows 3-D, structured mapping to further increase the accuracy of prospecting. The high resolution camera system already is proving to be an invaluable tool for the mining personnel. It has interchangeable heads that provide high power lighting, zoom lenses, wide angle or radial viewing in boreholes as small as 50 mm diameter (2 in diameter). Ideally suited for arduous conditions, the camera is robust and waterproof. It is fully remotely controlled from the control consol, which has a color monitor and VCR for recording all results. Use of the system has already greatly aided mine planning operations and future use looks to extend ore production efficiency further.[50]

Using the latest in laser and microprocessor technology, Analysis Geotech Ltd. has developed a rugged manportable survey tool able to gather comprehensive survey data from areas of difficult, dangerous, or impossible access in active or abandoned mine workings.

The system, known as Caveman, can be deployed down boreholes with a diameter of 120 mm (4.72 in) or greater, and can operate at depths to 300 m (984.2 ft) from its surface control unit. Once located within the cavity, the laser-based total station scans in a number of preprogrammed movements to enable complete excavations or particular areas to be surveyed. Once the system is scanning, the range plus horizontal and vertical angles are stored on RAM cards at the surface control unit. Once the survey has been completed, the data are processed by a customized geotechnical software package to facilitate prints, plots, and data conversion to allow input into a variety of sophisticated software packages.[51]

Crone Geophysics and Exploration Ltd. builds everything needed for a borehole Time-Domain Electromagnetic (TDEM) system. Its 3-D borehole, pulse-electromagnetic systems, that incorporate complete 3-component, TDEM borehole-logging, can be attached to a compatible surface system. They can detect conductive bodies up to 200 m (656.2 ft) from the hole to depths of

2,500 m (8,200 ft) or more determining conductor orientation, size, conductance, distance, and direction. The systems break down into manageable pieces for transport by one or two people and are fully tested, rugged, reliable, and flexible.[52]

Continuous Miner Automation

The USBM is steadily progressing in its goal to improve the safety, health, and efficiency of underground mining operations through computer-assisted mining. A microcomputer-based control and monitoring network was developed by the USBM and installed on a continuous mining machine (CMM). The network consists of microcomputers, each of which was developed to provide a particular function in the control process. The USBM-owned CMM with machine-mounted computers in conjunction with appropriate sensors, provides closed-loop control of the machine, navigation, and environmental monitoring. Off-the-machine microcomputers provide remote control of the machine, sensor status, and a connection to the network so that external computers can access network data and control the CMM. The generic structure of the network will allow for installation on most mining machines. The CMM was evaluated in 1992 in a fully supported experimental section of a coal mine. Experiments on machine appendage control, machine guidance, sensors for the detection of the coal-roof boundary, and simple automated mining clycles using a script as the source of computer commands to the machine were successfully conducted.

Guidance plays an integral part of computer-assisted mining by keeping unstaffed continuous miners on their sights. The USBM has been investigating different land-navigation systems, and the modular azimuth and positioning system (MAPS) seems to show the most promise. By combining their efforts with a defense contractor, Honeywell's Military Avionics Div., the MAPS manufacturers are moving toward perfecting an underground navigational system.

MAPS uses a ring-laser gyroscope (RLG), which is an optical gyroscope. It differs from a mechanical gyroscope in that it does not have any moving parts. RLG's are laser-based, solid-state devices that are small and lightweight, have low power consumption and a fast response level requiring less-frequent recalibration, and are reliable in rugged environments.

MAPS has multiple configurations. Problems occur when operating on an odometer because of track slippage, so a zero velocity update is used. When the system determines the machine has reached zero velocity, an update starts automatically completing error corrections in less than 30 seconds. The dynamic reference unit is the heart of the MAPS system. It contains three RLG's, three accelerometers, and a control and display unit. A terminal displays information to the user, providing a means to input control commands and data.

Two underground tests were performed at an experimental five-entry section in a West Virginia coal mine. The MAPS unit, installed on a Joy 14CM, was modified by the USBM to collect data on the machine's x-y position, azimuth, pitch and roll, and vibration. The first test evaluated MAPS' operation and accuracy on a miner cutting a 6.1-m (20-ft) lift of coal. During the second test, refinements were applied to the system based on the original test. During the beginning of the first test, researchers collected both cutting-cycle sequence and machine-position data as the operator cut coal. To determine the actual machine position, a Leitz Set 3 electronic transit automatically computed surveying information.

A comparison of MAPS data for x-y position and data obtained from the transit showed an increasing MAPS error. After 30 minutes of operation, the easting error was 19.1 mm (0.75 in) and the northing error was 191 mm (7.5 in). After 60 minutes of operation, the easting error was 191 mm (7.5 in) and the northing error was 260.4 mm (10.25 in). Modifications to MAPS software and changes to the operational procedure of the machine significantly reduced this error by a factor of 3.7. The USBM believes MAPS is a feasible guidance system for mining use and that most performance problems can be corrected by software modifications.[53]

A USBM coal research project recently gained national recognition; the radar coal thickness sensor developed by the USBM's Pittsburgh Research Center to measure the thickness of coal remaining on the roof, floor, or rib of a mine was one of two "R&D 100" awards the Agency won. The award is presented by Research and Development magazine to 100 of the world's most innovative and technologically significant developments. The coal thickness sensor reportedly solves penetration and focus problems that have plagued earlier attempts to use radar to measure coal thickness. The sensor's coal thickness data are used for remote guidance of a computer-assisted mining machine.[54]

BENEFICATION

Clean Coal Technology

The increasingly stringent specifications set by the market for both coking and steam coals have encouraged technical developments in coal preparation. Conventional coal cleaning mainly uses methods developed at least 40 years ago. Nevertheless, in recent years there have been major advances in instrumentation and control that have resulted in reduced costs and greater consistency in the cleaned product. There also have been advances in research into improved methods of cleaning, particularly deep cleaning.

Over the past 20 years, consumers have become much more aware of the costs and consequences of using coal containing unwanted mineral matter and impurities. Changing market needs reflect the need to control emissions and to minimize operating costs. Coal producers are consequently seeking improved cleaning methods, and there are significant opportunities for the application of new coal-cleaning technology.

The Otisca T-Process.—The Otisca T-

process is intended to produce high-value ultraclean products. The feed is finely milled and slurried in water. Agglomeration of the clean coal particles is based on pentane, which can be readily recovered by evaporation. The pentane is immiscible in water, and, with proper dispersion in the water/coal/mineral-matter mixture, it can coat the coal particles and form agglomerates. The plant needs careful design and containment for safe operation.

Otisca Industries has been working for several years on the process. A 14-mt/h (15.4-st/h) demonstration plant has been built and operated. More than 125 tons (137.8 st) of ultraclean coal has been produced by this method with an average ash content of 0.8% (dry basis). Some coals have been cleaned to ash contents as low as 0.2% to 0.3% when they were milled to a mean size of about 2 microns. This is one of the most technically advanced deep cleaning processes currently available. Process costs will inevitably be high, although good carbon recovery can be expected.

The Gravimelt Process.—The use of sodium hydroxide solutions to produce cleaned coal for conversion into electrode carbon for the aluminum industry was developed in Germany during World War II. Although successful, the process never achieved sustained industrial production.

Since the mid-1980's the main work on the possible scale-up of coal cleaning by chemical methods has been based on the use of strong alkalis, particularly in the TRW Gravimelt process in the United States and the work of the CSIRO in Australia. The TRW Gravimelt process uses molten caustic in a rotary kiln reactor operating at temperatures between 325° C (617° F) and 415° C (779° F). The coal feed is conventionally cleaned and is relatively coarse. It needs only to be milled to minus 3 mm (0.118 in).

The caustic penetrates the coal matrix and dissolves out virtually all of the sulfur and mineral matter, including much of the organic sulfur. Even after washing, some of the caustic is retained in the coal. An acid wash is used to recover most of the caustic, together with iron and alkali metals. Typically, about 5% to 10% of the coal is lost as low molecular weight hydrocarbons that have a high specific energy. The condensable organic material formed, representing another 10% of the coal weight, has similar high heating value.

There is also dissolved organic matter and sulfur in the caustic. All these byproduct streams, contaminated in one way or another, must be dealt with and, if possible, converted to salable or usable products. It is possible to achieve extremely low ash contents of less than 0.2%, also sulfur contents of below 0.7%.

CSIRO Caustic Process.—The CSIRO in Australia has built a continuous pilot plant based on the use of caustic solution. The unit is capable of processing about 1 mt/h (1.02 st/h) coal. The intention is not only to study the effects of process conditions on different coals, but also to produce tonnage quantities of ultraclean coal for combustion and other testing.

The reactions are considerably milder than those used in the Gravimelt process. Coal feed slurry is treated with hot caustic solution at 200° to 220° C (392° to 428° F) for up to an hour in a digester. At this stage, quartz and pyrite are completely dissolved. Clays are converted to sodalite (sodium aluminum silicare). The sodalite and any alkali minerals are dissolved in a subsequent acid-soak tank. The final process stage involves the recovery of mineral byproducts and the regeneration of reagents after treatment with lime. The full recycle stage has not yet been built. It is clear that chemical cleaning to produce ultraclean coals is and remains a high-cost process.[55]

Hyperbaric Drum Filters.—Based on the success of the hyperbaric disc filter in coal preparation, Andritz AG has now developed a hyperbaric drum filter. In addition, the company has developed what it claims to be the first pressure filter to operate with steam.

Very fine particles cause several problems in the filtration of coal slurries. One drawback is that considerable quantities of liquid are attached to the very fine particles due to the latter's large specific surface area. Furthermore, fine particles also reduce the size of the capillaries in the filter cake, thus increasing the critical pressure that the filtration system has to exceed to achieve the desired final cake moisture.

The maximum filtration pressure of conventional vacuum filters is limited by nature itself and by practical aspects to approximately 0.75 bar. The hyperbaric filter combines the continuous operating principle with an increase in filtration pressure of up to 6 bar simply by placing the entire disc or drum filter inside a pressure vessel. Hyperbaric filtration thus combines the continuous operation of conventional vacuum filters with the low final-moisture contents previously only achievable with plate and frame presses.

Compared with vacuum filters, generally hyperbaric filters will reduce the final cake moisture of concentrates with 75% plus 30 micron by about 10%, while achieving four times the throughput. Data are also available on concentrates containing more than 58% plus 0 micron producing filter cakes with 8% moisture at five times the specific throughput of existing plate and frame presses.[56]

Column Flotation.—Although column flotation is well accepted in the phosphate and mineral processing industries, its commercial use in coal is just now occurring. Columns 3 m (9.8 ft) in diameter are now operating in several coal preparation plants.

Column technology uses a concurrent flow of washwater that is added near the top of the froth. As the washwater flows downward through the froth beds, it carries the mineral particles that would have otherwise reported to the clean product. Conventional cell geometry does not allow for an effective use of wash water. The column's large length-to-diameter ratio allows deep, well-washed froths to be maintained.

Many similarities exist between brands of column cells. Most columns used for

coal preparation range from 6.1 to 12.2 m (20 to 40 ft) in height and 1.23 to 3.7 m (4 to 12 ft) in diameter. Most of the recent changes have been made in the air-sparging systems, which employ two types of spargers: porous-stone and a foam jet sparger. Column cells are not wholly trouble-free. Two common application problems do occur with column cells—improperly metered air and deep froths that are too stable.[57]

Work has been undertaken at Michigan Technological University (MTU) on packed columns. The packed column uses a vertical tube with conventional in-line corrugated packing. This promotes intimate particle and bubble contact in the small flow passages. The separation of clean coal and ash takes place in a frothy mixture passing through the winding flow passages. It is claimed that the packed column overcomes the intrinsic problem of vertical mixing that can occur in an open column. The mixing can make scale-up more difficult. It is also claimed that effective flotation extends down to particles of only a few microns in size. The practical limitation is not the separation device, but the degree of liberation needed and the cost of grinding.

In laboratory tests, MTU has achieved clean coal products with ash contents from 1% to 3% at weight recoveries ranging from 46% to 94%. Subsequently, the pilot unit produced a 2% ash product with more than 95% recovery using a coal feed containing 4.3% ash. This was in a single stage with a feed of minus 100 micron. By regrinding the first stage concentrate to a top size of 30 micron and treating a second time, a clean coal of about 1% ash was obtained with a recovery of 80%.[58]

Mineral Processing

Grinding.—A new micronizing technology, with applications in the minerals industry, has been developed by Oy Finnpulva AB. The Pulva FP opposed jet milling process can produce fine powders from hard as well as soft materials. The completely new technology is based on the use of compressed air. The energy consumption can be 50% to 70% lower than that of conventional micronizing processes. Twelve installations have already been delivered worldwide.

In the Finnpulva opposed jet mill system, the particles to be ground are accelerated to a high velocity in specially designed acceleration nozzles by using compressed air. The carrier air is supplied by a compressor that produces clean, oil-free, hot air. The jets are directed to a small space where the raw-material particles collide, and this collision is the main contributor to the grinding process. Milling efficiency is considerably better and energy consumption lower than conventional jet milling. After grinding, the kinetic energy of the carrier gas and the solid particles is utilized in the classifier to separate the fine and coarse fractions by centrifugal force. Coarse fractions can be returned to the mill for regrinding or used as a separate product. The humidity of the material to be ground can be 0% to 10%. The fineness of the raw material does not affect the quality of the product. The size of the jet mill determines the maximum raw-material grain size, which typically is less than 2 mm (0.78 in); usually the raw material can be ground to this size using pressure rolls.[59]

Image Analysis of Rock Size.—A USBM-developed prototype digital image analysis system has been on-line at USX's Mintac iron ore plant for more than a year. The system, designed by researchers at the USBM of Mines' Twin Cities (MN) Research Center, provides an automated measurement of the size distribution of fragmented ore. The prototype system has been measuring run-of-mine ore feed to a primary crusher. The system automatically determines a complete size distribution for every train car dumped into the 1.37-m (54-in) crusher. Additional studies conducted at the Coleraine Laboratory, Natural Resources Research Institute, University of Minnesota—Duluth, have proven the reliability and accuracy of the size distribution measurements provided by the USBM system. Cooperative research between the USBM and LTV Steel Mining Co. has been completed to develop a balling-drum control method, based on the same image-analysis system.

The size measurement system is based on an inexpensive solid-state television camera connected to, and controlled by, a computer interface card in an MS-DOS-based computer. The key to the system is an edge-defining, size-measurement algorithm that robustly and reliably interprets particle outline. No operator intervention is required, and there is little sensitivity to moderate changes in lighting conditions. A complete size distribution is determined every 12 to 15 seconds, but researchers expect to cut this time to less than 4 seconds.

The system has been successfully tested on a variety of minerals and ore types, including limestone, taconite, and granite. Applications for the size-measurement system include: measurement of the size distribution of rock broken after blasting; measurement of crusher feed and discharge; measurement and control of the balling-mill process; and measurement of the fine particles in rotary-kiln discharge. Research is continuing to improve the accuracy and sensitivity of this novel measurement technique.[60]

Gold Recovery.—A new method of treating refractory arsenical gold concentrates has been proposed that avoids the costly conventional steps of pressure leaching or roasting. Instead, gold-bearing pyrite and arsenopyrite concentrates are subjected to an alkaline leach under intense agitation. Undecomposed sulfides are then floated from the leached pulp, fine ground to less than 10 microns, and recycled to the leach together with fresh feed. The float tails, which are essentially sulfide-free, are then cyanided using conventional resin-in-pulp or carbon-in-pulp techniques. Laboratory tests on a variety of Russian ores have yielded gold recoveries of 96% to 99%.

The main advantage of the process is that only a very small percentage of the concentrate needs to be reground. About 65% to 80% of the particles in a typical

95% minus 40-micron flotation concentrate will be less than 15 microns in size and will be decomposed during alkaline treatment. Furthermore, lamellalike and columnlike particles (the latter are characteristic of arsenopyrite) also will be decomposed. Thus, the only particles that will not be decomposed and will need ultrafine grinding will be those more than 10 to 15 microns in size. Depending on the character of the material being treated, these will be typically in the range of 5% to 12% by weight of the initial concentrate.

Other advantages of the process are low consumption of alkali compared with pressure leaching, the simplicity of the equipment because nearly all steps can be performed in flotation machines, and that the process does not allow undecomposed sulfides to pass to cyanidation. This guarantees stable and high extraction of gold under cyanidation. Preliminary studies indicate that the treatment cost will be about 80% that of the roast-cyanidation route.[61]

Floatation Development.—The Contact Cell represents a different approach to pneumatic flotation that promises to be the forerunner of a new generation of flotation machines. The compact device provides very high air holdup rates (the percentage of air in the slurry) with contact times of less than 2 seconds. Results with a continuous pilot unit at various plants show notably higher recoveries than conventional cells, or column flotation, in roughing, scavenging, and cleaning applications. The Contact Cell consists of two parts: the Contactor, where the mixing of air and slurry takes place, and the Separation Vessel, where the mixture is allowed to disengage into concentrate and tailings. The latter functions as a column flotation unit.

Tests have shown that the Contact Cell does not conform with classical theories of flotation. Residence time is not significant compared with conventional cells, but does become significant when operating with contact times of less than 1 second. It is believed that once the air/slurry mixture enters the separation vessel, collection has neared completion after 1 second. The most significant parameter seems to be the quality of air within the contactor. Thus, variables affecting kinetics are air rate, air holdup (i.e., bubble size), contactor pressure, contactor residence time, and slurry characteristics (i.e., percent solids, particle sizing etc.). Affecting the performance of the separation vessel are the bias rate, froth depth, and to some degree, dispersion characteristics.

There were many other important variables affecting the performance of the cell. To mention some: froth level had an impact in reducing froth dropback and increased feed rates had a positive effect on recovery allowing the cell to operate with lower contactor pressures. In many instances, frother was required to enhance froth stability so as to permit washwater addition. The washwater system and its behavior in the separation vessel is similar to that in conventional column flotation. The overall test results gave grade-recovery curves that were generally improved over those obtained by the plant using conventional cells. The Contact Cell's fast kinetics, froth washing characteristics, and compactness are likely to encourage the development of a new generation of flotation machines for processing plants.[62]

Researchers at the USBM Salt Lake City (UT) Research Center are developing process controllers for mineral beneficiation operations. A new personal-computer-based controller recently was demonstrated in a column flotation circuit. New process control theories, such as Fuzzy Logic Controllers (FLC), neural networks, and adaptive control, are being developed rapidly within the government and private sectors. These new theories offer greater flexibility and optimized productivity of unit operations. However, application of these control theories to industrial processes has been lagging. Improved technology to interface computer systems to mineral processing circuits is required. USBM research in this area is seeking to fill this technology gap.

The interface developed by USBM researchers for the column flotation circuit supports RS422 communications (a type of data communications software) and analog-to-digital and digital-to-analog optically coupled sensor data links. Thus, an almost limitless number of controller functions and sensor points are possible in the flotation circuit, and any computer that supports RS422 communications may be used to control flotation column operations. A great benefit of this system is that the controller then becomes software-based. As new control theories emerge, only the control software will need replacement. There will be little or no hardware costs to give increased system control provided by the new control software. This control scheme is being tested using MS-DOS-based computers linked to a USBM-developed flotation column.[63]

Scientists at the USBM's Rolla Research Center have developed a froth-flotation process that removes heavy-metal-bearing minerals from process tailings. The process recovers the mineral components of the tailings while removing acid-forming minerals, making the wastes less susceptible to leaching of contaminants.

This novel process uses a combination of conventional and nonconventional flotation reagents to lower the metal content of tailings by as much as 95%. Because older tailings are extensively oxidized, the first step requires using sodium sulfide to reform metal sulfide coating on the surface. Conventional froth flotation processes then are used to remove the metal-containing minerals. As a unique part of the tailings decontamination and metal recovery program, researchers also are investigating the feasibility of using a newly invented device called the Air Sparged Hydrocyclone (ASHC). The ASHC has a throughput (tons per unit of time per cell size) that is 100 times greater than flotation cells. Successful development of this technology will result in a portable, compact unit for treating large volumes of tailings on-site without the usual expensive capital requirements.[64]

Lurgi Metallurgie GmbH has developed a new method for the flotation

of complex nonferrous sulfide ores. The Conox process will be applied for the first time in the Cayeli copper-zinc beneficiation plant, which is presently under construction in Turkey. The Conox process provides for the optimum setup of several parameters to establish an electrochemical milieu that is favorable for the selective flotation of finely intergrown complex ores. Because Conox requires only a few additional pieces of equipment, it can be implemented in existing plants. Owing to the resulting higher grade and improved recovery, the capital investment has a short payback period.[65]

A unique design in bubble generation technology applied to column flotation is being marketed by Control International S.A. in France and is known as Microcel. This technology was originally developed and patented at the Virginia Polytechnic Institute and State University, VA. The Microcel design recirculates part of the tailings flow of the column through an in-line static mixer. The high shear applied to the mixture of air and slurry in the static mixer produces microbubbles ranging from 150 to 800 microns with a very narrow bubble-size distribution. The bubble generator offers several advantages over other existing air sparger systems. These include the generation of very small bubbles, little risk of plugging, built-in scavenger system, no freshwater addition, no moving parts, and easy on-line maintenance. It has been installed successfully in full-scale production flotation columns in mineral processing and coal preparation plants.[66]

Ore Treatment.—Euro-Pulse, a new United Kingdom company specializing in mineral processing, has developed what it claims is a revolutionary method of ore treatment. The Ore Structure Modification process is the result of several years of fundamental studies that investigated rock behavior under an electrical field. It is said to modify internal rock structure and drastically increase its porosity by a highly selective application of electrical energy.

The process of ore structure modification is initiated by a specific level of electrical stress applied across the rock sample (characteristic to each ore). Above this threshold, a highly nonlinear flow of electric current is generated that creates gradual expansion of the interfaces between the valuable mineral and its rocky matrix. The rock porosity increases and its mechanical strength decreases. Also, as the applied electrical stress increases the process of interface expansion is accompanied by interlinking expanded interfaces, which increases the permeability of the rock.

The process reportedly offers cost benefits over existing methods by reducing energy consumption and extraction time. A mineral processing test facility for investigating individual ore characteristics and response to the outline technology has been expanded and is now available for potential customers.[67]

Pyrite Removal Using Bacteria

Many processes have been used to try to physically remove pyrite (FeS_2) from coal. Some processes attempt to chemically remove the pyrite, which can be expensive. In a joint venture, the Pittsburgh Energy Technology Center (PETC) and the USBM have teamed up with biotechnology to develop a simple and relatively inexpensive process based on the chemistry of coal itself.

A heap-leaching process uses iron-eating and sulfur-eating bacteria to help increase the pyrite's natural oxidation rate. When the bacteria, Thiobacillus ferroxidans, are introduced to the coal, the bacteria eat at the pyrite and accelerates the normally slow oxidation process to about six times the normal rate. The oxidized pyrite dissolves and forms rhomboclase, a soluble iron sulfate salt. Rhomboclase can be washed away from the heap by irrigating it with water. The washwater is treated and reused. The recycled water does build up acidity and is later neutralized in a water-treatment system.

With this faster oxidation process, what had been accomplished in 1 year now takes approximately 2 months. Roughly 50% of the pyrite in the coal can be removed using this leaching process. The goal of the bacterial leaching process is to determine its potential for removing pyrite from coal stockpiles at powerplants.[68]

Bottom Blown Oxygen Converter

One of the most significant developments in the refining of metals is the Bottom Blown Oxygen Converter (BBOC). Although designed primarily for lead-silver refining, the BBOC can be used for virtually any duty where impurities need to be selectively eliminated by oxidation. Examples of these include refining of lead and copper electrorefinery slimes, secondary copper, and low-grade concentrates containing platinum-group metals.

The BBOC was developed by Britannia Refined Metals Ltd. (BRM) to improve on conventional cupellation where air is blown over the surface of the molten metal to progressively oxidize impurities. Cupellation is characterized by slow reaction rates, due to poor oxygen transfer, and the buildup of a slag layer on the surface.

In the BBOC in contrast, oxygen is injected directly into the molten bath through a nitrogen-shrouded lance mounted vertically in the base of the converter. The lance is consumed sacrificially and, when the furnace is tilted to discharge slag, the lance assembly rises clear of the bath and can be easily replaced during the operating cycle.

The main advantages of the BBOC are as follows:

- A reaction rate 15 to 20 times that of a conventional cupel, which leads to reduced cycle times, volume requirements, and precious-metal inventories.
- A largely autogeneous process with substantial fuel savings. BRM reports fuel consumption that is only 20% of conventional cupellation-process.
- The slag layer can build up without hindering oxygen transport, which leads to improved slag/metal separation and predictable process

control.

- The oxygen is almost 100% consumed, which leads to low offgas handling and power requirements, and consequent excellent plant hygiene.
- Slag produced can be cast directly into anodes, eliminating the holding furnace.[69]

HEALTH AND SAFETY

Mining Statistics

For the fourth year in a row, coal mining deaths declined in the United States in 1992, with last year's 55 fatalities representing the second-lowest total on record. Coal mining deaths have dropped from 60 in 1991, 66 in 1990, and 68 in 1989. The lowest total recorded by the Federal Mine Safety and Health Administration (MSHA)—53—was in 1988. Overall, the death toll for the U.S. mining industry, including coal, metal, and nonmetal mines, was the lowest ever in 1992. The 98 deaths marked the first time the total dipped below 100 since Federal officials began keeping records.

Kentucky, a State that historically ranks high in coal mining deaths, recorded its lowest total ever with nine, one-half of its 1991 total. Although most States showed a decrease in mine fatalities, two States—West Virginia and Virginia—accounted for more than 52% of all coal-related deaths. Altogether, 29 miners were killed in the two States—17 in West Virginia and 12 in Virginia. West Virginia's total, nevertheless, is down from 21 in 1991 while Virginia's is up from 9 in 1991.

Kentucky placed third in mine fatalities in 1992. Next came Alabama and Tennessee, three each; Colorado, Illinois, and Pennsylvania, two each; and Indiana, New Mexico, Utah, and North Dakota, one each. There were no recorded fatalities in Wyoming, the Nations's leading coal producer, a repeat of 1991's performance. According to MSHA, 34 miners died in underground mines in 1992, compared with 21 in surface mines. In 1991, those numbers were 40 and 20, respectively.

Powered haulage accidents accounted for 15 of the deaths last year. Second was roof falls, which claimed 10 lives. Fatal machinery accidents finished third with nine. Smaller mines, those with fewer than 50 employees, experienced 36 fatalities at 24 mines in 1992, compared with 19 fatalities at 19 mines with more than 50 employees.[70]

Personal Safety Alarms

Methane versions of the MiniGard III and MicroGard Portable Alarms have received approvals from the MSHA for use in underground coal mines. The alarms, manufactured by Mine Safety Appliances Co., are battery-operated devices that can be handheld or worn on a belt. Both are available with a 0% to 5% methane-by-volume calibration for mining applications.

The MiniGard III is designed for simultaneously monitoring concentrations of methane, oxygen, and carbon monoxide. Audible and visible alarms alert the use of dangerous gas and oxygen concentrations.

In addition to detecting methane, the MicroGard monitors the atmosphere for both oxygen-deficient and potentially explosive oxygen-rich conditions. If limits are exceeded, the alarm activates a buzzer and provides concentration levels on an easy-to-read liquid crystal display panel.[71]

Scientists at the USBM Twin Cities (MN) Research Center and at the University of Minnesota have developed a cost-effective sampler that can be used by the mining industry and regulatory agencies to determine the amount of diesel exhaust aerosol (respirable-size particles) present in mine atmospheres. The easy-to-use sampler is wearable by mine personnel, inexpensive, and compatible with current personal sampling protocols.

The USBM conducted this research in response to reports issued by the National Institute for Occupational Safety and Health (NIOSH) and the Department of Labor's MSHA. NIOSH has recommended in its report that whole diesel exhaust be regarded as a potential occupational carcinogen. MSHA has been directed by an advisory committee to establish a diesel exhaust aerosol standard and regulations to minimize exposure to diesel pollutants in underground coal mines. Later reports released by these Agencies point out the need for developing measurement techniques for respirable diesel aerosol, with the MSHA report specifically requesting support from the USBM and NIOSH to develop these techniques.[72]

VLF Magnetic Systems' Canary mine messenger is a wireless communications system that improves safety and productivity of mining operations by instantly transmitting early-warning emergency signals or paper messages to underground workers. Recent tests have provided full coverage throughout the 3-mile-wide Central Canada Potash Mine in Saskatchewan.

Standard components include a transmitter, an antenna, a testing and reprogramming unit, custom operating software, and receivers. The Canary receiver and display screen is fully integrated into a helmet-light battery pack. The system was developed in conjunction with the Noranda Technology Centre, Montreal.[73]

Seal and Stopping Advances

The MSHA critically examines any devices or materials used as ventilation controls. Of particular concern are the controls' structural effectiveness and resistance to fire.

MSHA's Industrial Safety Division (ISD) has developed performance criteria and possible designs for air check applications. The emphasis was placed on the development of a run-through, curtain-type of control that would provide the flexibility, ease of use, and low maintenance of hanging conveyor belting but with resistance to the spread of flame and smoke in the event of a fire. After testing many different types of heat-resistant materials fabricated in a variety of manners, a final design was selected

that provided the best overall performance.

The curtain consists of a composite of double-layered, high-temperature ceramic fiber textile sewn together using ceramic thread and buffered on both sides with an approved 35-mil polyethylene plastic brattice. The brattice serves as a bumper to provide resistance to the abrasion caused by passing equipment. This curtain thermally degrades upon exposure to test fire. The ceramic fiber textile remains in place, providing a barrier to the spread of smoke and fire upwind. Fire spread upwind in mine fires is normally caused by radiation generated by flame temperatures in excess of 538° C (1,000° F). The ceramic fabric attenuates the temperatures generated by the test fire, preventing the spread of flame.

This ventilation control provides the ease of use and flexibility of a synthetic curtain constructed with hanging conveyor belting, but also has the air separation and fire-resistant properties consistent with nonresilient masonry and steel ventilation control structural materials. The low maintenance and fail-safe closing characteristics of the curtain make it an attractive alternative to the use of metal doors for this unique application.[74]

When conventional techniques no longer work in fighting a coal mine fire, the standard procedure is to construct permanent seals—bulkheads made from solid blocks. The speed at which these seals can be constructed is sometimes the difference between saving or closing a mine. In a mine fire situation, temporary seals are sometimes used to prevent air flow from reaching the fire, and also to keep smoke from contaminating other areas. Permanent seals, however, must be able to withstand a secondary explosion of at least 138 kPa (20 psi).

USBM researchers have been focusing attention on how different types of seals—solid-block bulkheads (conventional), rapid inflatable seals, and binary foam seals—react under disaster conditions. During full-scale tests by the USBM, only the solid-block, Mitchell-type seal withstood a 138 kPa (20 psi).

Similar pressure tests have been done on both the inflatable and rigid binary-foam seals. The inflatable seal, which takes about 10 minutes to erect, is made of nylon material and has structurally withstood small-scale tests. Eventually, the USBM hopes to fill the inflatable seal with a quick-setting foam for explosion tests. Both the small- and full-scale tests have shown promising results.

Permanent stoppings, traditionally constructed from concrete blocks, are used to maintain proper ventilation. The structural integrity of a permanent stopping is key in a mine fire situation. Miners fighting or escaping from a fire depend on permanent stoppings to prevent the spread of fire and also to keep toxins from reentering the intake side of the ventilation. The USBM has been investigating both concrete-block an galvanized-steel stoppings against fire endurance.

Both types of stopping were erected and subject to 70 minutes of an artificially re-created mine fire. Video cameras were used to determine if flames or smoke penetrated the stopping, while heat sensors monitored surface temperatures. Surface temperatures on the fire side exceeded 788° C (1,450° F). Both types maintained structural integrity with no flames or smoke penetrating the stoppings. A strong difference, however, did exist between the exposed-side surface temperatures. The exposed side of the block stopping had a temperature of more than 66° C (150° F), while the steel stopping had an exposed-side temperature of more than 482° C (900° F). When the exposed side of the steel stopping was coated with a 19.1-mm-thick (3/4-inch-thick) coating of plaster, temperatures were reduced by almost 50%. From these results, materials probably should not be stacked against permanent steel stoppings.[75]

MSHA Regulations

Among the health issues addressed by MSHA in 1992 was the concern about lung hazards resulting from excessive exposure of workers to crystalline silica. The Agency carried out a program to target operations producing finely ground silica for special monitoring. MSHA established a task force to work with NIOSH to recommend dust control improvements at selected operations.

The bag stacker job function at mineral processing facilities continues to be a major health concern of MSHA and to operators because of the dust exposures being recorded by these workers. One such technique, being considered for a number of years to reduce this exposure, was a bag and belt cleaner device. Because the majority of the bag stacker's dust exposure comes from product on the bag or belt, reducing this product accumulation could have a measurable effect on reducing the worker's exposure. A bag and belt cleaner device has been designed and fabricated by the USBM. This device is a 3.04-m (10-ft) section of conveyor that can be used at any mineral processing operation bagging 22.7 to 45.36 kg (50 or 100 lbs) of mineral product into paper bags. This device cleans the outside of the bags using a series of brushes and air knifes. The system is totally enclosed and under negative pressure so that no dust removed from the bags is emitted into the work environment, and thus a contaminant to plant personnel. The dust removed from bags is exhausted to a baghouse. A chain conveyor is used to transport the bags through this device, which also removes any product that has fallen on to the conveyor belt. Once exiting this cleaner device, the bags and the conveyor belt are free of product, which reduces the exposure of any plant personnel handling the bags, or any future users. Preliminary results on this device show it to be very effective at removing product from the bags and belt and reducing the exposure to plant personnel.

During 1992, MSHA continued its Special Emphasis Mine Program. The program addresses concerns at mines and mills that have the potential for fatalities or disabling injuries. These may be due to geological hazards or operating conditions such as the release of harmful chemicals into the atmosphere. In 1992, 19 operations were on the Special Emphasis Mine Program list. Of those,

12 were underground, 2 were quarries, 2 were open pit mines, and 3 were ball mills.

MSHA, in cooperation with State mining agencies, continued its Joint Mine Assistance Program. This program is designed to help small mine operators in the four States that accounted for 70% of all coal mining fatalities establish a tailormade accident prevention program. Federal and State mine inspectors offer assistance to mines in Kentucky, Pennsylvania, Virginia, and West Virginia.

Consideration of health standards for miners has been ongoing for several years. MSHA proposed new air quality regulations for coal and metal/nonmetal mines. While MSHA's proposed regulations are undergoing review, they have brought to light the need to prepare for dealing with air quality concerns in coal mines. The proposed rules were published in the Federal Register as applicable to coal mines in 1989. These proposed regulations are comprehensive. They provide protection in such areas as permissible exposure limits, carcinogens, exposure monitoring, and means of control. These changes contain standards for more than 140 substances that would be regulated for the first time in a mine environment.[76]

Methane Research

The USBM evaluated the use of exhaust gas to keep explosive gas mixtures from forming while auger mining highwalls. A combination of gasoline and diesel engine exhaust gasses, produced by the augering machine, was forced into the drill hole using a short section of pipe near the collar. Gas samples were taken and analyzed on-site with infrared detectors for oxygen, carbon dioxide, methane, and carbon monoxide. Evacuated bottle samples also were taken and analyzed in a gas chromotology laboratory for content. The combined gas results were analyzed for explosibility. Coal samples from various depths were used to obtain the gas content of the coal.

Personal carbon monoxide exposure levels also were monitored, and the maximum time-weighted average sample measured 20 ppm. The highest methane level observed was 9.6%. The levels of inert gas (carbon dioxide and nitrogen) were sufficiently high to prevent any methane ignitions. Results showed that for all conditions during mining, gas concentrations were nonexplosive. From the tests performed, the USBM has deemed this system a safe, simple, and inexpensive method for preventing explosions during auger mining.[77]

USBM researchers at the Pittsburgh Research Center are looking at fiber optics as a new means of sensing potential gas hazards in underground coal mines. An engineering prototype methane monitor that uses fiber-optic sensing has been designed as part of the USBM's research to improve mine safety.

A significant hazard in coal mines is the ignition of methane gas. Because methane is odorless and explosive when mixed with air to a concentration between 5% and 15%, it must be continually monitored. However, most methane monitors now in existence are powered by electrical sources that must be shut down during an emergency. Backup batteries have a very limited life. Once these are depleted, monitors cease to operate, possibly allowing dangerous levels of methane to accumulate. The reliability of methane monitoring may be enhanced by eliminating the need for electrical power by replacing current monitors with a totally passive, intrinsically safe, fiber-optic system.

In recent years, both the Government and industry have conducted much research on fiber-optic sensing. Because of the small return on investment in the limited mining market, the research has not been directed to mining applications. However, the use of fiber on the ocean floor for communications systems has proven that it is sturdy enough for the hostile mining environment. There are many advantages to fiber, including easy maintenance, low cost, high data capacity, and light weight. The abundance of silica ensures the availability of fiber far into the future. Because silica and plastic used to make the fiber are nonconductors, electrical sparking is not a problem.

The results are encouraging, but further research on the fiber-optic methane monitor is required before mine usage will be possible. Errors induced by temperature, bending, and index of refraction of the measured gases must be decreased. Also, a method of monitoring multiple sites will be determined to make the system economically feasible.[78]

Stockpile Safety

A stockpiling safety manual prepared jointly by the USBM and the National Mine Health and Safety Academy (Safety Manual No. 30) discusses hazards associated with the operation of mobile equipment on and around stockpiles. It reviews procedures that can be used to minimize the occurrence of accidents. The manual is a result of the USBM's research in stockpiling safety and strong foundation of stockpile safety work provided by MSHA Technical Support and MSHA Metal and Nonmetal Mine Safety and Health. The manual can be obtained from the National Mine Health and Safety Academy, Beckley, WV.

Operating mine haulage trucks near the crest of stockpiles and waste dumps is a potentially hazardous practice. It often results in a localized slope failure and a dump point accident. The USBM has developed a computer code (INSLOPE3) based on the kinematic method of limit analyses that determines an admissible truck weight for varying distances from the slope edge.

The program considers the material strength parameters, slope geometry, and inertial forces induced by vehicle braking. It can be used to assist in the determination of safe operating distances for a haulage truck from a slope edge, the development of safe vehicle operating procedures, and the admissible weight for a static concentrated loading near the crest of an otherwise stable slope.[79]

Fire Detection

A classification system has been developed by the USBM that can give a

mine operator an estimate of locations where fire-related hazards are most likely to exist. This system is based on data obtained from a review of fires that occurred from 1970 through 1989 and were reported by MSHA.

The objective of this research was to determine if degrees of hazard relative to fire source or location could be construed from information contained in the reports. Specifically, the propensity for fires to cause injuries and fatalities as well as the need to seal areas were examined. Source-related fires were found to exist throughout most mines; consequently, their random appearance made hazard assessment impossible. Research, therefore, concentrated on examining fire locations. Relative to all underground locations, fires occurring in belt entries were most likely to cause injuries while those in main haulageways were most liable for fatalities as well as sealing of at least the immediate area to extinguish. Results indicated a level of fatalities in main haulageways far greater than one would expect from random fluctuation.

Redundant levels of safety that exist at various underground locations were examined. These levels of safety were found to vary from place to place within a mine. Face, near-face, and belt locations had the highest levels of redundant safety. Conversely, haulageways had the lowest. This lack of safety levels was most likely due to the fact that equipment and activities in this entry were so varied.

A second study was undertaken to investigate what fire sources in haulage entries were most likely to cause fatalities. Results indicated that the most prolific source of haulage entry fires was the inadvertent grounding of trolley wires. The largest segment, encompassing 15 of 40 trolley wire fires, resulted from not maintaining adequate clearance between the trolley wire and the vehicle. Several novel fire prevention and control ideas have been proposed in response to frequently occurring fire-related problems in haulage entries.

Researchers at the USBM's Pittsburgh Research Center have developed a unique fire detector that can discriminate between the occurrence of real mine fires and the presence of diesel engine smoke. Called a submicron particle detector (SMPD), the apparatus can be used in other applications, including environmental monitoring and "clean room" monitoring. The USBM is actively seeking to commercialize the SMPD for any, or all, of its potential applications by licensing this technology to industry.

The SMPD was developed to eliminate the occurrence of false fire alarms in underground mines caused by operating diesel-powered equipment. Most fire detection systems now used in underground mines are based on measurements of airborne combustion products, such as carbon monoxide or smoke particles. The effectiveness of these systems can be reduced by false alarms set off by diesel-powered equipment that produce the same combustion products. These false alarms can be expensive to the mine operation because of downtime and labor required to verify the alarm.

The detector has been extensively tested by the USBM and has undergone in-mine tests and evaluations at operating coal mines that use diesel-powered equipment. Tests also have revealed that the SMPD offers potential applications in environmental areas such as particulate monitoring of smoke stack emissions. Clean room applications also may exist as well as the area of fire detection that extends beyond the mining industry.[80]

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TABLE 1

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

(Million metric tons)

Type and year	Surface			Underground			All mines[1]		
	Crude ore	Waste	Total[1]	Crude ore	Waste	Total[1]	Crude ore	Waste	Total[1]
Metals:									
1988	705	862	1,567	28	6	34	733	868	1,601
1989	725	1,009	1,734	45	5	50	770	1,013	1,783
1990	706	1,219	1,925	54	4	57	760	1,222	1,982
1991	737	1,313	2,050	72	2	74	809	1,315	2,124
1992	727	797	1,523	26	3	29	753	799	1,552
Industrial minerals:									
1988[2]	1,100	332	1,432	36	([3])	37	1,137	332	1,469
1989[4]	1,409	702	2,111	57	2	59	1,466	704	2,170
1990[2]	1,131	286	1,417	36	1	37	1,167	286	1,454
1991[4]	1,211	132	1,342	62	([3])	62	1,272	132	1,404
1992[2]	1,132	196	1,329	24	([3])	24	1,156	197	1,353
Total metals and industrial minerals:[1]									
1988	1,805	1,194	2,999	65	6	70	1,870	1,200	3,070
1989	2,134	1,711	3,845	102	7	109	2,236	1,718	3,954
1990	1,838	1,504	3,342	90	4	94	1,927	1,509	3,436
1991	1,948	1,444	3,392	133	2	136	2,081	1,447	3,528
1992	1,859	993	2,852	50	3	53	1,909	996	2,905

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

[2]Crushed and broken and dimension stone data were not available for 1988, 1990, and 1992 because of biennial canvassing.

[3]Less than 1/2 unit.

[4]Includes industrial sand and gravel. Construction sand and gravel data were not available for 1989 and 1991 because of biennial canvassing.

TABLE 2

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES[1] IN THE UNITED STATES IN 1992, BY COMMODITY AND STATE[2]

(Thousand metric tons)

Commodity	Surface			Underground			Total material handled [3]		
	Crude ore	Waste	Total	Crude ore	Waste	Total	Crude ore	Waste	Total
METALS									
Copper	334,079	393,213	727,292	5,419	120	5,539	339,498	393,332	732,831
Gold:									
Lode	230,852	273,336	504,187	5,333	752	6,084	236,184	274,087	510,271
Placer	11,349	19,041	30,390	W	W	W	11,349	19,041	30,390
Iron ore	135,797	106,233	242,029	W	—	W	135,797	106,233	242,029
Lead	—	W	W	6,759	W	6,759	6,759	W	6,759
Silver	—	W	W	2,824	W	2,824	2,824	W	2,824
Titanium	11,542	—	11,542	—	—	—	11,542	—	11,542
Zinc	W	W	W	4,751	W	4,751	4,751	W	4,751
Other[4]	3,178	4,796	7,974	748	1,955	2,703	3,926	6,751	10,677
Total metals	726,797	796,618	1,523,414	25,834	2,826	28,660	752,630	799,444	1,552,074
INDUSTRIAL MINERALS									
Abrasives	46	W	46	W	—	W	46	W	46
Asbestos	371	124	495	—	—	—	371	124	495
Barite	578	W	578	—	—	—	578	W	578
Boron minerals	2,025	W	2,025	—	—	—	2,025	W	2,025
Clays	40,623	35,175	75,798	68	1	69	40,691	35,176	75,866
Diatomite	1,181	W	1,181	—	—	—	1,181	W	1,181
Feldspar	636	—	636	—	—	—	636	—	636
Gypsum	12,708	14,867	27,575	2,595	W	2,595	15,303	14,867	30,170
Iron oxide pigments (crude)	26	—	26	—	—	—	26	—	26
Mica (scrap)	439	W	439	—	—	—	439	W	439
Perlite	760	178	937	W	—	W	760	178	937
Phosphate rock	151,796	—	151,796	W	—	W	151,796	—	151,796
Potash	—	—	—	1,902	—	1,902	1,902	—	1,902
Pumice[5]	492	W	492	—	—	—	492	W	492
Salt	3,143	—	3,143	11,772	—	11,772	14,915	—	14,915
Sand and gravel	858,708	—	858,708	—	—	—	858,708	—	858,708
Soda ash	—	—	—	6,045	—	6,045	6,045	—	6,045
Talc, soapstone, and pyrophyllite	516	W	516	—	—	—	516	W	516
Vermiculite	190	—	190	—	—	—	190	—	190
Zeolites	28	W	28	—	—	—	28	W	28
Other[6]	58,228	146,144	204,372	1,441	247	1,688	59,669	146,391	206,060
Total industrial minerals	1,132,494	196,487	1,328,982	23,823	248	24,072	1,156,318	196,735	1,353,053
Grand total	1,859,291	993,105	2,852,396	49,657	3,074	52,732	1,908,948	996,179	2,905,128
STATE									
Alabama	14,298	W	14,298	—	—	—	14,298	W	14,298
Alaska	20,912	21,887	42,800	W	W	W	20,912	21,887	42,800
Arizona	259,495	W	259,495	W	W	W	259,495	W	259,495
Arkansas	12,185	W	12,185	—	—	—	12,185	W	12,185
California	141,321	20,072	161,393	226	W	226	141,546	20,072	161,619
Colorado	30,016	W	30,016	W	W	W	30,016	W	30,016
Delaware	2,257	—	2,257	—	—	—	2,257	—	2,257
Florida	164,570	408	164,979	—	—	—	164,570	408	164,979

See footnotes at end of table.

TABLE 2—Continued

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES[1] IN THE UNITED STATES IN 1992, BY COMMODITY AND STATE[2]

(Thousand metric tons)

Commodity	Surface			Underground			Total material handled [3]		
	Crude ore	Waste	Total	Crude ore	Waste	Total	Crude ore	Waste	Total
STATE—Continued									
Georgia	15,178	W	15,178	—	—	—	15,178	W	15,178
Idaho	25,557	W	25,557	337	W	337	25,893	W	25,893
Illinois	37,281	W	37,281	W	W	W	37,281	W	37,281
Indiana	26,994	731	27,725	W	—	W	26,994	731	27,725
Iowa	16,900	W	16,900	W	—	W	16,900	W	16,900
Kansas	12,644	W	12,644	1,356	—	1,356	13,999	W	13,999
Kentucky	7,561	740	8,300	—	—	—	7,561	740	8,300
Louisiana	12,682	702	13,384	5,370	—	5,370	18,052	702	18,754
Maryland	11,127	197	11,324	—	—	—	11,127	197	11,324
Michigan	90,592	52,598	143,191	W	W	W	90,592	52,598	143,191
Minnesota	128,412	W	128,412	—	—	—	128,412	W	128,412
Mississippi	11,681	917	12,598	—	—	—	11,681	917	12,598
Missouri	10,328	W	10,328	W	W	W	10,328	W	10,328
Montana	48,227	W	48,227	3,096	W	3,096	51,323	W	51,323
Nebraska	12,173	159	12,332	—	—	—	12,173	159	12,332
Nevada	188,762	259,600	448,362	W	1	1	188,762	259,601	448,363
New Hampshire	5,845	W	5,845	—	—	—	5,845	W	5,845
New Jersey	16,367	W	16,367	—	—	—	16,367	W	16,367
New Mexico	46,495	W	46,495	1,953	W	1,953	48,448	W	48,448
New York	29,964	W	29,964	W	—	W	29,964	W	29,964
North Carolina	25,681	W	25,681	—	—	—	25,681	W	25,681
Ohio	47,090	1,953	49,044	W	W	W	47,090	1,953	49,044
Oklahoma	13,002	W	13,002	—	—	—	13,002	W	13,002
Oregon	16,638	W	16,638	W	W	W	16,638	W	16,638
Pennsylvania	18,716	555	19,271	—	—	—	18,716	555	19,271
Rhode Island	2,306	—	2,306	—	—	—	2,306	—	2,306
South Carolina	15,684	W	15,684	—	—	—	15,684	W	15,684
South Dakota	13,826	W	13,826	2,182	523	2,705	16,009	523	16,531
Tennessee	9,540	1,073	10,614	W	W	W	9,540	1,073	10,614
Texas	47,896	W	47,896	W	—	W	47,896	W	47,896
Utah	74,287	W	74,287	77	W	77	74,363	W	74,363
Vermont	3,634	61	3,695	—	—	—	3,634	61	3,695
Virginia	10,149	697	10,845	W	W	W	10,149	697	10,845
Washington	37,963	W	37,963	510	174	685	38,473	174	38,647
West Virginia	1,768	69	1,837	—	—	—	1,768	69	1,837
Wisconsin	27,718	—	27,718	—	—	—	27,718	—	27,718
Wyoming	5,865	W	5,865	6,026	—	6,026	11,892	W	11,892
Undistributed[7]	87,704	630,684	718,388	28,524	2,376	30,900	116,228	633,060	749,288
Grand total	1,859,291	993,105	2,852,396	49,657	3,074	52,732	1,908,948	996,179	2,905,128

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

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

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

[3]Includes material from exploration and development activities.

[4]Includes bauxite, beryllium, molybdenum, nickel, platinum-group metals, rare-earth concentrates, and metal items indicated by symbol W.

[5]Excludes volcanic cinder and scoria.

[6]Includes aplite, fluorspar, greensand marl, kyanite, magnesite, magnesium-brines, olivine, sulfur (Frasch), wollastonite, and industrial minerals items indicated by symbol W.

[7]Includes Connecticut, Hawaii, Maine, Massachusetts, North Dakota, and State items indicated by symbol W.

TABLE 3

VALUE OF PRINCIPAL MINERAL PRODUCTS AND BYPRODUCTS OF SURFACE AND UNDERGROUND ORES MINED IN THE UNITED STATES IN 1992

(Value per metric 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	$8.40	$0.72	$9.12	$22.05	$1.77	$23.81	$8.60	$0.73	$9.33
Gold:									
Lode	10.21	.72	10.92	39.24	.90	40.13	10.83	.72	11.56
Placer	3.01	.14	3.14	W	—	W	3.01	.14	3.14
Iron ore	8.63	—	8.63	W	W	W	8.63	—	8.63
Lead	—	—	—	23.37	29.39	52.76	23.37	29.39	52.76
Silver	W	W	W	10.72	14.86	25.58	10.72	14.86	25.58
Titanium	3.44	W	3.44	—	—	—	3.44	W	3.44
Zinc	W	W	W	40.10	W	40.10	40.10	W	40.10
Average, metals[2]	9.27	.66	9.93	27.65	9.81	37.46	9.86	.95	10.82
INDUSTRIAL MINERALS									
Abrasives	26.29	—	26.29	W	—	W	26.29	—	26.29
Asbestos	34.56	—	34.56	—	—	—	34.56	—	34.56
Barite	14.92	—	14.92	—	—	—	14.92	—	14.92
Boron minerals	129.11	W	129.11	—	—	—	129.11	W	129.11
Clays	27.05	.21	27.27	W	W	W	27.05	.21	27.27
Diatomite	63.20	—	63.20	—	—	—	63.20	—	63.20
Feldspar	31.81	—	31.81	—	—	—	31.81	—	31.81
Gypsum	5.15	—	5.15	5.21	—	5.21	5.16	—	5.16
Iron oxide pigments (crude)	80.19	—	80.19	—	—	—	80.19	—	80.19
Mica (scrap)	9.21	—	9.21	—	—	—	9.21	—	9.21
Perlite	20.55	—	20.55	W	—	W	20.55	—	20.55
Phosphate rock	5.59	—	5.59	W	—	W	5.59	—	5.59
Potash	—	—	—	67.46	—	67.46	67.46	—	67.46
Pumice[3]	25.36	—	25.36	—	—	—	25.36	—	25.36
Salt	54.96	W	54.96	17.45	W	17.45	25.48	W	25.48
Sand and gravel	3.62	—	3.62	—	—	—	3.62	—	3.62
Soda ash	—	—	—	71.27	W	71.27	71.27	W	71.27
Talc, soapstone, and pyrophyllite	14.45	W	14.45	—	—	—	14.45	W	14.45
Vermiculite	65.22	—	65.22	—	—	—	65.22	—	65.22
Average, industrial minerals[2]	5.40	.04	5.42	35.74	6.84	42.57	6.05	.18	6.23
Average, industrial minerals (excluding sand and gravel)[2]	12.30	.16	12.46	35.74	6.84	42.57	14.57	.81	15.38
Average, metals and industrial minerals[2]	7.04	.30	7.34	31.49	8.40	39.89	7.67	.51	8.18
Average, metals and industrial minerals (excluding sand and gravel)[2]	9.93	.55	10.49	31.49	8.40	39.89	10.95	.93	11.87

W Withheld to avoid disclosing company proprietary data; included in appropriate "Average."

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

[2]Includes unpublished data.

[3]Excludes volcanic cinder and scoria.

TABLE 4

CRUDE ORE AND TOTAL MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1992, BY COMMODITY AND STATE

(Percent)

Commodity	Crude ore		Total material	
	Surface	Underground	Surface	Underground
METALS				
Copper	98.4	1.6	99.2	0.8
Gold:				
Lode	97.7	2.3	98.8	1.2
Placer	[1]100.0	W	[1]100.0	W
Iron ore	[1]100.0	W	[1]100.0	W
Lead	—	100.0	W	[2]100.0
Silver	—	100.0	W	[2]100.0
Titanium	100.0	—	100.0	—
Zinc	W	[2]100.0	W	[2]100.0
Average, metals[3]	96.6	3.4	98.2	1.8
INDUSTRIAL MINERALS				
Abrasives	[1]100.0	W	[1]100.0	W
Asbestos	100.0	—	100.0	—
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	83.0	17.0	90.7	9.3
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	21.1	78.9	21.1	78.9
Sand and gravel	100.0	—	100.0	—
Soda ash	—	100.0	—	100.0
Talc, soapstone, and pyrophyllite	100.0	—	100.0	—
Vermiculite	100.0	—	100.0	—
Zeolites	100.0	—	100.0	—
Average, industrial minerals[3]	97.9	2.1	98.2	1.8
Average, metals and industrial minerals[3]	97.4	2.6	98.2	1.8
STATE				
Alabama	100.0	—	100.0	—
Alaska	98.1	1.9	99.0	1.0
Arizona	[1]100.0	W	[1]100.0	W
Arkansas	100.0	—	100.0	—
California	99.8	.2	99.9	.1
Colorado	99.3	.7	99.3	.7
Connecticut	W	[2]100.0	W	[2]100.0
Delaware	100.0	—	100.0	—

See footnotes at end of table.

TABLE 4—Continued

CRUDE ORE AND TOTAL MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1992, BY COMMODITY AND STATE

(Percent)

Commodity	Crude ore		Total material	
	Surface	Underground	Surface	Underground
STATE—Continued				
Florida	100.0	—	100.0	—
Georgia	100.0	—	100.0	—
Idaho	98.7	1.3	98.2	1.8
Illinois	[1]100.0	W	[1]100.0	W
Indiana	[1]100.0	W	[1]100.0	W
Iowa	[1]100.0	W	[1]100.0	W
Kansas	90.3	9.7	90.6	9.4
Kentucky	100.0	—	100.0	—
Louisiana	70.3	29.7	71.4	28.6
Maryland	100.0	—	100.0	—
Michigan	[1]100.0	W	[1]100.0	W
Minnesota	100.0	—	100.0	—
Mississippi	100.0	—	100.0	—
Missouri	[1]100.0	W	[1]100.0	W
Montana	94.0	6.0	95.0	5.0
Nebraska	100.0	—	100.0	—
Nevada	98.8	1.2	99.5	.5
New Hampshire	100.0	—	100.0	—
New Jersey	100.0	—	100.0	—
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	100.0	—	100.0	—
Oregon	99.8	.2	99.6	.4
Pennsylvania	100.0	—	100.0	—
Rhode Island	100.0	—	100.0	—
South Carolina	100.0	—	100.0	—
South Dakota	86.4	13.6	83.7	16.3
Tennessee	[1]100.0	W	[1]100.0	W
Texas	[1]100.0	W	[1]100.0	W
Utah	99.9	.1	99.9	.1
Vermont	100.0	—	100.0	—
Virginia	[1]100.0	W	[1]100.0	W
Washington	98.7	1.3	98.3	1.7
West Virginia	100.0	—	100.0	—
Wisconsin	100.0	—	100.0	—
Wyoming	49.3	50.7	57.6	42.4
Average, States[3]	97.4	2.6	98.2	1.8

W Withheld to avoid disclosing company proprietary data; included with "Surface" or "Underground."
[1]Includes underground to avoid disclosing company proprietary data.
[2]Includes surface to avoid disclosing company proprietary data.
[3]Includes unpublished data.
[4]Includes abrasive stone and millstones.

TABLE 5

NUMBER OF DOMESTIC METAL AND INDUSTRIAL MINERAL MINES[1] IN THE UNITED STATES IN 1992, 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	39	—	1	3	12	10	13
Gold:							
Lode	95	6	5	9	19	49	7
Placer	19	4	3	6	3	3	—
Iron ore	16	—	—	4	3	4	5
Lead	9	—	—	—	5	4	—
Silver	5	—	1	1	2	1	—
Titanium	4	—	1	—	2	—	1
Zinc	12	—	—	—	10	2	—
Others[2]	23	12	3	4	4	—	—
Total metals	222	22	14	27	60	73	26
				INDUSTRIAL MINERALS			
Abrasives	5	—	2	3	—	—	—
Asbestos	2	—	—	1	1	—	—
Barite	6	—	3	1	2	—	—
Boron minerals	3	-	—	1	1	1	—
Clays	826	19	174	511	122	—	—
Diatomite	11	—	2	5	4	—	—
Feldspar	10	—	2	6	2	—	—
Gypsum	59	—	2	14	43	—	—
Iron oxide pigments (crude)	3	2	—	1	—	—	—
Mica (scrap)	12	—	6	4	2	—	—
Perlite	10	1	3	3	3	—	—
Phosphate rock	16	—	—	—	2	8	6
Potash	5	—	—	—	5	—	—
Pumice[3]	17	1	8	7	1	—	—
Salt	26	—	1	3	17	5	—
Sand and gravel	6,091	142	775	2,847	2,227	99	1
Soda ash	6	—	—	1	—	5	—
Talc, soapstone, pyrophyllite	14	3	—	10	1	—	—
Vermiculite	5	—	—	4	1	—	—
Zeolites	7	4	2	1	—	—	—
Others[4]	17	1	1	10	3	1	1
Total industrial minerals	7,151	173	981	3,433	2,437	119	8
Grand total	7,373	195	995	3,460	2,497	192	34
				STATE			
Alabama	126	2	14	61	49	—	—
Alaska	30	3	3	11	9	3	1
Arizona	205	8	21	73	82	12	9
Arkansas	95	—	16	49	30	—	—
California	427	19	31	153	187	37	—
Colorado	271	8	53	121	85	4	—

See footnotes at end of table.

TABLE 5—Continued

NUMBER OF DOMESTIC METAL AND INDUSTRIAL MINERAL MINES[1] IN THE UNITED STATES IN 1992, 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							
Delaware	9	—	1	1	7	—	—
Florida	85	—	2	22	46	9	6
Georgia	172	—	19	107	46	—	—
Idaho	147	5	28	62	45	7	—
Illinois	170	4	14	64	79	9	—
Indiana	160	1	8	57	92	2	—
Iowa	178	3	21	94	59	1	—
Kansas	166	4	24	97	40	1	—
Kentucky	38	—	3	18	15	2	—
Louisiana	95	2	9	40	40	4	—
Maryland	71	4	10	27	29	1	—
Michigan	351	4	29	177	132	8	1
Minnesota	291	3	29	159	91	5	4
Mississippi	98	—	9	58	31	—	—
Missouri	132	2	23	66	37	4	—
Montana	126	5	20	62	30	8	1
Nebraska	184	4	26	121	33	—	—
Nevada	166	11	16	50	54	28	7
New Hampshire	54	—	3	27	24	—	—
New Jersey	67	1	10	13	40	3	—
New Mexico	129	11	11	67	37	1	2
New York	498	18	146	230	102	2	—
North Carolina	189	3	40	109	34	2	1
Ohio	275	9	28	85	149	4	—
Oklahoma	123	3	19	66	34	1	—
Oregon	110	5	17	42	45	1	—
Pennsylvania	171	7	23	82	59	—	—
Rhode Island	16	—	3	3	10	—	—
South Carolina	92	1	10	46	32	3	—
South Dakota	158	1	38	92	22	5	—
Tennessee	82	—	7	33	41	1	—
Texas	296	3	29	126	134	4	—
Utah	143	9	18	56	53	6	1
Vermont	84	1	14	60	9	—	—
Virginia	83	6	13	36	28	—	—
Washington	230	7	18	117	83	5	—
West Virginia	12	—	3	3	6	—	—
Wisconsin	238	2	17	127	89	3	—
Wyoming	157	7	46	84	16	4	—
Undistributed[5]	373	9	53	206	102	2	1
Total, States	7,373	195	995	3,460	2,497	192	34

[1]Based on crude ore mined. Excludes wells, ponds, or pumping operations.
[2]Includes bauxite, beryllium, manganese, molybdenum, nickel, platinum-group metals, and rare-earth concentrates.
[3]Excludes volcanic cinder and scoria.
[4]Includes aplite, fluorspar, greensand marl, kyanite, magnesite, magnesium-brines, olivine, sulfur (Frasch), and wollastonite.
[5]Includes Connecticut, Hawaii, Maine, Massachusetts, North Dakota, and undistributed data.

TABLE 6

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL[1] MINES IN THE UNITED STATES IN 1992, 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.
Bingham Canyon	Utah	Kennecott, Utah Copper Corp.	Copper	Do.
Sierrita	Arizona	Cyprus Sierrita Corp.	do.	Do.
Morenci	do.	Phelps Dodge Corp.	do.	Do.
Hibbing	Minnesota	Hibbing Taconite Co.	Iron ore	Do.
Bagdad	Arizona	Cyprus Bagdad Copper Co.	Copper	Do.
Inspiration	do.	Cyrpus Miami Mining Corp.	do.	Do.
Empire	Michigan	Empire Iron Mining Partnership	Iron ore	Do.
Ray	Arizona	ASARCO Incorporated	Copper	Do.
Pinto Valley	do.	Pinto Valley Copper Corp.	do.	Do.
Hoyt Lakes	Minnesota	LTV Steel Mining Co.	Iron ore	Do.
Tyrone	New Mexico	Phelps Dodge Corp. and Burro Chief Copper Co.	Copper	Do.
San Manuel	Arizona	Magma Copper Co.	do.	Open pit and stoping.
Continental	Montana	Montana Resources Inc.	do.	Open pit.
NSPC Project	Minnesota	National Steel Pellet Co.	Iron ore	Do.
Chino	New Mexico	Phelps Dodge Corp.	Copper	Do.
Smokey Valley Common Operation	Nevada	Round Mountain Gold Corp.	Gold	Do.
Goldstrike	do.	Barrick Goldstrike Mines Inc.	do.	Do.
Mission Complex	Arizona	ASARCO Incorporated	Copper	Do.
Zortman-Landusky	Montana	Pegasus Gold Inc.	Gold	Do.
Green Cove	Florida	RGC (USA) Mineral Sands, Inc.	Titanium	Dredging.
Thunderbird	Minnesota	Eveleth Mines	Iron ore	Open pit.
McCoy and Cove	Nevada	Echo Bay Mining Co.	Gold	Do.
Chimney Creek	do.	Goldfields Mining Corp.	do.	Do.
Sleeper	do.	Nevada Gold Mining Inc.	do.	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.
Lee Creek	North Carolina	Texasgulf Chemical Co.	do.	Do.
Fort Meade	Florida	Cargill Fertilizer Inc.	do.	Do.
Florida mines (2)	do.	Mobil Mining and Minerals Co.	do.	Do.
Hookers Prairie	do.	W. R. Grace & Co.	do.	Do.
Wingate Creek	do.	Nu-Gulf Industries Inc.	do.	Dredging.
Everett	Washington	CSR America Inc.	Sand and gravel	Do.
Henderson	Nevada	Nevada Ready Mix Co.	do.	Do.
Sheldon and Peoria	California	CalMat Co. of California	do.	Do.
Radum	do.	Beazer West Inc.	do.	Do.
Steilacoom	Washington	Lone Star Northwest	do.	Do.
Retsof	New York	Akzo Salt Inc.	Salt	Stoping.
Reliance	California	CalMat Co. of California	Sand and gravel	Dredging.
Rockland	Florida	U.S. Agri-Chemicals Co.	Phosphate rock	Open pit.
Arena	Texas	Pioneer Concrete of America	Sand and gravel	Dredging.
Irwindale	California	Beazer West Inc.	do.	Do.
Irwindale	do.	United Building Materials Inc.	do.	Do.
Briggs	Texas	Fordyce Co.	do.	Do.
Vernal	Utah	SF Phosphates	Phosphate rock	Open pit.

See footnotes at end of table.

TABLE 6—Continued

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL[1] MINES IN THE UNITED STATES IN 1992, IN ORDER OF OUTPUT OF CRUDE ORE

Mine[2]	State	Operator	Commodity	Mining method
		INDUSTRIAL MINERALS[3]—Continued		
South Amboy	New Jersey	Amboy Aggregates	Sand and gravel	Dredging.
Perkins	California	A. Teighert & Son Inc., Teichert Aggregates	do.	Do.
Sweetwater	Wyoming	General Chemical Corp.	Soda ash	Stoping.
Algonquin	Illinois	General Dynamics Corp.	Sand and gravel	Dredging.
Hardee Complex #1	Florida	CF Industries Inc.	Phosphate rock	Open pit.

[1]Excludes brines and materials from wells.

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

[3]Crushed and broken and dimension stone were not available for 1992 because of biennial canvassing.

TABLE 7

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL[1] MINES IN THE UNITED STATES IN 1992, IN ORDER OF OUTPUT OF TOTAL MATERIALS HANDLED

Mine[2]	State	Operator	Commodity	Mining method
		METALS		
Goldstrike	Nevada	Barrick Goldstrike Mines Inc.	Gold	Open pit.
Morenci	Arizona	Phelps Dodge Corp.	Copper	Do.
Chino	New Mexico	do.	do.	Do.
Ray	Arizona	ASARCO Incorporated	do.	Do.
Sierrita	do.	Cyprus Sierrita Corp.	do.	Do.
Empire	Michigan	Empire Iron Mining Partnership	Iron ore	Do.
Carlin Mines Complex	Nevada	Newmont Gold Co.	Gold	Do.
Bagdad	Arizona	Cyprus Bagdad Copper Co.	Copper	Do.
Bingham Canyon	Utah	Kennecott, Utah Copper Corp.	do.	Do.
Pinto Valley	Arizona	Pinto Valley Copper Corp.	do.	Do.
Inspiration	do.	Cyrpus Miami Mining Corp.	do.	Do.
Hibbing	Minnesota	Hibbing Taconite Co.	Iron ore	Do.
Hoyt Lakes	do.	LTV Steel Mining Co.	do.	Do.
Continental	Montana	Montana Resources Inc.	Copper	Do.
Tyrone	New Mexico	Phelps Dodge Corp. and Burro Chief Copper Co.	do.	Do.
NSPC Project	Minnesota	National Steel Pellet Co.	Iron ore	Do.
Tilden	Michigan	Tilden Magnetite Partnership	do.	Do.
Thunderbird	Minnesota	Eveleth Mines	do.	Do.
San Manuel	Arizona	Magma Copper Co.	Copper	Open pit and stoping.
San Xavier	do.	ASARCO Incorporated	do.	Open pit.
Valdez Creek	Alaska	Cambior Alaska Inc.	Gold	Do.
Smokey Valley Common Operation	Nevada	Round Mountain Gold Corp.	do.	Do.
Mission Complex	Arizona	ASARCO Incorporated	Copper	Do.
Twin Buttes	do.	Cyprus Sierrita Corp.	do.	Do.
Zortman-Landusky	Montana	Pegasus Gold Inc.	Gold	Do.
		INDUSTRIAL MINERALS[3]		
Florida mines (5)	Florida	International Minerals & Chemicals Corp.	Phosphate rock	Do.
Florida mines (2)	do.	Agrico Chemical Co.	do.	Do.
Lee Creek	North Carolina	Texasgulf Chemical Co.	do.	Do.
Fort Meade	Florida	Cargill Fertilizer Inc.	do.	Do.
Florida mines (2)	do.	Mobil Mining and Minerals Co.	do.	Do.
Hookers Prairie	do.	W. R. Grace & Co.	do.	Do.
Kern	California	U.S. Borax and Chemical Co.	Boron	Do.
Wingate Creek	Florida	Nu-Gulf Industries Inc.	Phosphate rock	Dredging.
Southard	Oklahoma	United States Gypsum Co.	Gypsum	Open pit.
Everett	Washington	CSR America Inc.	Sand and gravel	Dredging.
Henderson	Nevada	Nevada Ready Mix Co.	do.	Do.
Georgia mines (40)	Georgia	English China Clay Group	Clays	Open pit.
Sheldon and Peoria	California	CalMat Co. of California	Sand and gravel	Dredging.
Radum	do.	Beazer West Inc.	do.	Do.
Steilacoom	Washington	Lone Star Northwest	do.	Do.
Fort Dodge	Iowa	United States Gypsum Co.	Gypsum	Open pit.
Retsof	New York	Akzo Salt Inc.	Salt	Stoping.
Alabaster	Michigan	United States Gypsum Co.	Gypsum	Open pit.

See footnotes at end of table.

TABLE 7—Continued

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL[1] MINES IN THE UNITED STATES IN 1992, IN ORDER OF OUTPUT OF TOTAL MATERIALS HANDLED

Mine[2]	State	Operator	Commodity	Mining method
		INDUSTRIAL MINERALS[3]—Continued		
Reliance	California	CalMat Co. of California	Sand and gravel	Dredging.
Rockland	Florida	U.S. Agri-Chemicals Co.	Phosphate rock	Open pit.
Arena	Texas	Pioneer Concrete of America	Sand and gravel	Dredging.
Irwindale	California	Beazer West Inc.	do.	Do.
Do.	do.	United Building Materials Inc.	do.	Do.
Briggs	Texas	Fordyce Co.	do.	Do.
Las Vegas	Nevada	James Hardie Gypsum Inc.	Gypsum	Open pit.

[1]Excludes brines and materials from wells.
[2]Owing to commodity reporting difference, individual mine data may not be available.
[3]Crushed and broken and dimension stone were not available in 1992 because of biennial canvassing.

TABLE 8

MARKETABLE PRODUCT AND ORE TREATED OR SOLD AT SURFACE AND UNDERGROUND MINES[1] IN THE UNITED STATES IN 1992, BY COMMODITY

(Thousand metric tons unless otherwise specified)

Commodity	Marketable product			Ore treated or sold		
	Surface	Underground	Total[2]	Surface	Underground	Total[2]
METALS						
Copper	1,673	65	1,738	388,255	W	388,255
Gold:						
Lode	[3]302	[3]23	[3]325	242,613	5,387	248,000
Placer	[3]5	[3](*)	[3]5	13,993	W	13,993
Iron ore	42,749	27	42,776	136,142	W	136,142
Lead	—	248	248	—	6,759	6,759
Silver	W	[3]291	[3]291	W	2,825	2,825
Titanium	282	—	282	W	—	W
Zinc	W	180	180	W	4,751	4,751
INDUSTRIAL MINERALS						
Abrasives	46	W	46	W	W	W
Asbestos	16	—	16	146	—	146
Barite	326	—	326	1,083	—	1,083
Boron minerals	958	—	958	W	—	W
Clays	40,109	W	40,109	40,623	68	40,691
Diatomite	595	—	595	1,559	—	1,559
Feldspar	546	—	546	636	—	636
Gypsum	12,164	2,595	14,759	13,269	W	13,269
Iron oxide pigments (crude)	28	—	28	28	—	28
Mica (scrap)	85	—	85	W	—	W
Perlite	538	W	538	640	W	640
Phosphate rock	46,788	W	46,788	154,760	W	154,760
Potash	—	1,041	1,041	—	1,902	1,902
Pumice[5]	481	—	481	484	—	484
Salt	2,675	10,873	13,548	W	11,524	11,524
Sand and gravel	858,708	—	858,708	858,708	—	858,708
Soda ash	—	6,026	6,026	—	6,045	6,045
Talc and pyrophyllite	423	—	423	516	—	516
Vermiculite	190	—	190	190	—	190
Zeolites	28	—	28	29	—	29
STATES						
Alabama	14,289	—	14,289	W	—	W
Alaska	13,836	—	13,836	W	W	W
Arizona	32,477	W	32,477	315,508	W	315,508
Arkansas	12,185	—	12,185	12,185	—	12,185
California	109,074	(*)	109,074	143,360	336	143,697
Colorado	27,492	—	27,492	30,225	W	30,225
Delaware	2,257	—	2,257	2,257	—	2,257
Florida	57,842	—	57,842	W	—	W
Georgia	14,501	—	14,501	W	—	W
Idaho	19,542	170	19,712	W	339	339
Illinois	37,281	W	37,281	W	—	W

See footnotes at end of table.

TABLE 8—Continued

MARKETABLE PRODUCT AND ORE TREATED OR SOLD AT SURFACE AND UNDERGROUND MINES[1] IN THE UNITED STATES IN 1992, BY COMMODITY

(Thousand metric tons unless otherwise specified)

Commodity	Marketable product			Ore treated or sold		
	Surface	Underground	Total[2]	Surface	Underground	Total[2]
	STATES—Continued					
Indiana	26,994	W	26,994	26,994	W	26,994
Iowa	16,841	W	16,841	16,900	W	16,900
Kansas	12,597	1,174	13,771	W	W	W
Kentucky	7,561	—	7,561	7,561	—	7,561
Louisiana	12,613	5,466	18,079	W	W	W
Maryland	11,127	—	11,127	11,127	—	11,127
Michigan	62,393	W	62,393	90,943	W	90,943
Minnesota	63,596	—	63,596	129,003	—	129,003
Mississippi	11,549	—	11,549	W	—	W
Missouri	10,321	W	10,321	W	W	W
Montana	10,449	176	10,626	W	3,096	3,096
Nebraska	12,173	—	12,173	12,173	—	12,173
Nevada	24,294	4	24,298	200,281	2,248	202,529
New Hampshire	5,845	—	5,845	5,845	—	5,845
New Jersey	16,373	—	16,373	W	—	W
New Mexico	W	W	W	46,359	1,953	48,312
New York	29,606	W	29,606	W	W	W
North Carolina	18,397	—	18,397	W	—	W
Ohio	47,019	W	47,019	W	—	W
Oklahoma	13,002	—	13,002	13,002	—	13,002
Oregon	15,488	(4)	15,488	W	25	25
Pennsylvania	18,716	—	18,716	W	—	W
Rhode Island	2,306	—	2,306	2,306	—	2,306
South Carolina	8,570	—	8,570	W	—	W
South Dakota	7,681	(4)	7,681	W	2,182	2,182
Tennessee	9,540	W	9,540	9,540	W	9,540
Texas	47,793	W	47,793	W	W	W
Utah	17,733	48	17,781	W	112	112
Vermont	3,264	—	3,264	W	—	W
Virginia	10,148	W	10,148	W	W	W
Washington	37,817	(4)	37,817	W	510	510
West Virginia	1,768	—	1,768	1,768	—	1,768
Wisconsin	27,718	—	27,718	27,718	—	27,718
Wyoming	5,742	6,026	11,769	W	6,026	6,026

W Withheld to avoid disclosing company proprietary data.
[1]Excludes wells, ponds, and pumping operations.
[2]Data may not add to totals shown because of independent rounding.
[3]Metric tons.
[4]Less than 1/2 unit.
[5]Excludes volcanic cinder and scoria.

TABLE 9

MINING METHODS USED IN OPEN PIT MINING IN THE UNITED STATES, BY COMMODITY, IN 1992

(Percent)

Commodity	Total material handled	
	Preceded by drilling and blasting	Not preceded by drilling and blasting[1]
METALS		
Copper	96	4
Gold:		
Lode	100	—
Placer	36	64
Iron ore	94	6
Titanium	—	100
Zinc	97	3
Average, metals[2]	94	6
INDUSTRIAL MINERALS		
Abrasives	55	45
Asbestos	100	—
Barite	9	91
Boron minerals	100	—
Clays	—	100
Diatomite	31	69
Feldspar	100	—
Gypsum	93	7
Iron oxide pigments (crude)	100	—
Mica (scrap)	60	40
Perlite	66	34
Phosphate rock	3	97
Pumice[3]	51	49
Salt	—	100
Sand and gravel	—	100
Talc, soapstone, and pyrophyllite	78	22
Vermiculite	87	13
Zeolites	100	—
Average, industrial minerals[2]	3	97
Average, metals and industrial minerals[2]	49	51

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

[2]Includes unpublished data.

[3]Excludes volcanic cinder and scoria.

TABLE 10

EXPLORATION AND DEVELOPMENT ACTIVITY IN THE UNITED STATES IN 1992, BY METHOD, COMMODITY, AND STATE[1]

(Meters)

Commodity	Exploration							Development				
	Churn drilling	Diamond drilling	Percussion drilling	Rotary drilling	Other drilling	Trenching	Total	Drifting, cross-cutting, or tunneling	Raising	Shaft and winze sinking	Solution mining	Total
METALS												
Copper	—	10,770	W	24,833	—	W	35,602	3,519	99	—	—	3,618
Gold (lode)	W	52,331	21,578	88,133	25,044	792	187,878	15,189	1,332	45	—	16,565
Lead	W	35,025	30,063	W	W	—	65,087	3,592	W	3	—	3,595
Platinum-group metals	—	1,661	—	—	—	—	1,661	W	W	—	—	W
Silver	—	9,566	W	W	—	W	9,566	5,727	W	18	—	5,746
Zinc	—	18,702	W	—	—	—	18,702	W	37	—	4,877	4,913
Other[2]	30	6,816	145,453	96,222	14,639	354	263,515	6,473	840	—	139,166	146,479
Metals total	30	134,870	197,093	209,188	39,683	1,147	582,011	34,500	2,308	66	144,042	180,916
INDUSTRIAL MINERALS												
Industrial minerals[5]	64	24,575	23,531	67,492	—	1,027	116,689	280	64	—	—	344
Grand total	94	159,445	220,624	276,680	39,683	2,174	698,700	34,780	2,372	66	144,042	181,261
Percent of metals total[3]	(4)	23.2	33.9	35.9	6.8	.2	100.0	19.1	1.3	(4)	79.6	100.0
Percent of industrial minerals total[3]	.1	21.1	20.2	57.8	—	.9	100.0	81.4	18.6	—	—	100.0
Percent of grand total[3]	(4)	22.8	31.6	39.6	5.7	.3	100.0	19.2	1.3	(4)	79.5	100.0
STATE												
Arizona	—	11,645	W	1,127	—	W	12,771	W	—	—	—	W
California	—	W	6,150	W	W	W	6,150	309	W	W	—	309
Colorado	—	—	—	W	W	—	W	W	W	15	—	15
Idaho	—	W	351	W	W	—	351	W	W	—	—	W
Missouri	—	34,974	W	W	W	—	34,974	2,658	—	—	—	2,658
Montana	W	7,723	W	24,115	W	—	31,838	W	W	—	—	W
Nevada	—	10,648	21,452	62,927	55	785	95,867	162	—	—	—	162
Oregon	—	846	—	W	—	W	846	W	99	W	—	99
South Dakota	—	10,937	—	—	1,433	—	12,369	10,668	914	—	—	11,582
Tennessee	—	18,702	W	—	—	—	18,702	W	37	—	—	37
Utah	—	305	—	W	—	—	305	—	—	—	—	—
Washington	—	975	—	—	—	—	975	3,122	—	—	4,877	7,999
Wyoming	—	—	—	63,519	—	—	63,519	—	—	—	W	W
Undistributed[6]	94	62,690	192,671	124,992	38,195	1,389	420,033	17,860	1,322	51	139,166	158,398
Total States	94	159,445	220,624	276,680	39,683	2,174	698,700	34,780	2,372	66	144,042	181,261
Percent of all States[3]	(4)	22.8	31.6	39.6	5.7	.3	100.0	19.2	1.3	(4)	79.5	100.0

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

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

[2]Includes beryllium, gold (placer), iron ore, nickel, platinum-group metals, titanium (ilmenite and rutile), and metal items indicated by symbol W.

[3]Based on unrounded data.

[4]Less than 1/2 unit.

[5]Includes boron minerals, clays, diatomite, fluorspar, gypsum, lime, mica (scrap), perlite, phosphate rock, soda ash, and zeolites.

[6]Includes Alabama, Alaska, Florida, Georgia, Illinois, Michigan, Minnesota, New Mexico, North Carolina, Oklahoma, Virginia, and State items indicated by symbol W.

TABLE 11

TOTAL MATERIAL (ORE AND WASTE) PRODUCED BY MINE DEVELOPMENT IN THE UNITED STATES IN 1992, BY COMMODITY AND STATE[1]

(Thousand metric tons)

	Drifting, crosscutting, or tunneling	Raising	Shaft and winze sinking	Stripping	Total
METALS					
Copper	110	(2)	—	(2)	111
Gold:					
Lode	273	8	(2)	131,437	131,718
Placer	W	—	—	586	586
Iron ore	—	—	—	3,950	3,950
Lead	415	W	(2)	W	415
Silver	125	W	(2)	W	126
Zinc	W	1	—	—	1
Other[3]	102	11	—	669	782
Metals total	1,025	20	1	136,642	137,688
INDUSTRIAL MINERALS					
Gypsum	W	W	—	2,559	2,559
Pumice[4]	—	—	—	220	220
Talc, soapstone, and pyrophyllite	—	—	—	(2)	(2)
Other[5]	18	(2)	—	107	126
Industrial minerals total	18	(2)	—	2,886	2,904
Grand total	1,044	20	1	139,527	140,592
STATE					
Colorado	W	W	(2)	W	(2)
Idaho	124	W	—	W	124
Missouri	402	—	—	—	402
Nevada	1	—	—	131,750	131,752
Oklahoma	—	—	—	41	41
Oregon	W	(2)	W	W	(2)
South Dakota	64	5	—	—	69
Tennessee	W	1	—	—	1
Washington	174	—	—	—	174
Undistributed[6]	277	14	(2)	7,736	8,028
Grand total	1,044	20	1	139,527	140,592

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

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

[2]Less than 1/2 unit.

[3]Includes beryllium, platinum-group metals, and metal items indicated by symbol W.

[4]Excludes volcanic cinder and scoria.

[5]Includes diatomite, fluorspar, zeolites, and industrial mineral items indicated by symbol W.

[6]Includes Alabama, Alaska, Arizona, California, Illinois, Michigan, Minnesota, Montana, New Mexico, South Carolina, Texas, Virginia, and State items indicated by symbol W.

TABLE 12

INDUSTRIAL EXPLOSIVES AND BLASTING AGENTS SOLD FOR CONSUMPTION IN THE UNITED STATES, BY CLASS AND USE, 1988-92[e] [1]

(Thousand metric tons)

Year	Coal mining	Metal mining	Quarrying and nonmetal mining	Total mineral industry	Construction work	All other purposes	Total industrial[2]
TOTAL, BY USE[2]							
1988	1,422.9	199.6	270.0	1,892.5	145.2	111.1	2,148.9
1989	1,440.2	217.7	285.9	1,943.7	149.8	86.2	2,179.7
1990	1,451.5	226.3	290.4	1,968.3	145.2	42.8	2,156.3
1991	1,252.1	190.5	r245.5	1,688.1	118.0	43.6	r1,849.7
1992	1,274.6	199.6	245.0	1,719.2	127.0	46.9	1,893.1
BY CLASS AND USE							
PERMISSIBLES							
1988	12.2	—	.1	12.4	.1	—	12.5
1989	10.0	—	.1	10.1	.1	—	10.2
1990	8.7	—	.1	8.8	.1	—	8.8
1991	5.6	—	(3)	5.7	(3)	—	5.7
1992	4.9	—	(3)	4.9	(3)	—	5.0
OTHER HIGH EXPLOSIVES							
1988	9.1	4.5	29.5	43.1	20.4	4.5	68.0
1989	8.6	4.1	27.7	40.4	19.1	4.1	63.5
1990	8.2	3.6	26.8	38.6	19.5	2.2	60.2
1991	6.4	2.7	21.8	30.8	15.9	2.0	48.7
1992	5.0	1.8	16.8	23.6	12.2	1.5	37.3
WATER GELS AND SLURRIES							
1988	108.9	45.4	99.8	254.0	36.3	9.1	299.4
1989	106.1	44.5	97.5	248.1	35.4	9.1	292.6
1990	107.0	42.6	101.6	251.3	38.1	4.7	294.1
1991	100.2	39.9	95.3	235.4	35.8	4.3	275.6
1992	103.9	41.3	98.4	243.6	37.2	4.4	285.1
AMMONIUM NITRATE: FUEL OIL BLASTING AGENTS AND UNPROCESSED							
1988	1,292.7	149.7	140.6	1,583.0	88.5	97.5	1,769.0
1989	1,315.4	169.2	160.6	1,645.2	95.3	73.0	1,813.5
1990	1,327.7	180.1	161.9	1,669.7	87.5	35.9	1,793.1
1991	1,139.9	147.9	r128.4	1,416.2	66.2	37.3	r1,519.7
1992	1,160.8	156.5	129.7	1,447.1	77.5	41.1	1,565.7

[e]Estimated. [r]Revised.

[1]Distribution of industrial explosives and blasting agents by consuming industry estimated from indicies of industrial production and economics reported by the Department of Energy, Federal Reserve Board, Department of Transportation, and Bureau of the Census.

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

[3]Less than 1/2 unit.

ABRASIVE MATERIALS

By Gordon T. Austin

Mr. Austin, a physical scientist with more than 30 years of industry and Government experience, has been the commodity specialist for abrasive materials since 1986. Mr. William Field, statistical assistant, prepared the domestic data tables.

The combined value of production of natural abrasives, which include tripoli, special silica stone, garnet, staurolite, and emery, decreased about 24% in 1992. 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 significant increase in unit value and decrease in the quantity produced. Garnet showed a 6% increase in quantity and a 36% decrease in unit value. Staurolite decreased about 27% in the quantity produced and value compared with those of 1991.

The fused aluminum oxide industry showed a slight increase in the quantity produced and a 4% increase in the value of production. The silicon carbide industry saw a 7% increase in the quantity produced and a 10% increase in the value of production. Combined, the industries increased 4% in quantity and 6% in value compared with those of 1991.

The quantity of metallic abrasives sold and shipped increased slightly in quantity and 7% in value compared with those of 1991. 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 1992 were about 9% below the industry's high of 239,619 metric tons[1] in 1979. *(See table 1.)*

The United States continued as the world's largest manufacturer, exporter, importer, and consumer of synthetic industrial diamond. The estimated apparent U.S. consumption of industrial diamond stones was 5.9 million carats, an increase of 18% compared with that of 1991, but was still significantly greater than the 48-year low in 1987.

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, 8, 12, and 14.

FOREIGN TRADE

The total value of abrasive materials, exports plus reexports, was $383.3 million, about a 20% increase compared with the 1991 value.

The total value of abrasive materials imported was $482.1 million, an increase of 7% compared with the 1991 value. The average total value for the past 10 years was $405.1 million per year, with the high in 1990 of $512.8 million and the low of $289.9 million in 1983.

The United States has shown a trade deficit in abrasive materials for every year of the past 10 years. In 1992, the deficit decreased 25% compared with that of 1991. *(See tables 2, 3, and 4.)*

TRIPOLI

The category of tripoli, as broadly defined, is composed of extremely fine-grained crystalline silica 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 micrometer 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 1992, the quantity of crude tripoli produced decreased 4% to a new 10-year low and the value of production decreased slightly compared with those of 1991. The average production for the past 10 years was 100,589 tons per year, with a high of 112,928 tons in 1984 and a low of 84,777 tons in 1992. 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, increased 4% in quantity and 5% in value compared with those of 1991.

Tripoli is processed in mills that are jasper lined using flint or jasper pebbles in closed circuit with banks of mechanical classifiers. Material from the mechanical classifiers is 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, nearly 70% of the processed tripoli was used as an abrasive. Today, 73% 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 and is 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 resistant to wear and more resistant to chemicals than those in which water-ground whitings 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 make tripoli useful as a filler and extender in plastics make it valuable to the rubber and resin industries.

Tripoli contains 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 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 1992 to a 10-year low of 18,603 tons; 1992 was the eighth consecutive year of decline. During the 8-year period, consumption declined about 50%. The average annual consumption of abrasive tripoli for the past 10 years was 28,418 tons, with a high of 37,024 tons in 1984 and a low of 18,603 tons in 1992. The 1992 consumption was the lowest since 1949, when only 20,972 tons was sold or used.

After 4 consecutive years of decline, from 1988 through 1991, the amount of tripoli used as filler increased. The 10% increase in 1992 followed a 7% decline in 1991, 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 61,583 tons per year, with a high of 71,160 tons in 1987 and a low of 52,334 tons in 1991. U.S. Bureau of Mines data show that tripoli use in the United States as a filler is about 76% of the total, with abrasive, 24%.

Prices

The average reported value of abrasive tripoli, sold or used, in the United States was $149.38 per ton. The average annual value reported for abrasive tripoli for the past 10 years was $117.91 per ton, with the high value in 1992 of $149.38 and the low in 1983 of $92.74. 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 1992 was significantly lower than the annual rate of increase from 1983 through 1984.

The average reported value of filler tripoli, sold or used, in the United States was $196.62 per ton. The average annual value for the past 10 years was $147.55 per ton, with a high of $203.02 per ton in 1992 and a low of $102.84 per ton in 1983. 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 products 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. 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 production of oilstones, hones, whetstones, files, and grindstones increased about 25% in quantity to 340 tons from its 10-year low of 272 tons in 1991 and 27% in value to $4.6 million. The average annual production of the products for the past 10 years was 458 tons, with a high of 620 tons in 1984 and a low of 272 tons in 1991. The average value of annual production for the past 10 years was $5.3 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 1983 through 1984, when the average value of production was $3.9 million per year. The other was 1985 through 1992, when the value of production was 68% greater at an average value of $5.7 million per year. During 1985-92, the average annual quantity of production was less than the 10-year average and the average annual value of production was 8% 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. Production recovered significantly from the large decreases in 1991 that were 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.

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 1992 of oilstones, hones, whetstones, and grindstones, sold or used by U.S. producers, was $13,405 per ton. The average annual value of the same items for the past 10 years was $12,068 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 1983-84. The value per ton averaged $6,985, with a high of $6,985 and a low of $6,854 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 until 1992's slight increase. 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.

Foreign Trade

The value of exported special silica stone products was $7.6 million, an increase of 3% compared with that of 1991. The average annual value of exports for the past 10 years was $4.5 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 increases in 1989 and 1990, followed by the 1991 and 1992 lower values.

The value of imported products was a 10-year high of $2.5 million, an increase of 39% compared with that of 1991. The average annual value of imports for the past 10 years was $1.7 million, with a high of $2.5 million in 1992 and a low of $1.0 million in 1983. 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 1992, the trade surplus in special silica stone products was $5.1 million, a

decrease of about 9%. During the past 10 years, the United States enjoyed an average trade surplus of $2.9 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 had been one of declining surpluses until the 1989 and 1990 increases; the lower values for 1991 and 1992 are still almost twice 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

Definition, 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, 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; 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) Specification 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.

The California Air Resources Board (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 Division 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 millimeter, followed by -0.59 + 0.21 millimeter. The most popular grade of imported garnet in the U.S. market is the -0.59 + 0.25-millimeter 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 millimeter. Abrasive cutting applications' most popular grade of garnet is -0.25 + 0.177 millimeter, 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 resharpen itself, it will tend to burn or gouge the material being abraded, thus defeating the purpose of its use.

The California 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 the 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 ($Ca[MgFe]Si_2O_6$). 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 ten 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 develop 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. 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 nearly 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 former 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 dozer, 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-person 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 dozer 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, archaeological 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 the 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, which exposes 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 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, 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 1992, the four U.S. firms produced 54,139 tons of crude garnet concentrate worth $4.8 million, a 6% increase in quantity and a 36% decline in value compared with those of 1991. The average annual production for the past 10 years was 39,199 tons, with a high of 54,139 in 1992 and a low of 27,004 in 1983. The production trend for the past 10 years has been one of continued long-term growth with two downward adjustments. *(See table 8.)*

Consumption and Uses.—In 1992, the quantity of garnet sold or used by producers was 49,942 tons, an increase of 4%, and the value increased slightly to $13.3 million. The average annual quantity of garnet sold or used for the past 10 years was 37,064 tons, with a record high of 49,942 tons in 1992 and a low of 25,104 tons in 1984. The trend for the past 10 years was one of steady annual growth, except for 4% decreases in 1984.

The major industrial use for high-quality, high-value garnet since before 1880 has been as loose-grain abrasives 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 $89, a 40% decrease compared with the 1991 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.

In 1992, the average value per ton of garnet sold or used was $283, a slight increase from that of 1991. The average value for the past 10 years was $241 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 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 7,600 tons, a 24% decrease from those of 1991. 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 6 years. According to reports by producers, exports, with the exception of those for 1992, increased significantly during the past 10 years.

Mineral brokers and other garnet importers reported to the U.S. Bureau of Mines about 12,100 tons of imported garnet, an increase of 142% compared with those of 1989, 1990, and 1991. 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 6 years, showed garnet imports as stable for the past 3 years until the significant increase in 1992. The United States was a net importer of garnet in 1992 for the first time in history.

World Review.—The United States was the dominant world producer and consumer of garnet, accounting for approximately 45% of the estimated world output and nearly 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 former U.S.S.R. primarily produce for local markets.

Outlook

The U.S. production and consumption of industrial garnet during the next 5 years will be a function of the installed capacity and imports. 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 1997. 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 1992 using open pit mining methods. The U.S. production of emery decreased about 34% in quantity and value compared with those of 1991.

Consumption

The Bureau estimated that the United States consumed approximately 10,000 tons of emery in 1992. 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., Emeri-Crete Inc., Oregon Emery, and General Abrasives Co.

Foreign Trade

The United States did not export emery in 1992, 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 1992 was estimated to be in excess of 20,000 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 1992 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 decreased 36% in quantity and value compared with those of 1991.

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 1992, shipments of staurolite decreased slightly in tonnage and 17% in value compared with those of 1991. 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

Definition, 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] by ANSI Specification B7420-1981,[11] and by a proposed standard developed by the Industrial Diamond Association[12] 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 inplace diamond is kimberlite, an altered, dark-green 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 assumes 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 Leone[14] 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 alkalies.[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, 1992, had a goal of zero carats and an inventory of 3.9 million carats for crushing bort. The goal for industrial stones was 3.0 million carats and the inventory was 7.78 million carats. There is currently legislative authority for disposal of 3.9 million carats of bort and 4.8 million carats of industrial stones. 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 Suprahards, Inc., Cedar Knolls, NJ. Two firms, Megadiamond Industries Inc., a subsidiary of Smith International Inc., Provo, UT, and U.S. Synthetics Corp., Orem, UT, manufactured polycrystalline diamond from purchased synthetic diamond grit. Both firms 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.

U.S. secondary production of industrial diamond was from six firms. They were Amples 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 4.5 million carats from used drill bits, diamond tools, and wet and dry diamond-containing waste, an increase of 18% compared with that of 1991.

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 99 million carats, an increase of about 15% compared with 1991 consumption. Average annual consumption for the past 10 years was about 70.4 million carats. This was the result of the strong movement to industrial diamond in the U.S. manufacturing sectors because of the economic advantages in removing material and finishing surfaces using industrial diamond and diamond tools and wheels.

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 wiredrawing dies. Miscellane-

ous uses include: engraving points, glasscutters, 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 previously listed. 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 PDC is used in a majority of the diamond wiredrawing 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. Saws made with diamond grit were used for the cutting of concrete, stone, ceramics, and composite materials. Very fine saws sliced wafers from brittle metals and crystals for use in electronic and electric devices.

Finishing optical surfaces, jewel bearings, gemstones, wiredrawing 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 $1.14 per carat, $0.64 per carat, and $4.56 per carat, respectively.

The average annual value of imported natural grit and powder for the past 10 years was $1.28 per carat. The high value was $1.57 in 1983 and the low was $0.63 in 1989.

The average annual value of imported synthetic grit and powder for the past 10 years was $1.18 per carat. The high value was $1.47 per carat in 1983 and the low was $0.64 in 1992.

The average annual value of imported industrial diamond stones for the past 10 years was $8.38 per carat, with a high value of $9.98 in 1983 and a low of $4.56 in 1992.

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 83.6 million carats of natural and synthetic grit and powder. The material was worth a record $125.4 million. Additionally, the U.S. exported and reexported approximately 5.6 million carats of industrial stones, valued at $36.7 million.

The average annual exports plus reexports of natural and synthetic grit and powder for the past 10 years were 51.3 million carats, with an average value of $91.8 million. The highest level of exports plus reexports during the past 10 years was 83.6 million carats valued at $125.4 million in 1992. The lowest was 42.3 million carats valued at $82.5 million in 1983.

The average annual exports plus reexports of industrial stones for the past 10 years were 3.4 million carats per year, and the average value was $29.3 million. The high was 5.6 million carats in 1992, and the low was 1.7 million carats in 1990.

The average annual imports of natural diamond grit and powder were 8.7 million carats per year for the past 10 years. The high was 13.0 million in 1988, and the low was 3.9 million in 1983.

The average annual imports of synthetic diamond grit and powder were 39.3 million carats per year for the past 10 years. The high was 86.7 million carats in 1992, and the low was 14.8 million carats in 1983. Imports in 1992 were about 46% more than those in 1991 and 486% greater than those in 1983.

The 10-year average for imports of industrial diamond stones was 7.6 million carats per year, with a high of 11.0 million in 1990 and a low of 3.9 million in 1987. The 1992 imports were about 29% more than 1991 imports. *(See table 9.)*

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 former 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 1992 was approximately 51.8 million carats, a slight increase over that of 1991.

Synthetic industrial diamond production is significantly larger than the production of natural industrial diamonds. The countries that have synthetic diamond production, in declining order, are: the United States, Ireland, Russia, the Republic of South Africa, China, Germany, Sweden, Japan, Republic of Korea, Czechoslovakia, Romania, France, and Greece.

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, PDC and PDS 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. PDS and PDC 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. *(See table 10.)*

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 table 11.)*

Fused Aluminum Oxide

Government Programs.—The NDS, as of December 31, 1992, contained 227,152 tons of crude fused aluminum oxide and 46,169 tons of abrasive-grain fused aluminum oxide. There is no NDS goal for abrasive-grain fused aluminum oxide or crude fused aluminum oxide; all of the material is targeted for disposal.

Production.—At yearend, four firms were producing fused aluminum oxide at seven plants in the United States and Canada. Production of regular-grade fused aluminum oxide in 1992 was 142,545 tons, an increase of about 3% from that of 1991. The average annual production for the past 10 years was 142,757 tons. The high was 172,157 tons in 1988, and the low was 109,921 tons in 1983.

Production of high-purity fused aluminum oxide decreased slightly to 24,231 tons. The average annual production for the past 10 years was 21,290 tons. The high was 32,634 tons in 1988, and the low was 13,835 tons in 1986. Total 1992 production of 166,777 tons was slightly more than that of 1991.

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 increased 30% compared with that of 1991, and was a 10-year high. Total value of sales by individual end use was up. The value of sales for use in bonded abrasives increased 40%, coated abrasives, 45%; refractories, 20%; tumbling media, 36%; blasting abrasives, 37%; polishing cake and buffing compounds, 70%; antislip abrasives, 29%; polishing abrasives, 14%; and all other uses, 8%. *(See table 12.)*

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 $395 per ton. The average annual value for the past 10 years was $368 per ton, with a high of $395 in 1992 and a low of $324 in 1988. In 1992, the average value of high-purity fused aluminum was $594, down slightly from that of 1991, still less than the 1989 10-year high at $635 per ton. The average annual value of the past 10 years was $557 per ton, with a low of $476 per ton in 1988. The average value of all grades of fused aluminum oxide in 1992 was $424 per ton, a new 10-year high. The average annual value for the past 10 years was $391 per ton, with a high of $424 in 1992 and a low of $348 in 1988. 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 increased 11% to 11,968 tons; the value of exports plus reexports increased 12% to $28.3 million. The average value per ton of fused aluminum oxide, exported or reexported, increased slightly to $2,368. During the past 10 years, exports plus reexports have averaged 12,420 tons per year, with an average annual value of $20.3 million and an average value per ton of $1,653. The largest quantity of material exported in a single year in the past 10 years was 17,202 tons in 1989, and the smallest amount was 9,915 tons in 1986.

Imports decreased about 3% in 1992 to 136,000 tons, and the value of imports decreased about 7% to $74.2 million. Average annual imports for the past 10 years were 127,654 tons, with a high of 158,770 tons in 1984 and a low of 98,000 tons in 1989.

Silicon Carbide

Government Programs.—The NDS, as of December 31, 1992, contained 37,305 tons of silicon carbide; the goal was zero. During 1992, the Defense National Stockpile Center of the Defense Logistics Agency disposed of 6,329 tons of silicon carbide. Existing legislation authorizes disposal of all of the silicon carbide.

Production.—During 1992, three firms produced silicon carbide at four plants in the United States and Canada. Production of abrasive-grade material increased 5% to 44,673 tons. Average annual production for the past 10 years of abrasive silicon carbide was 46,318 tons, with a low of 36,193 tons in 1983 and a high of 54,339 tons in 1990. Production of metallurgical-grade silicon carbide increased about 8% to 39,611 tons. Average annual production of metallurgical-grade silicon carbide for the past 10 years was 52,475 tons, with a high of 64,998 tons in 1988 and a low of 36,562 tons in 1991. Total production of silicon carbide increased 7% in 1992 to 84,283 tons, compared with a 10-year average annual production of 105,399 tons. The high was 123,917 tons in 1984, and the low was 78,943 tons in 1991. The level of production in 1991 was the lowest since 1955. *(See table 11.)*

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 increased about 12% in 1992 and was 76% 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 33%, coated abrasives were up 99%, refractories decreased slightly, tumbling media decreased 13%, blasting abrasive increased 9%, wiresawing abrasives were down 5%, polishing cake and buffing compounds were up 160%, antislip abrasives were up 21%, polishing abrasives were up 21%, metallurgical was down 17%, and all other uses were up 98%. *(See table 12.)*

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 $536, metallurgical-grade averaged $493, and the average value of all grades was $516. The average value per ton of abrasive-grade material for the past 10 years was $497, with a high of $571 in 1983 and a low of $436 in 1985. Metallurgical-grade silicon carbide averaged $443, with a high of $481 in 1991 and a low of $391 in 1988. For all grades the average was $468, with a high of $526 in 1983 and a low of $417 in 1985. 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 1992 were 13,547 tons, a 34% increase compared with that of 1991. While the total value of silicon carbide exported plus reexported increased 11%, the value per ton decreased 17% to $886, a 10-year low, and was only 48% of the 10-year high of $1,865 in 1986. The average annual exports plus reexports for the past 10 years were 6,551 tons, with a high of 13,547 tons in 1992 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 $1,410, with a high of $1,865 in 1986 and a low of $886 in 1992.

Imports of silicon carbide in 1992 increased 27% in quantity to 89,000 tons, 12% in total value to $50.8 million, and decreased 12% in average value per ton to $571. The average annual imports for the past 10 years were 79,066 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.

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 the production. Publishing production data would disclose company proprietary data. Export and import data were not available.

Metallic Abrasives

Production.—Nine firms produced metallic abrasives in 10 plants in 1992. The quantity and value of steel shot and grit produced increased about 5% and 7%, respectively. The average value per ton was $402, a slight increase compared with that of 1991. The average annual production for the past 10 years was 185,265 tons, with a high of 213,879 tons in 1990 and a low of 140,483 tons in 1983. The average value per ton during the period was $363, with a high of $402 in 1992 and a low of $310 in 1987. Michigan, Pennsylvania, Virginia, and Ohio, in decreasing order of quantity, supplied the production of steel shot and grit.

During 1992, two firms, one in

Michigan and one in New York, reported production of cut wire shot. Production of shot and grit other than steel inclined significantly in 1992, 94% in quantity to 11,477 tons and 49% in value to $8.2 million. The average value per ton increased about 42% to $722. The average annual production of these types of shot and grit for the past 10 years was 14,278 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 $566, with a high of $934 in 1991 and a low of $360 in 1987. *(See tables 13 and 14.)*

Consumption.—The quantity of steel shot and grit sold or used increased slightly to 205,623 tons, the total value increased 4% to $85.7 million, and the average value per ton increased slightly to $417. The average annual quantity of steel shot and grit sold or used for the past 10 years was 186,967 tons. The high was 214,787 tons in 1988, and the low was 139,377 tons in 1983.

The quantity of other shot and grit sold or used increased 5% to 12,089 tons. The value increased about 50% to $8.7 million. The average value per ton increased 43% to $723. The average annual quantity of these shot and grit sold or used for the past 10 years was 14,392 tons, with a high of 18,192 tons in 1984 and a low of 9,152 tons in 1985.

The estimated apparent domestic consumption of all types of metallic shot and grit increased 4% in quantity to 203,555 tons, decreased slightly in total value to $79.0 million, and decreased 4% in average value per ton to $388. 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 193,663 tons, with a high of 224,216 tons in 1988 and a low of 153,597 in 1983. 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.

Foreign Trade.—U.S. exports of metallic shot and grit increased slightly to 26,936 tons. The total value of exports increased 49% to $24.3 million, and the average value per ton increased 43% to $903. The average annual tonnage of metallic shot and grit exports for the past 10 years was 13,448 tons, with a high of 26,936 tons in 1992 and a low of 6,334 tons in 1986. The average value per ton for the past 10 years was $750, with a high of $948 in 1987 and a low of $390 in 1989.

U.S. imports of metallic abrasives increased 39% in quantity to 12,779 tons, increased about 15% in total value to $8.9 million, and decreased 18% in value per ton to $699. The average annual imports for the past 10 years were 5,843 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 $935, with a high of $965 in 1988 and a low of $280 in 1984.

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.

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[1]All units of measure in this chapter are metric.

[2]American National Standards Institute. Specifications for Grading of Certain Abrasive Grains on Coated Abrasive Products. ANSI B74.18-1977, 37 pp.

[3]———. Specification for Size of Abrasive Grains-Grinding Wheel, Polishing, and General Industrial Uses. ANSI B74.12-1976, 11 pp.

[4]Coes, L., Jr. Abrasive. Springer-Verlag, NY, 1971, 177 pp.

[5]Vogel, H. H., and Bartos Mines Corp., Staff. Abrasives. Ch. in Industrial Minerals and Rocks (Nonmetallic Other Than Fuels). AIME, New York, 5th ed., 1983, pp. 21-25.

[6]Thaden, R. E. Abrasives. Ch. in United States Mineral Resources. U.S. Geol. Surv. Prof. Paper 820, 1973, pp. 27-33.

[7]Work cited in footnote 4.

[8]Work cited in footnote 5.

[9]Candler, H. P. Industrial Diamond. A Materials Survey. BuMines IC 8200, 1964, 150 pp.

[10]American National Standards Institute. Specifications for Checking the Size of Diamond. ANSI B74.16-1971, 12 pp.

[11]———. Specification for Grading of Diamond Powder in Subsieve Size. ANSI B74.20-1981.

[12]Industrial Diamond Association Inc. 1983 Listing of Members.

[13]Wilson, A. N. Diamonds From Birth to Eternity. Gemological Inst. of Am., 1982, 450 pp.

[14]Works cited in footnotes 9 and 13.

[15]De Beers Consolidated Mine Ltd. Occurrences, Mining and Recovery of Diamonds. Kercim Pres. Ltd., Slough, Bucks, England, 1973, 44 pp.

Hoppe, R. Diamond From the Kalahari. Eng. and Min. J., v. 181, No. 5, May 1989, pp. 64-69.

[16]Born, W. What Diamond Recovery Should Mean to You. Abrasive Eng. Soc., July-Aug. 1980.

[17]General Electric Co., Specialty Materials Department. Stratapax Drill Blanks. Sales Brochure No. SMD31-451, 8 pp.

[18]Indiaqua. New Polycrystalline Diamond Product Development at DRL. V. 38. 1984/1, p. 125.

[19]Work cited in footnote 14.

[20]Hawkins, B. Diamonds in China. Dep. Mines and Energy Affairs, Republic of South Africa, No. 1/82. July 1982, 10 pp.

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Industrial Diamond. Ch. in Mineral Commodity Summaries, 1993.

Manufactured Abrasives Mineral Industry Surveys, quarterly.

Mineral Facts and Problems, 1985.

TABLE 1
SALIENT U.S. ABRASIVES STATISTICS

Abrasive materials		1988	1989	1990	1991	1992
Production of:						
Natural abrasives						
Tripoli (crude)	metric tons	99,928	105,230	94,390	88,642	84,924
Value	thousands	$864	$2,537	$3,194	$3,271	$3,256
Special silica stone (crude)[1]	metric tons	1,892	898	3,709	2,205	1,732
Value	thousands	$566	$147	$230	$161	$239
Garnet[2]	metric tons	42,506	42,605	47,009	50,860	54,139
Value	thousands	$4,707	$4,408	$6,939	$7,534	$4,842
Emery	metric tons	869	W	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	544,899	535,213	514,869	454,572	468,772
Value[4]	thousands	$209,998	$227,761	$218,207	$195,635	$208,560
Foreign trade (natural and artificial abrasives):						
Exports (value)[5 6]	do.	$281,633	$260,363	$270,928	$295,743	$351,187
Reexports (value)[5 6]	do.	$19,302	$33,771	$24,545	$24,209	$32,088
Imports for consumption (value)[5 7]	do.	$501,707	$419,084	$512,766	$450,880	$482,134

W Withheld to avoid disclosing company proprietary data.
[1]Includes crude material used for producing grindstones, oilstones, whetstones, and deburring media; excludes data on material used for grinding pebbles and tube-mill liners.
[2]"Primary" garnet; denotes the first marketable product and includes crude concentrate.
[3]Includes Canadian production of crude silicon carbide and fused aluminum oxide plus shipments of metallic abrasives by producers.
[4]Excludes United States and Canadian production and value of aluminum-zirconium oxide.
[5]Source: Bureau of the Census, U.S. Department of Commerce.
[6]F.a.s.
[7]Customs value.

TABLE 2
U.S. EXPORTS OF ABRASIVE MATERIALS, BY KIND

Kind		1991		1992	
		Quantity	Value	Quantity	Value
NATURAL					
Industrial diamond, natural or synthetic, powder or dust	thousand carats	77,642	$115,866	81,474	$119,146
Industrial diamond, natural or synthetic, other	do.	1,163	5,721	2,920	14,997
Natural abrasives, crude	thousand kilograms	1,680	1,730	2,193	1,741
Natural abrasives, other	do.	10,811	15,335	14,778	13,426
MANUFACTURED					
Artificial corundum (fused aluminum oxide)	do.	10,763	25,259	11,531	27,407
Silicon carbide, crude or in grains	do.	10,138	10,812	13,512	11,844
Grinding and polishing wheels and stones:					
Diamond	number of items	688	13,366	812	22,973
Polishing stones, whetstones, oilstones, hones, similar stone	do.	1,564	7,231	1,969	7,365
Wheels and stones, n.e.c.	do.	647	2,110	1,608	7,044
Abrasive paper and cloth, coated with natural or artificial abrasive materials	thousand kilograms	12,499	82,027	14,924	101,096
Metallic abrasive:					
Grit and shot, including wire pellets	do.	25,790	16,285	26,587	24,147
Total[1]		XX	295,743	XX	351,187

XX Not applicable.
[1]Data do not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 3
U.S. REEXPORTS OF ABRASIVE MATERIALS, BY KIND

Kind		1991		1992	
		Quantity	Value[1] (thousands)	Quantity	Value[1] (thousands)
NATURAL					
Industrial diamond, natural or synthetic, powder or dust	thousand carats	1,204	$3,470	2,091	$6,233
Industrial diamond, natural or synthetic, other	do.	1,759	16,008	2,676	21,730
Emery, natural corundum, pumice in blocks	thousand kilograms	92	388	163	269
MANUFACTURED					
Artificial corundum (fused aluminum oxide)	do.	373	791	437	935
Silicon carbide, crude or in grains	do.	12	14	35	161
Grinding and polishing wheels and stones:					
Diamond	thousand carats	50	949	28	579
Polishing stones, whetstones, oilstones, hones, similar stone	thousand items	24	213	31	227
Abrasive paper and cloth, coated with natural or artificial abrasive materials	thousand kilograms	365	2,309	309	1,784
Metallic abrasives:					
Short grit, pellets, etc.	do.	127	67	349	170
Total		XX	24,209	XX	32,088

XX Not applicable.
[1]F.a.s.

Source: Bureau of the Census.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF (NATURAL AND ARTIFICIAL) ABRASIVE MATERIALS, BY KIND

Kind		1991		1992	
		Quantity	Value[1] (thousands)	Quantity	Value[1] (thousands)
Silicon carbide, crude	thousand metric tons	65	$32,751	83	$36,019
Aluminum oxide, crude	do.	116	48,817	115	46,310
Abrasives, ground grains, pulverized or refined:					
Silicon carbide	do.	r5	12,462	6	14,776
Aluminum oxide	do.	24	30,555	21	27,897
Emery, corundum, flint, garnet, other, including artificial abrasives	do.	11	4,304	21	6,172
Papers, cloths, other materials wholly or partly coated with natural or artificial abrasives	do.	19	117,090	20	132,007
Hones, whetstones, oilstones, polishing stones	thousand items	2	1,845	4	2,505
Abrasive wheels and millstones:					
Burrstones manufactured or bound up into millstones	do.	1,469	4,367	935	3,890
Solid natural stone wheels	do.	406	1,372	153	796
Diamond	do.	679	16,024	664	18,918
Abrasive wheels bonded with resins	do.	6,312	28,873	5,734	29,308
Other	do.	(2)	36,147	(2)	42,204
Grit and shot, including wire pellets	thousand metric tons	9,207	7,820	12,779	8,931
Diamond, natural and synthetic:					
Natural industrial diamond stones	thousand carats	5,341	31,298	3,570	21,221
Miners' diamond	do.	2,255	19,259	6,215	23,415
Powder and dust, synthetic	do.	59,382	43,235	86,720	55,739
Powder and dust, natural	do.	10,606	14,661	10,565	12,027
Total		XX	450,880	XX	[3]482,134

[r]Revised. XX Not applicable.
[1]Customs value.
[2]Quantity not reported.
[3]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 5
PROCESSED TRIPOLI[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use		1988	1989	1990	1991	1992
Abrasives	metric tons	26,360	26,192	24,090	21,239	18,603
Value	thousands	$3,151	$3,172	$3,083	$3,382	$2,779
Filler	metric tons	68,618	63,080	56,468	52,334	57,603
Value	thousands	$9,876	$9,185	$11,041	$10,009	$11,326
Total quantity[2]	metric tons	94,978	89,272	80,558	73,575	76,205
Total value	thousands	$13,027	$12,357	$14,124	$13,391	$14,105

[1]Includes amorphous silica and Pennsylvania rottenstone.
[2]Data may not add to totals shown because of independent rounding.

TABLE 6
SPECIAL SILICA STONE FINISHED PRODUCTS SOLD OR USED AS REPORTED BY U.S. PRODUCERS[1]

Year	Quantity (metric tons)	Value (thousands)
1988	371	$5,415
1989	377	5,459
1990	450	6,328
1991	272	3,600
1992	340	4,554

[1]Includes grindstones, oilstones, and whetstones. Excludes grinding pebbles, tube-mill liners, and deburring media.

TABLE 8
GARNET SOLD OR USED, AS REPORTED BY U.S. PRODUCERS

Year	Quantity (metric tons)	Value (thousands)
1988	41,896	$11,144
1989	41,320	9,768
1990	45,935	11,759
1991	48,051	13,044
1992	46,098	13,049

TABLE 7
U.S. PRODUCERS OF SPECIAL SILICA STONE PRODUCTS IN 1992

Company and location	Type of operation	Product
Arkansas Abrasives Inc.:		
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:		
Paron, AR	do.	Do.
Hall's Arkansas Oilstones Inc.:		
Pearcy, AR	Stone cutting and finishing	Whetstones and oilstones.
Hardrock Mining Inc.:		
Hot Springs, AR	Tumbling and sizing novaculite	Metal finishing media and deburring media.
Hiram A. Smith Whetstone Co. Inc.:		
Hot Springs, AR	Stone cutting and finishing	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
Ed Kramer & Sons:		
Baraboo, 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:		
Lake Hamilton, AR	do.	Do.
Wallis Whetstone:		
Malvern, AR	Quarry	Crude novaculite.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF INDUSTRIAL DIAMOND, BY COUNTRY

(Thousand carats and thousand dollars)

Country	Natural industrial diamond stones (including glazers' and engravers' diamond, unset) (7102.21.3000 and .4000)				Miners' diamond, natural and synthetic (7102.21.1010 and .1020)				Diamond powder and dust, synthetic (7105.10.0020; 0.0030 and .0050)				Diamond powder and dust, natural (7105.1011 and .0015)			
	1991		1992		1991		1992		1991		1992		1991		1992	
	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]
Australia	20	$207	118	$240	(2)	$2	3	$24	—	—	—	—	3	$2	1	$48
Belgium	206	1,156	66	504	100	530	339	5,414	265	$83	536	$208	2,090	4,166	2,280	5,653
Canada	4	26	(2)	2	(2)	4	14	100	95	61	198	114	(2)	8	223	44
China	34	38	46	26	10	4	—	—	2,674	943	1,738	698	161	135	138	143
Germany	20	161	(2)	7	159	926	6	208	3,890	3,651	4,758	6,068	380	787	403	798
Ghana	791	5,639	617	4,397	2	60	11	88	31	25	42	55	27	83	180	475
Hong Kong	153	542	11	9	—	—	1	60	636	206	262	71	r170	r133	7	80
India[3]	—	—	173	207	—	—	—	—	8	6	11	12	20	17	25	19
Ireland	90	484	79	363	1,433	2,995	5,293	6,681	36,456	29,569	54,928	35,833	3,599	5,415	3,227	2,090
Israel	8	29	3	390	—	—	—	—	—	—	52	58	121	103	(2)	7
Japan	9	429	7	539	12	636	9	108	2,839	2,550	2,275	1,952	r5	r13	336	438
Netherlands	65	3,430	8	2,605	38	894	128	1,767	—	—	—	—	—	—	—	—
South Africa, Republic of	28	128	25	137	—	—	—	—	—	—	340	411	—	—	—	—
United Kingdom	1,251	11,904	1,224	8,379	420	9,064	318	5,178	727	848	2,273	2,052	1,493	2,420	800	672
Zaire	2,546	6,348	1,130	3,198	48	2,732	77	3,379	31	21	31	28	1,140	540	1,131	517
Other	115	779	63	216	33	1,412	16	409	11,732	5,269	19,276	8,180	1,395	840	1,812	1,043
Total[4]	5,341	31,298	3,570	21,221	2,255	19,259	6,215	23,415	59,382	43,235	86,720	55,739	10,606	14,661	10,565	12,027

rRevised.

[1]Customs value.

[2]Less than 1/2 unit.

[3]Previously included in "Other."

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

Source: Bureau of the Census.

TABLE 10

DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY[1]

(Thousand carats)

Country	1988				1989				1990			
	Natural			Synthetic[4]	Natural			Synthetic[4]	Natural			Synthetic[4]
	Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]	
Angola[e]	950	50	1,000	—	1,165	80	[5]1,245	—	r1,060	r73	r1,133	—
Australia	17,413	17,413	34,826	—	17,540	17,540	35,080	—	17,331	17,331	34,662	—
Botswana	10,660	r4,570	15,229	—	r10,680	r4,570	15,252	—	r12,150	r5,200	17,352	—
Brazil	r350	180	r530	—	350	150	500	—	600	900	1,500	—
Central African Republic	284	59	343	—	334	81	415	—	303	78	381	—
China[e]	200	800	1,000	15,000	200	800	1,000	15,000	200	800	1,000	15,000
Côte d'Ivoire[e 6]	8	3	11	—	9	3	12	—	9	3	12	—
Czechoslovakia[e]	—	—	—	5,000	—	—	—	5,000	—	—	—	5,000
France[e]	—	—	—	4,000	—	—	—	4,000	—	—	—	4,000
Gabon[e]	400	100	500	—	400	100	500	—	400	100	500	—
Ghana[7]	r55	r465	r520	—	r124	r370	r494	—	r163	r487	r650	—
Greece[e]	—	—	—	1,000	—	—	—	1,000	—	—	—	1,000
Guinea[e 7]	136	10	146	—	r137	10	r147	—	r119	r8	r127	—
Guyana	1	3	4	—	3	5	8	—	r5	r13	r18	—
India	11	3	14	—	3	12	15	—	3	r e15	r18	—
Indonesia[e]	7	22	29	—	7	25	32	—	7	23	30	—
Ireland[e]	—	—	—	60,000	—	—	—	60,000	—	—	—	60,000
Japan[e]	—	—	—	25,000	—	—	—	25,000	—	—	—	25,000
Liberia	67	100	167	—	62	93	155	—	40	60	e100	—
Namibia	r925	r50	r975	—	910	r20	r927	—	r750	r15	r763	—
Romania[e]	—	—	—	5,000	—	—	—	4,500	—	—	—	4,500
Russia[8 9]	—	—	—	—	—	—	—	—	—	—	—	—
Sierra Leone[6]	12	6	18	—	90	39	129	—	66	12	78	—
South Africa, Republic of:												
Finsch Mine	r1,320	r2,600	3,920	—	r1,600	r3,000	4,610	—	r1,480	r2,700	4,178	—
Premier Mine	r700	r1,540	2,239	—	r700	r1,520	2,215	—	r720	r1,600	2,328	—
Venetia Mine	—	—	—	—	—	—	—	—	20	40	62	—
Other De Beers' properties[10]	r1,400	r520	1,919	—	r1,350	r530	1,880	—	r1,200	r460	r1,652	—
Other	r380	r40	426	—	r350	r50	411	—	r380	r100	488	—
Total	3,800	4,700	8,504	e55,000	4,000	5,100	9,116	e60,000	r1,600	r4,900	8,708	e60,000
Swaziland	44	29	73	—	33	22	55	—	25	17	42	—
Sweden[e]	—	—	—	25,000	—	—	—	25,000	—	—	—	25,000
Tanzania	r105	r45	r150	—	r105	r45	r e150	—	r60	r25	85	—
U.S.S.R.[e 9 11]	r11,000	r11,000	r22,000	41,500	r11,500	r11,500	r23,000	41,500	r12,000	r12,000	r24,000	41,000
United States	—	—	—	W	—	—	—	W	—	—	—	W
Venezuela	54	r75	r129	—	70	185	255	—	88	245	333	—
Yugoslavia[e 12]	—	—	—	5,000	—	—	—	5,000	—	—	—	5,000
Zaire	2,724	15,439	18,163	—	2,663	15,092	17,755	—	2,914	16,513	19,427	—
Total	r49,206	r55,122	r104,331	241,500	r50,385	r55,842	r106,242	246,000	r52,093	r58,818	r110,919	245,500

See footnotes at the end of table.

TABLE 10—Continued

DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY[1]

(Thousand carats)

Country	1991				1992			
	Natural			Synthetic[4]	Natural			Synthetic[4]
	Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]	
Angola[e]	r899	r62	r 4 961	—	935	65	1,000	—
Australia	17,978	17,978	35,956	—	21,000	21,000	42,000	—
Botswana	r11,550	r4,950	r16,506	—	10,000	5,000	15,000	—
Brazil	600	900	e1,500	—	600	900	1,500	—
Central African Republic	r296	r82	r379	—	296	82	378	—
China[e]	200	800	1,000	15,000	200	800	1,000	15,000
Côte d'Ivoire[e 6]	11	4	e15	—	11	4	15	—
Czechoslovakia[e]	—	—	—	5,000	—	—	—	5,000
France[e]	—	—	—	e4,000	—	—	—	4,000
Gabon[e]	400	100	500	—	400	100	500	—
Ghana[7]	r175	r525	e700	—	175	525	700	—
Greece[e]	—	—	—	1,000	—	—	—	750
Guinea[7]	r91	6	r97	—	90	5	95	—
Guyana	r7	r38	r e45	—	8	42	50	—
India	3	r15	r18	—	3	15	18	—
Indonesia[e]	8	24	32	—	6	21	27	—
Ireland[e]	—	—	—	60,000	—	—	—	60,000
Japan[e]	—	—	—	30,000	—	—	—	30,000
Liberia	40	60	e100	—	60	90	150	—
Namibia	1,170	r20	r1,187	—	1,500	50	r1,549	—
Romania[e]	—	—	—	4,500	—	—	—	4,000
Russia[8 9]	—	—	—	—	9,000	9,000	18,000	60,000
Sierra Leone[7]	r160	r83	243	—	165	85	250	—
South Africa, Republic of:								
Finsch Mine	r1,200	r2,280	r3,483	—	1,200	2,250	r3,446	—
Premier Mine	700	r1,550	r2,250	—	740	1,700	r2,444	—
Venetia Mine	100	200	303	—	660	1,200	r1,868	—
Other De Beers' properties[10]	r1,500	r400	r1,897	—	1,350	500	r1,849	—
Other	400	r100	r498	—	450	100	r549	—
Total	r3,900	r4,530	r8,431	e60,000	4,400	5,750	10,156	60,000
Swaziland	r34	r23	r57	—	36	24	60	—
Sweden[e]	—	—	—	25,000	—	—	—	25,000
Tanzania	r70	r30	r100	—	70	30	100	—
U.S.S.R.[e 9 11]	r10,000	r10,000	r20,000	60,000	—	—	—	—
United States	—	—	—	90,000	—	—	—	90,000
Venezuela	r102	r112	r214	—	108	115	223	—
Yugoslavia[e 12]	—	—	—	5,000	—	—	—	5,000

See footnotes at end of table.

TABLE 10—Continued

DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY[1]

(Thousand carats)

Country	1991				1992			
	Natural			Synthetic[4]	Natural			Synthetic[4]
	Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]	
Zaire	3,000	r14,814	r17,814	—	3,000	12,000	15,000	—
Total	r50,694	r55,156	r105,855	359,500	52,063	55,703	107,771	298,750

rEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.

[1]Table includes data available through May 25, 1993. Total natural 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 Brazil (1988-90), and Central African Republic (1988-90), 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.

[2]Includes near-gem and cheap-gem qualities.

[3]Natural gem and industrial data may not add to totals shown because of independent rounding.

[4]Includes all synthetic diamond production.

[5]Reported figure.

[6]Figures are estimates based on reported exports and do not include smuggled diamonds.

[7]Figures do not include smuggled artisanal production.

[8]Formerly part of the U.S.S.R.

[9]All production in the U.S.S.R. from 1988-91 came from Russia.

[10]Other De Beers' Group output from the Republic of South Africa includes Kimberley Pool, Koffiefontein Mine, and Namaqualand mines.

[11]Dissolved in Dec. 1991.

[12]Dissolved in Apr. 1992; however, information is inadequate to formulate reliable estimates of individual country production.

TABLE 11

CRUDE ARTIFICIAL ABRASIVES MANUFACTURERS IN 1992

Company	Location	Product
The Exolon-Esk Co.	Hennepin, IL	Silicon carbide.
Do.	Thorold, Ontario, Canada	Fused aluminum oxide (regular).
General Abrasive Triebacher, Inc.	Niagara Falls, NY	Fused aluminum oxide (regular and high-purity).
Do.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular) and silicon carbide.
Saint-Gobain/Norton Industrial Ceramics Corp.	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.
Superior Graphite Co.	Hopkinsville, KY	Do.
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).
Washington Mills Ltd.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular).

TABLE 12

END USES OF CRUDE SILICON CARBIDE AND ALUMINUM OXIDE (ABRASIVE GRADE) IN THE UNITED STATES AND CANADA, AS REPORTED BY PRODUCERS

Use	1991			1992		
	Quantity (metric tons)	Value (thousands)	Yearend stocks	Quantity (metric tons)	Value (thousands)	Yearend stocks
SILICON CARBIDE						
Abrasives	42,380	$21,921	2,164	44,673	$23,954	2,956
Metallurgical	36,563	17,579	5,400	39,611	19,510	5,258
Refractories and other	W	W	—	W	W	—
Total	78,943	39,500	7,564	[1]84,283	43,464	8,214
ALUMINUM OXIDE						
Regular: Abrasives and refractories	138,440	52,783	7,840	142,545	56,284	6,388
High purity	24,516	15,175	1,449	24,231	14,388	1,134
Total	162,956	67,958	9,289	[1]166,777	70,672	7,522

W Withheld to avoid disclosing company proprietary data; included with "Metallurgical."
[1]Data do not add to total shown because of independent rounding.

TABLE 13

U.S. PRODUCERS OF METALLIC ABRASIVES IN 1992[1]

Company	Location	Product (shot and/or grit)
Abrasive Materials Inc.	Hillsdale, MI	Cut wire, steel.
Barnsteel Abrasives	Butler, PA	Annealed iron and steel.
Chesapeake Specialty Products	Baltimore, MD	Steel.
Durasteel Abrasive Co.	Pittsburgh, PA	Do.
Ervin Industries Inc.	Adrian, MI	Do.
Do.	Butler, PA	Do.
Metaltec Steel Abrasives Co.	Canton, MI	Do.
National Metal Abrasive Co.	Wadsworth, OH	Do.
Pellets Inc.	Tonawanda, NY	Cut wire.
The Wheelabrator Corp.	Bedford, VA	Steel.

[1]Excludes reclaimed materials.

TABLE 14

ANNUAL PRODUCTION, SHIPMENTS, AND PLANT CAPACITIES FOR METALLIC ABRASIVES IN THE UNITED STATES, BY PRODUCT[1]

Product	Production		Shipments		Capacity[2]
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	(metric tons)
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
1992:					
Chilled iron shot and grit	W	W	W	W	W
Annealed iron shot and grit	W	W	W	W	W
Steel shot and grit	202,325	81,330	205,623	85,700	235,705
Other[3]	11,477	8,270	12,089	8,725	XX
Total[4]	213,802	89,601	217,712	94,424	XX

W Withheld to avoid disclosing company proprietary data; included with "Other." XX Not applicable.

[1]Excludes secondary (recycle) producers.

[2]Total 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.

[3]Includes cut wire, aluminum, stainless steel shot, and items indicated by symbol W.

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

ADVANCED MATERIALS

By William J. McDonough

Dr. McDonough, physical scientist, Branch of Materials, has more than 25 years of technical and managerial experience in both industry and the Federal Government. He has been with various departments of the Federal service for 19 years.

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 11 years, the publishers of Ceramic Industry magazine have conducted the only systematic survey of the ceramics industry, relying on companies volunteering their sales figures and on the magazine's own estimates for essential nonreporting companies. The information on advanced ceramics reported here is from the results of the Ceramic Industry surveys of 1990 through 1992. These data are generously provided in advance of publication by Ms. Patricia Janeway, Editor in Chief and Associate Publisher of Ceramic Industry.

Kline & Co., Inc. data are the basis for the reported 1990 through 1992 estimated markets for advanced polymer, metal matrix, and carbon-carbon composites. These data are provided by Mr. John M. Quarmley, Project Manager of Advanced Materials for Kline & Co., Inc. Additional data on polymer composites are obtained from Mr. Joel Broyhill, Statistical Division, Composites Institute, Society of the Plastics Industry, Inc.

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 1993 Corporate Technology Directory is a reference on more than 35,000 U.S. entities that manufacture or develop high-technology products. The Corp Tech data used throughout this chapter for a particular technology identifies sales revenues into distinct ranges versus the number of companies reporting revenues for that particular revenue range.

Some definitions of what constitutes advanced polymer, metal matrix, and carbon-carbon (C-C) 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, except where complex composites do exist with both continuous fibers, chopped fibers, and other second-phase particulates commingled in the same composite. Data relating to the more general categories of polymer and conventional polymer composites are reported separately in the U.S. Bureau of Mines (USBM) "Nonrenewable Organic Materials" chapter of the 1992 Annual Report.

Composite(s) market revenues are usually valued at the fabrication feedstock stage. For example, metric tons and value of continuous fiber or matrix resin are common reported values; but lately, the total tonnage and value of both prepregnated stock and final fabrication stock also are included. One of the figures in this chapter (figure 10) is a simplified fabrication material flow sheet indicating both tonnage and value for individual stages in the fabrication of typical advanced polymer composites. This figure should give the reader a feel for the complexity involved in making composites.

Metal matrix composites are composed of a continuous metallic phase and dispersed reinforcing phase(s). 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.

C-C 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 C-C materials have been included; however, the more technically important C-C composites usually exhibit higher density (1.4 to 2.1 grams per cubic centimeter), strength, and thermal conductivity.

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, updated annually, biannually, or triannually, 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 communities. The EC consortia are seriously challenging the United States through EC efforts to cooperatively develop "critical technologies," commencing with market driven research and development (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 continuing recession has made the United States more aware of manufacturing competitiveness as the Nation attempts to sustain annual revenues generated by exports.[2] Adding to the uncertain export revenues is the realization that this current recession is worldwide. The reunification of West and East Germany has caused high inflation rates in the new German Republic. The German Government raised interest rates to arrest its internal inflation, but the Deutch Mark is also the benchmark of the new EC. This anti-inflation action, primarily, plus other EC economic infrastructure problems, resulted in monetary chaos for most EC members. Collectively, these problems are adding to the continuing recession. Japan, meanwhile, is faced with falling currency ratios that make its products too expensive for global competition. For the first time in decades, Japanese companies are laying off employees and reporting business revenue losses.

In the United States, cuts in the U.S. Department of Defense (DOD) budget, the huge interest on the national debt, and the downsizing of large corporations by as much as 30% in personnel to cover business revenue losses all contribute to the scarcity of investment money necessary to fuel manufacturing growth.[3] Truly, 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, under newly elected President Clinton, is still 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 1992 ends, the actual role of the Federal Government is still being defined owing to the (1) change in Federal power structure and (2) the complexity of the economic and political problems inherent in creating such a technology plan.

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 Corporation uses more than 10,000 subcontractors in all its business and manufacturing endeavors. U.S. Department of Commerce (DOC) data report that for the U.S. manufacturing sector, more than one-half of all goods are 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. One of the big limitations is that these original equipment manufacturers (OEM's) must compete, most often on a yearly basis, for contracts to continue or followup with an already existing series of parts or assemblies. The reason is that both large corporations and governmental operations run on an annual fiscal year funding. Therefore, for many contractors, small and large, there is no guarantee of additional funding to continue their manufacturing or service efforts beyond 1 or 2 years. All these factors and many more not mentioned contribute to 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]

The situation in the United States is improving as both the Federal and State government and industry go to longer term contracts. Many States and counties use a 2-year funding interval, and the new Clinton administration indicates that it intends to ask Congress for a 2-year budget cycle. DOD, in 1992, was funding many programs over a 3-year interval. In the industrial sector, the use of cooperative agreements between large corporations and their subcontractors is beginning to evolve into longer term business commitments. There is hope that the U.S. Congress will, by enactment of new laws, allow 3- to 5-year funding of programs, especially those programs

aimed at "dual use" manufacturing, involving the initiation of flexible manufacturing, wherever possible.

Japan, as mentioned in last year's Annual Report, has a similar small business situation in the manufacturing area. There, small companies, numbering more than 800,000 with less than 300 employees per company, produce 60% of Japan's goods and for the most part use new manufacturing technologies and other aids to maximize return on investment.[7] The Japanese manufacturers, both large and small, operate under a business climate of longer term contracts and a nonserial, management style of business planning; e.g., quality circles, plus 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 were started in the 1920's, along with their agriculture extension services. Both are based on the success of the U.S. Department of Agriculture extension services. The Japanese, obviously impressed with the U.S. agriculture extension service centers concept, also extended this concept to their then-emerging industrial sectors.

The EC was quick to copy the success of today's Japanese economy and has expanded or set up more industry driven manufacturing service centers, for example, the 13 centers of the Max Planck Institute in Germany.

Industry Structure.—This entire document 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 C-C composites. The industry structure for the first three technologies is similar in their involvement of both large and small manufacturers. The C-C industry resulted from fabrication facilities established within large aerospace corporations that were initially supported by the Federal Government for defense applications. The C-C industry structure will be discussed separately from the other three technologies.

The former three broad-based technologies grew from national laboratory and/or large company internal R&D (IRAD), and once a technology was ready for commercialization, the fabrication was contracted out to smaller companies or specific divisions of large companies. Many examples exist in all advanced composites areas where the manufacturing companies include a few very large companies in addition to many small companies. Many of the small companies are subcontractors to the large companies. But today, a significant number of these small companies are entrepreneurial companies. They are founded by engineers or scientists and initially start with assistance from Government funding, such as the Federal Government's Small Business Innovative Research Programs (SBIR). These various SBIR programs, in more than 10 Government Departments, competitively award funds to small companies ranging from $25,000 for phase 1 and up to $2 to $4 million for final phase 3.

The C-C composites industry, in contrast to the other three advanced technologies, is related to the DOD'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. C-C 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 in addition to numerous aerospace applications. In the 1990's, increased use of C-C composites is called for in the commercial aircraft of both the United States and the EC.

The companies manufacturing C-C 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 C-C 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 C-C composites, are tied to the ongoing "downsizing" of the DOD (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 less than 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—all positive deliverables to the large assembler companies. The revenue mix of small companies versus large companies will be partially delineated in the individual subsections of this chapter.

Recycling Advanced Materials.—Material recycling is increasing worldwide as awareness grows that humankind should give an accounting of stewardship with regard to the Earth's finite resources. Recycling of aluminum containers has reached 70%, with steel container recycling at a respectible 40%, up from 34% from last year. Various polymeric materials are being preidentified at their manufacture for recycling purposes. The recycling of advanced materials, especially composites, is in various conceptual stages of defining their total environmental impacts. Technical advances in optimizing recycling are possible because the industry is small in volume and revenue and can start recycling as an advanced materials "system" concept.

Advanced materials recycling requires new thinking, starting with "design to recycle" concepts. These concepts are necessary because a composite component, when used structurally, could conceivably contain all four types of materials: polymer, metal, ceramic, and carbon fiber. Usually, these compound composites are designed using finite element analysis (FEA) to determine the material properties desired, based on projected use and the preliminary shape of the component. Computer-aided design (CAD) and computer-aided engineering (CAE), together with FEA, delineate the composite materials necessary to meet the expected stresses and strains during an estimated lifetime of service. In addition, once the materials are selected and the technical cost modeling completed, material substitution may occur to bring the costs down to competitive values with existing technologies.

One good example of a complex composite is the composite outer body panels on General Motors' all purpose vehicles.[8] The recycling of these panels, as manufactured today, is complicated by the inexpensive ceramic filler material (30% by weight) mixed in with expensive polymer resin and fiber(s). Also, the use of two or three different fiber types to provide the designed-for stiffness, compression resistance, and impact resistance make these panels unfriendly to recycle. If the panels are ground up to make auto fluff, the high-tech components are degraded so as to make them uneconomically viable to recover. Besides, auto fluff today is usually deposited in municipal land fills that are rapidly closing due to socioeconomic reasons. Preliminary studies on recovering or reusing auto fluff are ongoing in Europe and the United States in an effort to develop economical uses for ever-increasing amounts of auto fluff per vehicle.

The selection of the materials for these outer body panels 8 to 10 years ago did not consider the concept of design to recycle. That situation will change in the near future. Recycling awareness by U.S. manufacturers is just in its initial stages, with the role model country being the German Republic. Under German law, manufacturers are setting up joint companies to study the recyclability of most material products, including anticipated advanced material types.[9]

The recycling of electronic components, such as circuit boards, to recover precious metals is a growing business in the United States and is driven by the high value of the precious metals.[10] Advances in secondary (recycle, recover, or reuse) smelters and refineries allow for very high concentration rates. For example, concentration rates are, as follows, in the order of: a secondary smelter, 10 to 1; an electrolytic refinery, 200 to 1; and, a doré furnace/refinery, up to 100,000 to 1. Therefore, material containing as little as 300 parts per million of gold can be concentrated. Furthermore, estimated loss of precious metal per batch is as low as 2% to 3% precious metal.[11] The evolution of more efficient smelters and refineries portends increased recycling of all metals in the quest for sustainable development.

Advanced structural ceramics are used in small quantities in the world today, and recycling considerations are only at an awareness stage. Besides, the value of advanced ceramics is in the value added, by the design, the processing, and the achievement of high-performance goals. The ceramic feedstock powders are made from abundant elements of the Earth such as silicon, nitrogen, carbon, and aluminum. It is the high-purity, low cation and anion impurity content demanded by the high-performance goals that makes these powders expensive today. Also, today's high-purity raw materials are costly because the economy-of-scale laws are not maximized. Therefore, the recycling of these materials may be limited because the "old component" exhibits little value in its recovered feedstock materials. On the other hand, these advanced ceramics are inert to the chemical and physical environment of the Earth and, thus, would not be pollutins.

Annual Review

The importance of advanced materials to the U.S. economy has been emphasized in 1992 through increased activities in Federal and State government participation, in industry awareness, and in university pronouncements. The Federal Government, through the establishment of Presidential councils targeting advanced materials, identified critical technologies in 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 planning side of these various State activities are continuing to go forward even though the 10 big industrial States suffered severe losses in revenue generation because of the current economic downturn. Because all States must live with balanced fiscal budgets, State activities in establishing new incubator centers, State university technology transfer activities, and tax incentives for luring new business are all on reduced budgets.

Meanwhile, the industrial sector continues to create more joint ventures among companies, 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 U.S. business success.

The following sections on 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), also 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 DOD, Emerging Technologies by 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. 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.

National Academy of Sciences and National Science Foundation.—In June 1992, a National Materials Advisory Board (NMAB) of the Academy of Sciences released a report on "High Performance Synthetic Fibers for Composites." The report offered 14 conclusions and recommendations of how U.S. companies can compete with the Japanese. Currently, Japan leads the world in both quality and quantity of synthetic fibers, especially carbon fiber. A second NMAB study commissioned by the National Science Foundation on the state of U.S. technology reported a slight decrease in the total government and industrial R&D expenditures in the past 5 years. The study estimated that an increase of $25 billion in annual private and Federal spending on research, development, and engineering (R, D, & E) would be necessary for at least 5 years to allow the United States to catch up technically. Report data indicated that Japan spends 3% of its gross domestic product (GDP) on nonmilitary R&D, and the EC also spends 3% of its GDP on nonmilitary R&D, whereas the United States spends 1.9% of its GDP on nonmilitary R&D.[12]

The summary of a National Science Foundation workshop entitled "Report on the National Science Foundation Advanced Structural Materials and Processes Workshop" pinpoints the challenges before U.S. manufacturers in today's global economy. For instance, the United States must not only develop and adopt new materials that offer improved performance, but it also must manufacture these new materials in proficient ways that utilize today's process engineering techniques. Examples of these techniques are "smart" processing with sensors, flexible and/or just-in-time manufacturing, and total quality control for all steps in the manufacturing, commencing with R&D on through final product inspection. This summary recommended a tripartite consortium made up of government, industry, and university sectors, with the U.S. Government acting as a facilitator. The actual markets can only be developed by customer demand for higher performance products. In the past, the U.S. Government, especially DOD, was the customer for most of the products developed by its own funding of R&D. Today, global markets dictate the market pull, and that situation requires a more complex global marketing strategy.[13]

Congressional Actions.—Congressional Acts, passed in 1989 and 1990 with appropriated funding commencing in 1991, addressed and refined U.S. needs for manufacturing competitiveness. For example, Defense Advanced Research Projects Agency (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 (ATP) (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, other Congressional legislation passed in 1991 created the Department of Energy's (DOE) National Technology Initiative. This initiative will concentrate on increased technology transfer and cooperative research, development, and engineering between the U.S. Government and industry.

The Comprehensive Energy Policy Act of 1992 contains funds that will enhance advanced materials in the following technical areas: near net shape

processing of ceramics, high-temperature composite ceramics, and smart and flexible process manufacturing of ceramics.[14]

The National Competitive Act of 1992 and the Manufacturing Strategy Act of 1992 contain add-on funds for (1) the ATP of the DOC (2) a Government-backed pool of venture capital to develop critical technologies, and (3) a White House-level "Council on Technology and Competitiveness." In addition, since the signing of the Federal Technology Transfer Act of 1989, the number of CRADA's formed has increased significantly. From September 1990, the total number of CRADA's went from approximately 500 to more than 1,600 in September 1992. This increase is attributed mainly to legislation allowing the 11 Federal laboratories in the Department of Energy to enter into CRADA's. The anticipation is that these CRADA's will spin off new technologies and manufacturing companies to increase U.S. competitiveness.[15]

Department of Defense.—In 1992, the goals and missions of DOD 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. The DOD is still 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 former U.S.S.R. into separate nations, coupled with a sluggish U.S. economy, as ample reasons to justify reduced DOD expenditures. The DOD, however, recognizes the importance of maintaining a level of expertise in critical technologies as necessary to keep 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 also can be used to increase U.S. GDP through improving U.S. commercial competitiveness.

One example of the DOD's critical technologies implementation is DARPA's manufacturing "insertion" programs. Government "insertion" programs fund newer and usually more expensive manufacturing techniques than are currently in use. Companies do not want to invest in new manufacturing techniques because of the initial cost and uncertainty of the market duration. Therefore, the Government assists companies in setting up newer techniques so that in a national emergency, the newer manufacturing lines will be able to respond to increased output or more flexibility in adding newer products at anytime in the future. The Government is actually pulling technology in that it buys the product, but also pays, in part, for the modern manufacture of the product. Defense was dropped from DARPA and the name changed to ARPA to increase public awareness of this Agency's commitment to dual-use technology development, up to and including manufacturing. 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 ARPA 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 ARPA 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.

The National Defense Authorization Act of 1993 (Oct. 1992) allots $100 million for dual use critical technology partnerships, $100 million for advanced material manufacturing under various Manufacturing Technology (ManTech), Programs and $200 million for dual use technology development in general, plus $35 million for a new initiative on "agile manufacturing."[16]

ARPA, through its Advanced Manufacturing Technology Programs for the microelectronic industry, wants to set up flexible manufacturing lines for a high-quality wafer output of about 1,000 per month. Currently, small quantity output is not available at a reasonable price per wafer. This, in reality, keeps many entrepreneurial people from designing a chip aimed at a niche market. For example, a niche market could be an electronic chip and appropriate sensors designed to "smart" control the ubiquitous household kitchen toaster to never burn toast. From the military side, small qualities of specialized chips at a reasonable cost would allow more flexibility in designing chips for niche utilizations with possible dual-use civilian markets.[17]

The U.S. carbon fiber manufacturers today have a 50% overcapacity and are seeking new markets as military orders decline and commercial aerospace is slowed by the recession. Some of this overcapacity is the result of DOD announcements made 5 years ago requesting that carbon fiber technology and capacity reside in the United States for defense efforts. The U.S. companies built the carbon fiber capacity from 1.6 thousand metric tons in 1986 to more than 3.6 thousand metric tons by 1990 and in 1992, the total capacity in the United States was about 5.4 thousand metric tons. However, today, just more than one-half of that capacity is idle, and many U.S. companies have sold off their carbon-carbon business to international firms or consortia. The nonmilitary use of carbon fiber is still very limited because of the high cost of fabrication. Additionally, the actual fiber costs are still between $200 and $2,000 per kilogram with the more desirable grades in the $1,000-plus range per kilogram. ARPA is continuing to support carbon-

carbon and carbon-polymer development through its dual use technology programs. Meanwhile, the carbon fiber manufacturers are attempting to seek out niche markets in an effort to decrease their overcapacity.[18]

Agency Programs.—The Federal Government always has 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, the Environmental Protection Agency (EPA), in addition to the Departments of Commerce, Energy, Interior, and Agriculture. Even unclassified ARPA and DOD projects are included. The 1990 funding level for all these materials-related projects was 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).[19] The AMPP is coordinated by FCCSET with industrial and university input as part of its planning and feedback mechanisms. Short-term goals are to make 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 AMPP, released near the end of 1991, contained a chapter entitled "Introduction to the AMPP."

Tables 1, 2, and 3 show summary data from the 1992 AMPP indicating last year, present year, and projected funding levels.[20] Table 1, Total AMPP R&D Funding, by Agency, covers fiscal year 1992, fiscal year 1993 (appropriated), and fiscal year 1994 (submitted budget) for the 10 Agencies. Table 2 is Total AMPP R&D Funding, by Research Component, for the same 3 fiscal years covering the following components: synthesis and processing; theory, modeling, and simulation; materials characterization; education and human resources; and national user facilities/other. Table 3 delineates fiscal year 1993 Total AMPP R&D Funding, by Material Class. There are 11 "classes" of materials ranging from bimolecular to superconducting, the class identification resulting from the crosscut workshops sponsored by FCCSET. Note that table 1 clearly shows the DOD AMPP funding decreasing over the 3-year period while the Department of Energy, NSF, and NASA funding, in particular, are increasing along with various other Agencies. An approximate 9% increase overall in AMPP occurred from fiscal year 1991 to fiscal year 1992, while the total fiscal year 1994 (President's Budget Request) shows a 2.5% decrease relative to fiscal year 1992. This requested decrease reflects the overall budget decreases recommended by the outgoing Bush administration. President Clinton's budget requests with "budget balancing" will show up in fiscal year 1995. In the immediate past, Congress had, if anything, slightly increased this type of funding over the amount submitted by the White House Office of Management and Budget. A perusal of table 2 by research component indicates that national user facilities funding increases by approximately 2.5% while the other components slightly decrease. The user facilities are important to U.S. competitiveness because they allow companies and universities access to R, D, & E equipment, located in the national laboratories, at a reasonable service fee and usually in a timely manner. The opening of more user facilities dedicated to improving manufacturing technology know-how also is included in this budget request. In table 3, material class funding relates the changes in funding levels as the U.S. Government targets very specific classes of advanced materials. For instance, note the substantial increases in biomolecular materials and advanced polymers. *(See tables 1, 2, and 3.)*

Another example of U.S. competitive awareness is the Department of Commerce's Office of Technology Administration (DOC-OTA), established in 1989.[21] 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 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 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 USBM, 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 multivolume series *The New Materials Society.*[22] The Branch of Materials is the focal point for data gathering and analysis of overall raw and processed materials flows in society and is specifically responsible for the collection and interpretation of data on the nonfuel use of organic materials, commodity ceramics, and advanced materials.

A second example of USBM activity in

1992 was a manuscript entitled "Towards A New Materials Paradigm" by Lou Sousa, an economist in the Branch of Issue Analysis. It examines new thinking concerning U.S. competitiveness and the use of advanced materials. Mr. Sousa sees the materials paradigm gradually shifting from a resource-based and supplier-driven model to one that is increasingly technology based and customer focused. For example, the Federal R&D coordinating and planning committees are using more and more input from the industrial and university sectors. Furthermore, the Federal Government's role as a facilitator for the technology and industrial competitive needs of the U.S. economy appears to be under way. Additionally, Federal research priorities will always be shaped in a political setting, but objective analysis studies based on this new materials environment will counterbalance distortions caused by political compromise.[23]

The National Institute of Standards and Technology (NIST) began seeking partners during 1992 to develop a "Multi-purpose Technology Development Center" in Gaithersburg, MD. Industry, State, local, and/or nonprofit organizations will share the $7 to $8 million building and the $1 million annual operating costs. Cost sharing is the expected mechanism for new Federal partnerships such as this undertaking.[24]

Multiagency funded Federal research programs in superconductivity in 1992 totaled $250 million and produced the following highlights: improvements in the electrical properties of copper oxide superconductors, enhancements in the flexibility of superconductor wires, and advancements in thin film electronic circuit applications. Worldwide, a few thin film applications have been introduced into niche market areas. These early commercializations indicate the promise for this very high potential, high expectation technology that offers an improved standard of living for all humans.[25]

Government/Industry Highlights.— An industrial survey sponsored as a joint study reveals U.S. industrial leaders' thoughts on industrial competitiveness. The "Industrial Policy and American Competitiveness Survey," sponsored by Ernst & Young and Plant Engineering Magazine, compiled the responses of more than 475 industrial senior executives or plant managers. Five top-rated results commenced with customer service being most important for rebuilding competitiveness. Technology innovation was ranked second and internal organizational excellence was third. All three of these factors must go hand in hand to ensure a quality product at a reasonable return on investment. The fourth factor viewed good supplier relations as critical to technology innovation and organizational excellence. The fifth factor called for a national industrial policy that would stimulate capital investment. Industrial business leaders want an industrial policy that fosters cooperation, not confrontation, and see such a policy as the key to our country's future economic growth in the global marketplace.[26]

The U.S. semiconductor equipment manufacturers, with the help of Sematech Corp., are slowly regaining their revenue lead in the world market. VLSI Research, Inc. of San Jose, CA, reports $9.9 billion in total sales by this group in 1991 or 43% of the total market. That total market grew in 1992 by 3%, and the United States reached the 47% share or parity with the Japanese. The gain by these U.S. firms is attributed to recapturing U.S. market share from the Japanese through significant improvements in technology and performance.[27]

The World Semiconductor Trade Statistics Program, an association of semiconductor industry leaders, reported global sales in 1992 of $58.8 billion, with U.S. chip sales increasing by a healthy 16.2%, reaching $17.9 billion or 30.4% of the total. Japanese chip sales declined by 6.7%, falling to $19.5 billion or 33.1% of the total. The Japanese electronics industry showed signs of maturity since its consumer equipment market is saturated and its cost of capital advantage is eroded by the decreasing dollar-to-yen ratio. U.S. microcomputer companies continue to make sales in Japan by introducing personal computer's at one-half the price of Japanese personal computer's. Today's world monetary situation favors the U.S. electronics industry over the next 2 years in its effort to recapture its prior world leadership.[28]

The Microelectronics and Computer Technology Corp. (MCC), a consortium between the DOD/ARPA (and other Agencies) and U.S. computer manufacturers, is establishing a new Field Emission Display Consortium to build high-volume capacity "flat panel displays." This technology, originally researched in the United States, is being actively developed at the manufacturing level by three Japanese companies with assistance from Japan's Ministry International Trade Industry (MITI). Even today, all flat screened computers; i.e., laptops, notebooks, etc., black and white and especially color, are manufactured in Japan. This complex technology, especially for "active matrix" liquid crystal displays, has very high rejection rates. The Japanese admit to rejection rates commencing as high as 80%, but today those rates are closer to 40% and are decreasing. These high rejection rates are the result of the millions of operations per screen that must be successfully completed in the manufacture of one laptop screen; that is, the numbers of pixels per screen area—each displaying tricolor capability. This new U.S. consortium is tasked with building the necessary manufacturing to build these displays (screens) for defense use and for commercial use in the booming laptop and notebook computer market. A huge market just over the horizon is the use of flat panel displays in the new high definition television (HDTV). Technical competitiveness could be restored if U.S. companies are successful in this endeavor to manufacture high-quality displays at a reasonable cost and a fair return on investment.[29]

The Telecommunications Industry Association, comprised of about 550 U.S. telecommunications equipment manufacturers and suppliers, petitioned

the Congress and the White House in 1992 to modify the export control regulations to allow U.S. firms to compete globally in new markets opening up in East Europe, the former U.S.S.R., and China. The projected market for telecommunications to the year 2000 is about $20.0 billion for these regions, and U.S. companies would like to compete. Currently, restrictions and regulations prevent "defense sensitive equipment" from being exported. Congress is considering major modifications to export control laws, and some regulations have been changed to allow increased trade. The telecommunications industry relies heavily on advanced materials for its state-of-the-art "solid-state devices" necessary for today's communication networks or those planned by the year 2000.[30]

The U.S. Advanced Battery Consortium, a joint U.S. Government-automaker consortium, awarded $54 million in contracts in its efforts to develop a suitable energy source for electric vehicles. Two of the more promising batteries considered under these contracts are the lithium-polymer battery and the lithium-metal sulfide battery. The strategy for introducing electric vehicles, mandated by California law, for 1996 calls for initial use of "advanced" lead-acid batteries, followed by a shift to other types as they develop and reach the marketplace. A breakthrough in low-cost, high-power density-per-weight batteries would drastically change the dominant role that internal combustion engines have had on the lives of all Americans.[31]

Industrial Production.—The Industrial Research Institute's survey on industrial/internal research and development (IRAD) funding for 1992 reported a decline owing to the current recession. Funding declines ranged between 2% to 4% with very few companies indicating a planned increase in IRAD for 1992. Companies, in general, were beginning to question the effective use of IRAD and whether or not some of their IRAD investments would be better utilized in upstream sectors of manufacturing such as engineering, prototyping, and manufacturing itself. A high-performance product must still maintain high quality control to be cost effective in the global marketplace and provide a reasonable rate of return to the manufacturer.[32]

The revenue created by U.S. manufacturing has been decreasing by approximately 1% per year over the past 15 years, but over the past 3 years the adjusted annual revenue appears to be leveling.[33] 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, stereo lithography for prototyping, and employing "just in time," "design to assemble," and "total quality" concepts coupled to flexible manufacturing facilities.[34]

At the same time, the U.S. industry in 1992 continued the trend of making ventures and partnerships with foreign companies by jointly developing new technology, especially technology requiring advanced manufacturing processes.[35] 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.[36] 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.

The U.S. Robotic Industries Association (RIA) pointed out the large disparity between the Japanese and the U.S. use of robotics in manufacturing. Total quality manufacturing and "6 Sigma" quality control statistics (3 rejects or mistakes per 1 million operations) are going to be necessary to globally compete against these already existing standards in Japan. The Japanese attainment of these quality goals in manufacturing in large part can be attributed to robotic use. Data show that about 400,000 robots work in Japanese factories compared with 45,000 in the United States. The Japanese have about 290 robots for every 10,000 workers while the United States has about 30 robots per 10,000 workers. The Japanese MITI has spent $120 million between 1983 and 1990 on advanced robot technology and is currently spending $200 million on microrobotics for the 1992-95 period. In Japan, companies can obtain 10-year financing for robots at about 5% interest. The RIA also reported that Japanese small businesses can obtain interest-free loans up to $240,000 to buy robots. In 1992, the supplementation for all applications to small businesses by the Japanese Government is 20 times the allocation of funds by the U.S. Government. Most major industrial countries rely on small businesses for more than 60% of all their manufactured goods. Therefore, the RIA is lobbying the Federal Government intensively to be aware of the vital role that robotic technology plays in global competition where quality and performance at a price make the difference.[37]

The foreign ownership of U.S. companies in 1992 is revealed in the following data: 7% of all U.S. manufacturing is foreign controlled, 10% of all U.S. shipments of goods is foreign controlled, and 21% of all U.S.-based chemical companies is foreign controlled.[38]

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 with regard 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 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 4 shows domestic and world data coverage for 1990, 1991, and 1992 for the four technologies covered in this document (advanced ceramics, advanced polymers, metal matrix composites, and C-C composites). Data are in U.S. dollar revenues generated and metric tons produced. Note, in table 4, the reported values by two different sources are in reasonable agreement and the data overall reflect the continuing world recession. For just 1992, table 5 lists estimated world revenues and metric tons by regions of the world: Pacific Rim, North America, Western Europe, and Total. The table 5 footnotes give "value per weight data" per technology or per world region for comparison purposes.

The many projections of world markets for advanced materials, as presented 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. Figures 1 and 2 show these revisions in trends by graphically comparing a 1988 forecast with a 1991 forecast. Figure 1 depicts advanced materials trends and forecasts for the United States, and figure 2 contains similar data for advanced materials trends and forecasts for the world. In 1988, 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 underestimation 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 former U.S.S.R. and other fiscal and economical factors caused recessionary times in 1990-92 for the United States, the EC, and the Pacific Rim countries. Unemployment in 1992 is 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 product's consumer performance appeal can usually be accomplished by utilizing new materials; i.e., advanced materials.

European Community Highlights.—Leadership in advanced materials is shifting toward mainland Europe, with the United Kingdom having difficulty in keeping up in composites and fibers. At the same time, the reunification of the Federal Republic of Germany (FRG) has placed a large fiscal burden on its Government funding programs. Many existing programs have been momentarily downsized, and that includes FRG funding for advanced materials development. Meanwhile, France has been reaping the benefits of strong Government support in its research laboratories and industry. The group of 12 countries in the EC may be joined in the future by Finland, Norway, Sweden, and Switzerland. Also, the former Warsaw Pact countries may become associate or full members. Incorporating these countries, particularly less-developed economies, will pose economic pressures, cultural challenges, and strains upon the existing EC infrastructure.[39]

E.I. du Pont de Nemours & Co. (DuPont) opened its European Composites Development Center in Bad Hamburg, Germany. Amid announcements that a few international companies had sold off their composites ventures or have dramatically scaled back their investments in advanced materials, DuPont dedicated a new European center and presented an upbeat perspective for continuing the commercialization of advanced composites. DuPont is aware of all the technical problems with these materials in addition to their high cost, but continues to be optimistic because real progress has been accomplished. For instance, 8% nonmetallic components are in today's automobiles and composites are 80% of the structure of the next generation helicopter, 35% to 50% of a combat aircraft, and 8% to 12% of a commercial aircraft. Also, composites are being used more in aircraft engines and in areas of sports recreation and medicine.[40]

Multinational companies, such as International Business Machines Corp. (IBM), DuPont, Ford Motor Co., and General Motors, already have a presence in Europe and feel secure in their research and marketing positions. Other companies that have marketed in the United States and Europe without European domestic content are seeking joint manufacturing and research linkages.[41]

Current research trends for electronic ceramics were discussed at the Third International Conference on Electronic Ceramics held in Maubeuge, France, in June 1992. Market Intelligence Research Corp. expects the total world revenue for electronic ceramics to double between 1991 and 1997, from $8.1 billion to $19.1 billion, with a compound annual

growth rate of 5%. The European market is expected to reach almost $2 billion by 1995, with Germany currently dominating at $531 million, followed by France at about $257 million. The trend for ceramic substrates, currently a $250 million worldwide market, is expanding at a 9% annual rate. Japan leads this market with $140 million and an 11% growth rate, followed by the United States at $70 million and 9% growth, and Europe at $40 million and 10% growth. Even though alumina currently dominates the market share for substrates, aluminum nitride is expected to replace alumina for certain applications and will therefore have growth rates as high as 40% (Japan) to 60% (Europe).[42]

Significant multinational research efforts within the EC are addressed under the framework of the European Research in Advanced Materials (EURAM), which is coordinated with Basic Research in Industrial Technologies for Europe (BRITE) and the European Research Coordination Agency (EUREKA). Major technical areas concerning advanced materials focused on the following selected themes:

- Metallic materials and matrix composites.
- Materials for magnetic, optical, electrical, and superconducting applications.
- High-temperature nonmetallics.
- Polymers and organic matrix composites.
- Materials for specialized applications; e.g., biomaterials, packaging, and civil engineering.

In the realm of metallic alloys, emphasis is placed on aluminum, titanium, magnesium alloys, electrical contact and magnetic materials, coatings, tooling materials, and development of thin-wall castings. For engineering ceramics, property optimization, ceramic composites, and high-temperature are being studied. Within the area of composite materials, metal and organic systems are to be addressed.[43]

Western Europe still represents a "developing country" in the semiconductor business. The per capita consumption of semiconductor products is double in the United States ($64) and sixfold in Japan ($183). In fact, Western Europe is the only one of the three countries producing fewer semiconductors than it consumes. Hence, Europe should have an excellent semiconductor growth market, and the political transformation of Eastern Europe promises additional market potential in the long term.[44]

The European Polymer Federation (EPF), part of the European Science Foundation, redefined its science and engineering goals with increased emphasis on the development of advance polymer materials. The EPF identified a number of topics that will have higher priorities in the overall European Community Programs. The four areas include: optoelectronics, polymers with supramolecular architecture, reactive processing of polymers, and computer-aided polymer research. The European Science Foundation, the equivalent of the U.S. National Science Foundation, is joining with other EC agencies to go beyond R&D toward industrial pilot plants and commercialization. Like the NSF, the ESF is commencing rapid technology transfer to industry as the EC prepares for increasing competitiveness for global markets.[45]

European composite programs push ahead on primary structure applications. In particular, introduction of the Airbus composite wing structure is planned for all future aircraft manufactured by the EC. Weight savings throughout the aircraft could amount to 1,000 kilograms. In addition, a graphite/epoxy monocoque skin for the European Fighter Aircraft has a new fabrication method that can be automated and/or mechanized for production. Finally, thermoplastic composites are being moved into full-scale aircraft production of interior panels, cargo compartment covers, airfoil-shaped ribs, and wing panels.[46]

The advantages of using advanced ceramics in aircraft turbine engines was enunciated in a 1992 study by Rolls Royce Industries of United Kingdom. Based on a maximum allowable temperature of 1200° C, a currently designed airliner with 300 seats and a range of 7,564 kilometers would exhibit the following technical enhancements:

- 10.0% saving in engine weight,
- 2.3% increase in thrust,
- 12.5% increase in thrust/weight ratio, and
- $7.0 million reduction in life-cycle costs to the customer.

This study clearly shows why R&D is continuing on advanced ceramic composites, which hold promise of eventually being "man rated" for use in commercial airliners. The life-cycle reduction costs of $7 million are significant for a new airliner priced between $70 million and $100 million, depending on accessories. This study also relates to R&D on advanced metal matrix composites, which can increase the turbine engine efficiency and offer reduced life-cycle costs over existing turbine engines.[47]

Germany is currently the European leader in producing rare-earth magnets. It has 60% to 65% of the overall market worth approximately $17 million. German auto equipment firms are pioneering the applications trail. Total permanent magnet sales in Europe were estimated at $470 million in 1992.[48]

The Joint European Submicron Silicon (JESSI), created in 1989 to help European microelectronics on its way, highlighted certain flagship research projects for 1992. These projects concentrate on:

- High-definition television
- Broadband telecommunications
- Safety electronics for automobiles
- Digital audio broadcasting
- Cellular mobile phones

These projects are part of an overall strategy to strengthen and improve the focus of the EC on microelectronics by sponsoring R&D that will lead to EC competitiveness in their own marketplace against Japanese and U.S. companies.[49]

The Third European Conference on Diamond, Diamond-like, and Related Coatings was held in Heidelberg on August 31 through September 5, 1992. Highlights from this conference featured visually transparent polycrystalline films that can approach the thermal conductivity of natural single crystal diamonds at room temperature or higher.

Numerous papers addressed the issue of thermal conductivity as a function of crystalline size. These diamond films can be used as interfaces for diamond-coated tools. In addition, highly oriented diamond films were reported to be grown on silicon substrates. These films appear destined for protective coatings for infrared detector windows, radomes, and similar applications.[50]

The use of "engineering plastics (EP's)" continues to grow in European automotive applications. Out of the approximately 1.2 million metric tons of all types of plastics used in automobiles, 40% was "engineering plastics." The growth of EP's is projected at a modest 16% over the next 5 years, mainly in high-temperature applications such as oil pump gears, water pump bodies, impellers, and CAM-phase adapters. The specter of European automotive companies buying back their old vehicles to recycle them might require that all plastic materials be of one family of polymers. "Design to recycle" is being considered even as major European car manufacturers propose pilots plants to study vehicle disassembly. An example is the "Pravda" recycling project involving all major car manufacturers. A similar project called "Accord" is ongoing in the United Kingdom. Preliminary conclusions indicate that for today's vehicles roughly one-quarter of the "plastic" components can be recycled into primary or secondary car applications. Investigations to improve the percentage of plastics recycled and decrease the costs to recycle will eventually result in automobiles "designed for recyclability."[51]

The EC is making an effort to unify and harmonize member differences by focusing on the developing sciences and technologies related to the commercial sector, especially aerospace and manufacturing competitiveness. Small- to medium-size enterprises are receiving emphasis in design, manufacture, and quality assurance.[52]

Pacific Rim Highlights.—The Japanese Science and Technology Agency (STA) released its report on the research activities of Japan's private-sector manufacturing firms. The STA surveyed 1,301 firms, eliciting a 64% response. Some important facts concerned the ratios of R&D funding to sales for various sectors, for example, medical sector, 11.0%; communications sector, 8.6%; machine tool, 6.6%; and an overall average of 3.6%. The survey indicated that most Japanese manufacturers expect global competition to increase and suggested ways to decrease the tension. One group, 36%, suggested cooperative R&D internationally, while 28% offered technology transfer, and 12% recommended overseas research facilities. In the latter situation, the Japanese responders expected that technology will be both exported and imported. The survey contains many tables and charts and offers a terse view of Japanese industrial thinking as of 1992 on R&D aimed at the global marketplace.[53]

Japan's R&D efforts in metal matrix composites continue to grow. Japan has continued to pursue this technology not only with increased R&D but with projects to develop applications in several areas. The collective focus is on economically viable materials in the commercialization of metal matrix composites. The Japanese interests range from applications relevant to a company's overall activities, such as copper-matrix composites for electronic substrates at Toshiba to interests driven by larger government programs, such as research on Nicalon™ fiber-reinforced aluminum for high-temperature strength. Understandably, high emphasis is placed on processing with a slight surge in R&D toward "the wetting of reinforcement phases by molten metals." This large coordinated program has been ongoing for at least 10 years and continues today at an aggressive pace based, in part, on successful products entering the marketplace.[54]

Pacific Rim buildup of engineering resin plant capacity will dramatically increase global production of polycarbonate, acetal, polybutylene terephthalate, and acrylonitrile-butadiene-styrene by 1995. Some say this buildup could create an era of massive worldwide oversupply. The expansion estimates a 30% rise in global polycarbonate production, a 20% increase in acetal capacity, and an additional 12 to 17 thousand metric tons per year of polybutyleneterephthalate. Polycarbonate is the biggest buildup with 254-thousand-metric-tons-per-year capacity scheduled to be completed in Taiwan (two new plants), Japan (two startups and two expansions), and the Republic of Korea (three grassroots polymerization facilities) by 1995. The other major expansion is 60 thousand metric tons per year of acetal also in Taiwan, Japan, and the Republic of Korea. One-half of these plants are new ventures, and it appears that tough competition lies ahead.[55]

An assessment of C-C composite research in the Pacific Rim countries revealed both an ever growing production capacity for carbon fibers, coupled with increased R&D funding for C-C composites. For example, Toho Rayon Co., Ltd., the largest producer of fibers in Japan having a total capacity of 10,000 metric tons per year, is producing 4,000 metric tons per month for acrylic and rayon fibers and 170 metric tons per month for carbon fibers. Toho weaves about 5,000 square meters per month and prepregs 200,000 square meters per month of undirectional, roving, and fabric materials. All portions of the fabrication are performed in this plant, from manufacturing of the fibers and precursors for densification, to weaving of the preforms, to impregnation and final heat treatment. Overall Japanese funding for "improved process control" of C-C composites was slightly increased in 1992. As the Japanese technical efforts continue to make progress and products, the lack of U.S. research information may eventually limit U.S. companies in their ability to develop improved C-C composites. Japanese companies appear to be on a technical learning curve for bringing advanced C-C composites into commercial competition.[56]

The Society for the Advancement of Materials & Process Engineering's (SAMPE) second exposition was held in Japan in December 1991, spotlighting new markets:[57]

- Construction—carbon-fiber rebar was displayed, but Japan's construction industry has not yielded the hoped-for market for advanced composites.
- Cars—Honda showed off its metal-matrix components and is using carbon-reinforced aluminum for engine cylinder liners in its Preludes.
- Trains—Japan Railways displayed a model of its MLU002 test vehicle, which included glass- and carbon-fiber composites to make a maglev train. The MLU002 was destroyed by a fire on October 3, 1991, and taught a bitter lesson in material selection.
- Bicycles—Ashi Engineering displayed a paper bicycle employing main tubes of epoxy matrix with washi, traditional Japanese construction paper.

The strong Japanese effort to enter the commercial aviation market as a builder of airframes may be reflected in the joint U.S.-Japan F-16 fighter plane being built in Japan. The latest advances in carbon fiber-polymeric matrix composites are Japanese developed and are being transferred to the fighter plane in exchange for Japan learning the complex technology of building airframes incorporating advanced materials. Japan reportedly spent an estimated $2.0 billion on the composite technology and the tooling necessary to incorporate its latest advanced composites in the F-16 airframe. This military learning curve should allow the Japanese an easier technology learning curve for building their own commercial aircraft in the not-to-distant future.[58]

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 number of trade magazines devoted to the technology development of advanced materials. More universities and colleges offering associate degrees list courses pertaining to advanced materials—both processing and manufacturing aspects. As a further example, trade magazine announcements show that more types of advance polymeric materials and composites are being studied in corporate laboratories and pilot plants of large chemical companies.[59] 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.[60] 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 offer new uses for composite materials, especially fiber-reinforced thermoplastic polymers, without sacrificing existing safety standards.

A California law requiring 40,000 "zero pollution" passenger vehicles registered in the State by the year 1998 translates into urban/suburban electric vehicles. A European consortium won the initial contract to manage the earlier phases of this electric vehicle project.[61] These vehicles are to be built in California utilizing advanced polymer composites, along with other advanced composites, and many people believe it will mark 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.[62]

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 engineered into advanced ceramic composites. These materials require more expensive, controlled particle size and very low level impurity 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 its 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, controlled thermal and/or electrical conductivity, and resistance to high-temperature corrosion and/or erosion. Therefore, depending on the specific application, these materials can be engineered to exhibit optimum mechanical, electrical, electronic, magnetic, and optical properties.

The number of chemical compositions and processing variables necessary for high-performance advanced ceramics is 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, often are 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 found 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 (S_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 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 high cost 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° 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, thin sheetlike paper, 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. The latter armor applications also benefit because of boron carbide's low density. In addition, boron carbide's high neutron cross section allows its use 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° C. Silicon nitride is being evaluated for components in gas turbine engines, heat engines, and high-temperature bearings; in cutting tools; in industrial wear parts; and in 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. Although 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 how 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 when taken to or past 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 metallic-like toughness in ceramics is obtainable by applying the principles of engineered materials. Both lower cost feedstocks and processing R&D efforts are under way 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 1992 were Corning Inc., Corning, NY, $1,115 million; Cooper Industries, Houston, TX, $557 million as Champion Spark Plug CO; AC Spark Plug Div. of General Motors Corp., $324 million, mostly spark plugs; Allied Signal, Morristown, NJ, $220 million, as Autolite Spark Plug Div.; and Coors Ceramics Co., Golden, CO, $186 million. *(See table 7.)*

The largest worldwide producers of advanced ceramics in 1992 were Kyocera Corp., Kyoto, Japan, $2,787 million; Murata Mfg. Co. Ltd., Kyoto, Japan, $2,109 million; Compagnie de Saint-Gobain, Paris, France, $1,392 million; Phillips Electronics N V, Netherlands, $1,145 million; and Corning, Inc., Corning, NY, $1,115 million. *(See table 7.)*

The top 10 worldwide advanced ceramics producers with 1992 sales of more than $300 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. Table 7 shows that only 3 out of the 10 world's largest producers of advanced ceramics for 1992 are U.S. based.

The Corp Tech ceramic producer/company data profiles, as depicted in figure 3, are useful in identifying how mature a particular industry is.[63] For the U.S. advanced ceramics companies, the number of companies, in the sales ranges of high, medium, and low, resemble a bell-shaped curve. As shown in figure 3, these companies represent a skewed bell-shaped curve. The shape of any bell curve (Gaussian distribution in mathematics) allows comments to be drawn about the distribution. In figure 3, a bell-shaped curve skewed toward the high-range sales volume is indicative of a mature, more fully developed industry where the long-standing companies have invested in R&D and are reaping market share with their advanced materials products. *(See figure 3.)*

Technology.—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.[64]

Solid Freeform Fabrication for Rapid Prototyping.—Advanced materials usually enter the marketplace as "niche market" products, and one advanced material may be the basis of 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 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 (see detailed explanation following). 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 without using molds or forms, hence the terminology "solid free form fabrication" (SFF). The use of sinterable powders would thereby allow many more prototype applications. The new technique builds solid prototypes by selective laser sintering of powders in a process similar to using liquid feedstock in stereo lithography. Starting at the bottom or base line, a thin layer of powder is automatically machine spread over the constant area of the fabrication container. The rastering (moving) computer-controlled laser beam rapidly sinters any powder in the path of its beam. The path the laser beams follow in this two-dimensional array is determined by the CAD/CAM input. Once the first sintered baseline prototype shape is a finished thin film solid, the next layer of powder is automatically machine spread over the same constant area of the fabrication container. Then, by repetitive actions, through laser rastering coupled to selected laser sintering and thin layer powder spreading, the SFF part is finished. Any three-dimensional shape (with holes, cutbacks, channels, etc.) can be prototyped with a high degree of accuracy and repeatability. For example, using wax as a powder feedstock and selectively sintering the wax powder into a solid shape results in lost-wax pattern(s) for investment castings, tools, molds, and short production runs of prototype parts. Initially, wax, polycarbonate, and polyvinyl carbonate powder feedstocks were successfully utilized. Today, nylon and other polymeric powders along with metal and ceramic powders are being investigated as candidate feedstocks to increase the family of powders amenable to selected laser sintering. Preliminary results indicate that solid free form fabrication of parts can be produced 60% cheaper and 80% faster than machined prototype parts.

Continued R&D into rapid prototyping using advanced materials as feedstocks 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), incorporating advanced materials and designed to produce high-quality components, are fabricated 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. Additionally, when firing the machined part to remove the polymeric binders, early stage (low-temperature) component sintering must occur, otherwise the machined shape will sag under the force of gravity or worst case, just fall apart to powder. This machinable billet stock 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.

The precedent for producing and commercially selling machinable billets resides in the metals industry for metals as common as steel billets and as high technology as cutting tool billets. Large-volume, high-tech materials companies are developing ceramic billets for their own internal use. In some material categories, these billets have become commercially available owing to market shifts and large company business refocusing. The commercial selling of ceramic billet stock 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 at industry, national laboratories, and universities in the area of machinable billet stock ceramics, and that fact will eventually allow more small 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 considerably lowers 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. Initial program goals, augmented by ongoing tests and evaluations of monolithic (nonreinforced) silicon nitride, call for a 3,000-hour turbine lifetime. This lifetime can be compared to the 2,000-hour lifetime of today's metal internal combustion engines. At the end of 1992, monolithic silicon nitride turbine components approached 1,000 hours in lifetime tests. The lifetime limiting factors are all related to intrinsic brittle fracture of silicon nitride. Once processing-induced flaws are minimized by extreme care in fabricating and final machining of the components, intrinsic mechanisms, such as high-temperature diffusional or grain boundary creep, cause almost all in-service failures. Silicon nitride, like most monolithic ceramics, has low resistance to fracture and must use reinforcements to improve its toughness and creep resistance to acceptable performance levels (lifetimes). 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 and is entering in-service lifetime testing. 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.

Composite materials cost more because the number of processing steps is larger and more complex compared to monolithic materials. For example, advanced ceramic composites require processing under high pressure at elevated temperature to sinter the matrix phase together. The "inert" reinforcements (between 20% to 30% volume 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.

These most promising technical results for silicon nitride composites have led 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, according to 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 that if compositelike 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 and other technologies requiring higher temperature performance, such as heat exchangers, etc.

Annual Review

Industrial Production.—The companies involved in the worldwide ceramics industry range from ceramics-only producers to ceramic divisions within large multinational corporations. Part of table 4 and all of tables 6, 7, and 8 contain information available for calendar year 1992. The data were obtained from a Ceramic Industry magazine survey and from Kline & Co., Inc.

The U.S. sales data for individual 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, 1991, and 1992 are shown as part of table 4. In table 4, U.S. and World Production for Advanced Materials, the 1990 and 1991 data are from Ceramic Industry magazine survey forms, while the 1992 data are estimated data supplied under contract to Kline & Co., Inc. The 1992 data of U.S. revenue for total advanced ceramics are at this time single point data, and no comments on changes can be inferred. However, the 3% decrease in worldwide advanced ceramic revenues for 1992 versus 1991 can be compared with a 12% sales increase in worldwide revenues for 1991 versus 1990. For both the United States and the world, the 2 years of data most probably reflect the worldwide recession, which is still continuing into 1993.

Tables 6, 7, and 8 show the changes in emphasis instituted by Ceramic Industry magazine and Kline & Co., Inc. due to the emergence of multinational corporations. Table 6 lists the world's top 10 advanced ceramics producers by revenue sales as reported from their survey forms. Table 7 shows estimated 1992 U.S. sales and quantities sold (metric tons) for three advanced ceramic technologies: electronic ceramics, ceramic coatings, and engineering ceramics. Table 8 contains survey data for 1992 worldwide sales for six advanced ceramic technologies: low-voltage porcelain, capacitors/packaging, engineering ceramics, other electronics, optical fiber, and "other."

Figure 3 is in the Corp Tech data format and lists U.S. ceramic producers by total annual sales in 1992. The total number of U.S. companies is plotted against sales volume where the sales volumes are broken into histogram subset of arbitrary sales amounts. The interpretation of figure 3 is that the ceramic industry total is a mature

industry with quite a large number of large revenue-producing companies. Unfortunately, Corp Tech data do not allow the generation of similar results for advanced ceramics companies. The reason is basically that Corp Tech data come from annual company reports, and most large corporations do not break down sales revenue in subcategories. Also, large corporations do not want competitors to know how much revenue was gained from its advanced ceramics segment.

Figures 4 and 5 are histogram plots of the data in tables 4 and 5 for better analysis. Figure 4 is the estimated U.S. market for advanced ceramics by end use for 1992. Figure 5 is the estimated world market for advanced ceramics by end use for 1992. The category of electrical/electronic ceramics dominates the revenue produced and is still the fastest growing technical sector.

***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 resulted in a slight decrease in industrial R&D funds. However, the Federal Government's Advanced Materials and Processing Program (AMPP) for 1992 reported an increase in funding related to defense programs while the overall AMPP decreased slightly.

The 1992 funding for ceramics is $152.1 million plus an unknown percentage of $184.7 million for composites funding. In addition, the DOC ATP for R&D on precompetitive engineering, design, and manufacturing was funded at $80 million this year, with more than $100 million requested for 1993. 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, part of the current research is aimed at 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 solution 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 advanced material composites depends on the fibers' 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 high-quality products 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).—Advanced materials, especially those containing second-phase reinforcements, must rely on cost effective NDE in a more interactive manner than any products made in the past. The reproducibility of advanced materials at the time of manufacture and the lifetime reliability under actual service require more accurate and sophisticated NDE techniques. In recent years, computer-aided NDE gives both quality control and quality assurance to newly manufactured composite(s). Information is obtained on matrix defects, fiber breakage during fabrication, poor fiber-matrix adherence, and existence of voids and inclusions. All these process-induced defects are potential causes for premature in-service failure. At the present time, NDE techniques are external examinations of a component for as-processed flaws, but in the near future,

NDE techniques will act as both external evaluators and proactive internal sensors. The latter, proactive internally positioned sensors, allow real-time detection of time- and stress-related events such as material fatigue and creep. Defect sensitive NDE capabilities have increased to the point where internal sensors in a component output information on the time-stress status of the component. This need to monitor component performance under in-service use has come together with the use of computer-aided NDE and the implanting of internal sensors as a permanent part of complex composite materials. The marriage of these two interrelated NDE technical developments has been demonstrated in laboratory R&D.[65]

Adding to the extrinsic aforementioned processing flaws are failure modes caused by advanced composites undergoing stress-related formation of microcracks during service. 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 these materials. Also, the lack of experience in longtime use of advanced 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 structural composites. Also, 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.

Reproducibility can be increased by using computer-aided NDE for process interactive control. The detection of unacceptable defects early in the manufacturing process cycle would increase production yields and provide technical feedback for optimizing and correcting certain stages in the process flow sheet. Current R&D areas for the NDE characterization of composite properties include NDE of advanced materials, correlation of NDE signatures and material properties, in situ NDE for investigating fracture mechanisms and damage assessment, in situ NDE for process and quality control during manufacture, and in situ NDE for lifetime assessment based on intrinsic and extrinsic changes in the component because of its service history.

Today, inspection of each component before incorporation into a finished assembly requires a multiplicity of NDE techniques. For example, 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 NDE techniques are being developed both for external examination and for the actual intelligent processing of materials during manufacture. The characterization of aluminum alloy matrix components reinforced with silicon carbide particulates at various stages in the process flow sheet by NDE is an example of such techniques. This family of metal matrix composites is slowly entering the automotive engine marketplace as reciprocating (rotating) components. Various NDE techniques are used during the entire processing stages, and R&D is well along on incorporating sensors to intelligently control the manufacturing steps. The various sensors in use today in the electronics industry and the evolution of intelligent processing will be a special topic in the 1993 chapter. As an example, two of many concepts presently under development use pressure and acoustic sensors. The first method incorporates pressure sensitive detectors (piezoelectric or light emitters) coupled with wires or optical fibers to transmit data to computer-aided NDE. The second method involves sound detectors to receive acoustic emissions from critical stress-bearing regions in the component for transmittal to an analyzing NDE computer (sound is emitted when microcracks grow).

For advanced ceramic materials, such as the ceramic rotors under development for automotive turbo chargers or the ceramic turbine engine, research is continuing on using X-rays from compact synchrotrons or other X-ray sources 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) and be most helpful during the prototyping of ceramic structural components or during the initial setup and on-lining of a new ceramic processing facility.

NDE techniques being developed today offer the necessary process control both externally and internally (intelligent processing) for the advanced composites of tomorrow to be cost effective, to offer high performance, and to change positively the materials sustainability sought for the near future.

Outlook

The recession in the industrial countries of the Northern Hemisphere makes the economic data reported for 1992 similar in total value to revenue data for 1990 and 1991. The 1992 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 1992 in advanced ceramics decreased over the previous year, and if 1990 through 1992 are viewed collectively, total revenues appear to be level or are slightly decreasing. But both data sources projected an increase of 6% to 8% for the next 2 years, and most marketing analysis groups think this recession will cease in the near future.

Ceramics and composites R&D

funding, two separate classifications under the Government AMPP, increased in 1992. Larger increases in AMPP funds are projected for 1993 with a modest decrease scheduled for 1994. The 1994 budget request reflects the beginning of the Clinton administration's planned cutback in Federal expenditures of about 5% in each of the next 4 to 6 years. 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 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 R&D talents with 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

Composites combine the desired characteristics of two or more materials to create a new material with a combination of properties not available by traditional methods of manufacture. Initially, polymers resins called epoxies were combined with low-cost, low-strength, continuous glass fibers. The processing techniques for glass fiber manufacture yielded thin diameter yarn such that the glass fiber was commercially available on spools similar to synthetic fibers, such as rayon and nylon. The continuous fibers were woven into a cloth before incorporation into the resin epoxy. The combining of matrix feedstock materials (polymer, metal, ceramic, or carbon based) and second-phase reinforcements, such as woven fibers, evolved into the ever growing array of composites known today.

Definitions, Grades, and Specifications.—From a consumer-use viewpoint, polymer materials can be divided into two classes: polymer commodity materials and polymer composites. Polymer commodity materials are characterized as high-volume, low-cost materials with the only feedstock material being low-cost matrix-forming resin(s). On the other hand, polymer composites are low-volume, higher- to high-cost composites that usually require specialized processing techniques and utilize more expensive matrix resins in addition to reinforcements. Initial polymer matrix composites were first used as substitute materials in nonload-bearing applications. From these early beginnings, polymer composites evolved into two basic types: polymer composites that directly substitute for existing materials in the commercial marketplace and advanced polymer composites (APC's) designed for structural loads and greatly improved technical performance. Typical reinforcements include long or continuous fibers in various morphological forms (tape, woven sheets, three-dimensional shapes), chopped or short fibers, whiskers (strong single crystals shaped like sewing needles), and second-phase particles (second phase means chemically not reactive with the matrix under designed operating conditions). Therefore, an individual polymer composite, utilizing a low-cost commodity resin, may contain all known types of reinforcements. However, a polymer composite that utilizes either commodity resins or newer high technology resins plus continuous fibers as the primary source of reinforcement is defined as an APC. The incorporation of continuous fibers as all or part of the reinforcement, usually to improve significantly mechanical properties, requires more costly and time consuming processing to achieve the designed properties. These continuous fibers used in APC's are typically high-strength glass (S-glass), carbon fibers, boron, ceramic, aramid, or other organic fibers. Additionally, polymer composites that contain short fibers incorporated into matrices of advanced polymer resins; e.g., a thermoplastic resin with high-temperature capabilities, would be considered APC's based on their matrices.

Polymers matrices are classified as two basic types depending of the chemistry of the polymer resin(s): thermoset and thermoplastic. Thermoset matrices 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 thermoset matrices are epoxies, phenolics, vinyl esters, polyesters, and urethanes. On the other hand, thermoplastic matrices are polymers, with less cross-linking, that can be remelted and reformed. They tend to be less brittle (tougher), more flexible, and exhibit bidirectional mechanical properties. Thermoplastics are stronger in the direction parallel to the strongly linked polymeric chains than in the direction perpendicular to these linked chains. Consequently, if many chains are aligned, the resultant thermoplastic polymer matrices are much stronger in one direction than the others. In addition, these APC's besides incorporating long or continuous fibers as the primary reinforcement, also may contain secondary reinforcements in the form of short fibers, whiskers, or particles.

APC's exhibit excellent strength-to-density ratios, high stiffness, high fracture toughness, etc., and are usually fabricated utilizing specialized processing technique(s). Normally, the resulting

properties tend to approach theoretical maximums attainable from the particular combination of materials used as feedstocks to form the composite. Organic resins used as polymer matrices may consist of epoxies, polyimides, polyacrylates, polyesters, or a number of other high-temperature polymer resins. The continuous fibers may be selected from families of high-strength glasses, carbon/graphites, or various ceramics, such as aluminum oxides and silicon carbides, 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 polymer resins, polymer resin fillers (chemically inert ceramic powders used to displace the expensive polymer resins), and copolymer alloys may be used together as matrix feedstocks.

The polymer matrix resins most often used for APC's are the thermoset epoxies and the engineering and high-performance thermoplastic resins. 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.[66] Specifications for the composites themselves (matrix plus reinforcement) are not written as are commodity materials; instead, the specifications are written for each individual application.

The fact that the great majority of APC's manufactured today are composed of epoxy reinforced with carbon fiber or high-strength glass fiber is mainly the result 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. Second, epoxy composites are relatively easy to fabricate because the resin-catalyst mixture has a low viscosity and is suitable for a variety of "prepreging" discussed below, and forming operations. Moreover, epoxy resins wet reinforcing fibers very effectively, producing a strong bond between them. Epoxy matrices 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. Epoxy matrices 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.— The Society of Plastics Industries' Composites Institute, compiles an annual list of U.S. polymer composites shipments (in thousands of metric tons) for nine market categories. The Composites Institute shipment data do not distinguish between polymer composites and APC's although both data are included in figure 6 and its tabular form, table 9. Therefore, the Kline & Co. data for U.S. advanced polymer composites, which is about 90% of the data contained in this section, are included in the SPI data under market categories such as marine, transportation, corrosion-resistant equipment, aircraft/aerospace/military, etc.

The weight percentage of APC's contained in the U.S. polymer composites shipments, figure 6, can be determined by summing the estimated U.S. market for APC's by end use, figure 8. The estimated 7,500 metric tons of APC's yields less than 1% of the 1.2 million metric tons of polymer composites shipped. No dollar value data were available from the Composites Institute on polymer composites, while the APC's in figure 8 calculate to an average of $295 per kilogram.

An example of one dominant use of polymer composites is in the area of corrosion-resistant equipment, where the average composite value is closer to $29 per kilogram. Corrosion-resistant equipment represents 13% of total polymer composites shipments. In this market sector, polymer composites are used in 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. Polymer composites' high strength, low density, and relative ease of assembly, as well as resistance to corrosion, has resulted in the replacement of other materials.

On the other hand, APC's, because of their high cost, are used most notably in defense, aerospace, and in 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 such 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.[67] Boeing Co. has teamed with Sikorsky Aircraft to make the new LH helicopters, both having airframes and skins largely constructed of epoxy-carbon composites.

For commercial aircraft, the major airframe manufacturers are planning to increase use of APC's 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.[68]

In sporting goods, the desire for better performance regardless of cost has created a market for fiberglass and carbon reinforced APC's in tennis rackets, golf club shafts, skis, sleds, 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

final parts producers. These manufacturers then form the composite to the desired shape and cure the resin to complete fabrication of the product. Thus a composite manufacturer has the option of purchasing polymer and fiber or buying 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 recent introduction of APC's to the industrial segment devoted exclusively to manufacturing industrial tool forms is growing rapidly and now accounts for 5% of the total U.S. advanced composites shipments.[69] Technically, tooling forms provide the contour configuration that an in-fabrication part assumes as it is finally cured. Metals such as aluminum and steel and electroformed nickel are commonly used as tooling materials. But APC tooling has advantages over metal. There is a better match of coefficient of thermal expansion between the composite being made and the tool form. APC 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 for APC's are developing. For example, robot arms made using APC's 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 APC sector is such that the APC materials area is dominated heavily by a few large companies. Meanwhile, there are many smaller companies involved in the actual fabrication of commercial parts using APC's. In 1992, more than 90% of the world production of APC's were produced by the members of Suppliers of Advanced Composite Materials Association (SACMA), a trade association with less than 30 member companies—about a dozen in the United States, about 10 in Europe, and a few in Japan. Figure 7, in the Corp Tech data format, shows the 27 member companies of SACMA plotted as total number of companies versus APC sales volume for sales volumes ranging from less than $1 million to greater than $500 million annual revenue. As shown in figure 7, it is the many companies that are intermediate to small in sales volume that actually fabricate most of the APC parts. On the other hand, the membership of the Composites Institute, the largest organization inside the Society of Plastics Industries, is about 450 members. Because most companies in SACMA also belong to SPI, the remaining companies in SPI are involved in fabricating and producing polymer composites, not the main thrust area of this discussion.

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.[70]

The most widely used techniques for the fabrication of APC's 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 APC's produced. On the other hand, the closed mold methods include reaction injection molding, high-pressure laminating, and match die (low-pressure) molding. These closed mold methods are used to manufacture the remaining 35% of domestic APC production.

Two high-volume techniques, 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 methods or slightly more than 40% of the total APC production. The remaining open mold methods, filament winding, pultrusion, and centrifugal casting, comprise the remaining 38% of the open mold production and 25% of the total.

The most common closed mold method is reaction injection molding, accounting for 58% of the closed mold production or 20% of the total APC's production. 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 total APC production.[71]

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 the polymeric material 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 (newer method). This capability allows the use of PET in the hot-filled food packaging market. Both the old and new methods produce a material that is chemically the same, PET. But changes in processing alter the internal structure of the material, resulting in greatly enhanced properties.

Mold design or tool form is an 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. It is important to consider all of the following: 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 an APC.

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, computer-aided design methods—CAD, CAM, and Finite Element Analysis (FEA)—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. Engineering polymer composites are being used in applications from microwave food packaging to sporting goods and satellites. APC's special properties have been exploited by design engineers in structural applications. Polymers seem to possess 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 at a higher performance level.

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 also are 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 with metals.

The automotive industry is becoming 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 the sheet molding compound (SMC) method. A recent example was the Pontiac Fiero all-composite exterior. Composites have also found applications in automobile structural parts, in addition to drive shafts and leaf springs. The prime substitution appears to be in inner and outer body panels. Today, the roof and liftgate of the 1992 General Motors Saturn are made from SMC. Later models of the Camaro and Firebird also have composite body panels.[72]

The latest American high-performance sports car, the Dodge Viper, has glass-reinforced acrylic body panels. It is Chrysler's first composite-intensive vehicle.[73] APC's also have 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.[74] The number of composite industry executives who feel that recyclability is very important has risen steadily from 25% in 1988 to 55% in 1992.[75]

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 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.[76]

The first large recycling attempts are being studied and undertaken in the European automobile industry, especially in the Republic of Germany with its proposed "German Refuse Act for Car Recycling." Although the polymers used in automobile components did not usually contain continuous fibers, some of these parts can be considered complex composites. For example, outer body panels can be made of two different polymer resins, one for the smooth outer panel for spray painting and the second resin to contain the filler and a variety of chopped and continuous fibers. The fibers can be, for instance, aramid fibers (Kevlar) for impact or shear strength, glass fibers (E thru S series) for compression strength, and carbon fibers (PAN and Pitch types) for tensile strength. Some fiber preforms or prepregs are actually mixtures of chopped fibers and continuous fibers, all added to satisfy economically technical performance criteria indicated by CAD/CAM and finite element analyses.

The proceedings of an international conference on polymer composites contained a first-ever session entirely devoted to recycling automobile polymer components (48th Annual Conference, Composites Institute, Society of the Plastics Industry, Inc., Feb. 8-11, 1993). A summation of two or three papers indicated that recycling of the components

is possible by first grinding up the scrapped component to yield one or two end products. The more common end product and the least in cost is fiber-rich recyclate made up of fine particle residue containing groundup resin, ceramic filler, and chopped-up fiber(s).[77] These fiber-rich recyclate powders are then added as part of the total "filler volume" to fabricate a new component.

After complete reprocessing, physical property tests indicate that the mechanical properties begin to degrade rapidly when the recyclate powders are between 10 and 20 volume percent of the total filler amount (based on original feedstock formulations).[78] The degradation problem appears to be related to the stiffer fluidity (viscosity) of the resin-with-filler-plus-recyclate residue when compared to the original resin-filler system. Increasing the processing temperature does not allow the recycled system a mechanical property parity with the original feedstock system except at recyclate residue loadings between 10 to 20 volume percent original filler. Lesser volumes of filler are not profitable. A German consortium, called ERCOM, has been tasked with recycling polymer automobile components for reuse into new parts—no down-cycling to secondary markets, such as garden posts, park benches, etc. The output of ERCOM are two end products in each of three different sizes available for experimentation to all countries. The fiber-rich recyclate powders mentioned above are the main ERCOM output. However, through further and more costly processing, small factions of groundup resin and filler, sans fibers, also are available for reprocessing studies.[79] Using this secondary ERCOM sans fiber recyclate to reprocess new components results in an excess of resin and related outflow problems when fabricated under the same processing conditions as the original components. Investigations to optimize these processes are continuing today.

A report from Japan indicates that since 1991, Japanese "Recycling Law" has called for the complete dismantling and shredding of all reinforced polymers, including the hulls of ships, large storage tanks, bathtubs, and other constructed structures. The shredded parts are then put into landfill sites. But Japan, like Europe and the United States, is also looking at reusing groundup polymer recyclate powders to fabricate like-value new products. In June 1992, Nissan and Fuji Heavy Industries announced a joint recovery program for "bumpers" that are damaged or removed from Nissan cars. The joint venture agreed to pick up the spent "bumpers" throughout the Japanese islands, where they will eventually be reprocessed to fabricate new bumpers.[80]

APC's were the central focus of a U.S. paper by Owens-Corning personnel on recycling continuous fibers. The report covered recent efforts in the recycling of reinforced composites, in general, but with special emphasis on the role of glass fibers. Among the approaches discussed are direct remolding of thermoplastic composites, grinding of thermoset composites for use as a reinforcing filler, recovery of "clean" fiber and its reuse as reinforcement in new products, and remelting of recycled glass fibers as raw feedstock for the manufacture of new fibers.[81] Its R&D indicates that the chemical and/or thermal processes necessary to recover both thermoset and thermoplastic resins can damage the surface of the glass fiber in such a manner that the recovered fibers can only be remelted in order to be recycled into a new product of acceptable value.

Another R&D effort on polymer composites, aimed at "design for recycling," is under way in an international effort. Groundup sheet molding compound (containing fiberglass reinforcements) from Fiat body parts has been added to polypropylene along with a Union Carbide reinforcement derived from organosilicon precursor chemicals. The properties of the resulting "recycled" 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 other applications of similar economic value.[82]

For APC's, the main recycling problem is how to separate the fibers from the resin and filler and reuse all of them economically. Recycling APC's containing carbon fibers preforms may become economically feasible because of the high cost of carbon fibers (currently between $500 and $1,000 per kilogram depending upon higher strength modulus). The matrix materials currently used are predominantly thermoset epoxy resins. Therefore, much of the research conducted has been for the recycling of this type of composite matrix.[83] In the uncured or unset 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 or thermosetting, however, epoxies are insoluble.[84] Fortunately, most scrap consists of prepreg sections so this technique can be readily utilized. Cured epoxies also can be decomposed thermally below 400° C in air or at higher temperatures under an inert gas (to protect the carbon fiber from oxidation). The fibers may be recovered; however, the fiber surface 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 recycling should be easier for the newer thermoplastic matrix APC's. A composite with a thermoplastic matrix can be softened or melted and recycled simply by reprocessing. While the matrix is fluid a new component can be fabricated with physical properties the same as the original or slightly lower. Most complex polymer composites employ a low-cost, inert ceramic powder filler mixed into the expensive resin to decrease the total amount of resin necessary. Typically, 30 to 50 volume percent of an APC is ceramic filler, and the recycling of APC's causes slight property degradation owing to complex interactions among the resin, the filler, and the fiber preform. Because the matrix material melts at high temperatures (rather than decomposing), separation is possible even after curing, and both the fibers and the matrix (with filler) may be recycled.

Economic Factors.—The defense and aerospace industries have remained the principal driving forces behind the growth of APC's. The next area for expansion will be in commercial transport aircraft.

Currently, the United States is the leader in applications of APC 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. For 1992, a positive trade balance of $28.3 billion, or a 0.05% increase, was attributed to the U.S. aerospace industry.[85]

Survival in the aerospace 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 DOD 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 DOD budget cuts will be balanced by increases in commercial applications of advanced composites.[86]

To compete effectively with traditional materials in the aerospace market (metal alloys based on aluminum, steel, and titanium), producers of advanced composites need to market aggressively their new materials. Current material use (by weight) in the Boeing 767 airliner is 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.[87]

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 (RCRA). The proposed 1992 revision or modification of the Clean Air Act is likely to require regulation of the polymer industry in general, including the production of composites. In 1992, Congress momentarily shelved the reauthorization of the RCRA. The Superfund Act has taken priority over RCRA due to budget constraints and the change to the Clinton administration. The RCRA legislation, as written currently, will impact heavily on solid waste regulations. This act ultimately will dictate national recycling goals. In light of these possibilities, a standing task force of the Society of the Plastics Industry is reviewing the industry's stand on workable policies regarding resource conservation, pollution abatement, and energy.

In addition, 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[88] but in the past 4 years has followed the GDP, reflecting the current recession. 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 owing 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 result only in oversupply.

Consumption and Uses.—U.S. polymer composite markets, which include the APC shipments at less than 1% of total, can be divided into nine subcategories: aircraft-aerospace-military, construction, consumer products, appliance-business equipment, corrosion-resistant equipment, electrical-electronic, marine, transportation, and other. Table 9 presents the shipments of these materials by market category for the years 1987-92 with estimated 1993 data, released in February 1993. Data for this table were compiled by the Society of the Plastics Industry.[89] Figure 6 is a plot of the data listed in table 9 with the following difference: the consumer, business, and other market categories are shown as one "block" for clarity of interpretation.

The U.S. aircraft-aerospace-military shipments showed no growth from 1988 to 1991 with a decrease recorded for the past 2 years. After peaking in 1989, the 1990 and 1991 shipments dropped approximately 5% compared with those in 1989. The 1992 shipments dropped further, to approximately 22% of 1989 shipments. The 1993 forecast equals the 1992 level. The appliance-business equipment market shipped 12% less in 1991 than the high level period of 1990. But in 1992, total appliance-business

shipments increased 5% over those in 1991 and the forecast 1993 projecting levels are comparable to those of 1990. Clearly, the appliance-business equipment shipments are increasing in spite of the continuing recession.

The U.S. construction industry also appears to have recovered from the recession. In 1991, construction shipments dropped 10% from the 1990 level. Construction shipments in 1992 rebounded 13%, while 1993 estimated shipments call for an increase of 8% over those of 1992. At some time between the 1992 shipments and the estimated 1993 shipments, the construction industry is expected to exceed the record shipments of 230,000 metric tons recorded in 1987.

The U.S. consumer products shipments from 1987 to 1992 are exhibiting a pattern similar to the construction industry. With consumer products shipments in 1990 as a baseline, shipments decreased by 10% in 1991 but increased 8% in 1992. Consumer products shipments for 1993 are estimated to increase another 8%, exceeding shipment levels not recorded before.

Taking 1990 and 1991 as a baseline, the U.S. corrosion-resistant shipments recorded a 9% loss. Even the 1993 forecast estimates indicate only a very modest increase over 1992. Polymer composites appear to be holding their share in this market sector. The decline and holding values of 1992, along with estimated 1993, probably are reflecting the general economic recession. This latter statement is more believable 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 saw a small decrease (less than 1%) in 1991 when compared with those of 1990. But 1992 witnessed a 12.4% increase relative to 1991. The 1993 forecast for the electronic-electrical market is estimated at a 4% growth over 1992 shipments. The 1992 and estimated 1993 shipments, together, are most probably reflecting the price wars and computer company shake-outs occurring in the PC industry. With revenue increases of 18% and 22%, respectively, for the past 2 years, and with PC performance increasing rapidly, the large number of PC's sold in the past 2 years (more than 5 million) contribute to the increased electrical-electronic shipments. *(See table 10.)*

The popularity of fiberglass boats over the past decade made the marine market the fastest growing user of polymer composites at that time. The current 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, and coupled with the current recession was the 10% excise tax the U.S. Congress added to luxury items that cost more than $100,000. Marine trade associations relate that many luxury boat building companies went out of business as wealthier people chose not to buy expensive items and pay the 10% excess tax. Therefore, marine shipments for the boating industry continue to decline. For 1990, shipments declined 11% relative to those in 1989. The year 1991 recorded the lowest marine shipments or a 35% decrease relative to 1990, for 1992 recorded a 6% increase over 1991. It seems that the marine market for polymer composite shipments hit a low in 1991 and is slowly increasing (6% increase for 1992 relative to 1991). Also, the U.S. Congress is in the process of repealing the 10% excise tax but it can only do so if it finds other items to tax so that there is no net loss of revenue to the Federal Government. Repeal of this 10% excise tax is predicted to assist the marine boating industry in recovering from its current slump.

The U.S. polymer composite shipments for the transportation market in 1990 stood at 320,000 metric tons. Comparing 1990 shipments to those in 1992, an increase of 6% was recorded. This increase plus the estimated 1993 increase of 6% indicate that the transportation market for polymer composites is not affected by the current recession. Automobile trade magazines seem to be reporting increased uses of polymers in all types of automobile applications from outer body panels, nonstructural shrouds, to structural bearing components. The transportation market shipments are expected to increase gradually as the quest for better fuel economy drives this industry toward continually striving to decrease the weight of the automobile without compromising safety.

The "other products" market uses polymer composites in medical equipment, orthopedic appliances, and dental materials along with many other niche market areas or specialties. From 1990 to 1991, this market decreased 7%, saw increased shipments in 1992 to 5% over those of 1990, and for 1993 estimated "other product" shipments to increase 6% over those of 1992.

The Corp Tech data format (discussed early) is shown in figure 7, where the total numbers of APC producers are plotted against sales volume. The sales volume(s) are broken in incremental ranges to give the figure the look of a histogram. Figure 7 relates that the key producers have large sales volume and that many large companies are in competition with each other. These large companies are necessary because of the significant investment necessary to be a supplier of APC's. Because this type of composite is usually "load bearing" and may be "man rated for service," many different engineering and technological skills are required to bring these composites to the marketplace in a timely and cost effective manner.

A large portion of the data used in this advanced materials document was obtained from Kline & Co. Its data are estimated and contain not only shipment value in metric tons, but more importantly, sales revenues for different market segments of what Kline & Co. call APC's. Kline & Co. defines the APC market segments as: aircraft, missiles and space, recreation, armor, and industrial/other. Because Kline & Co. generates market surveys for inquiring customers, its market studies are focused on contemporary market niches. For example, figure 8 is estimated U.S. market for APC's, by end use, for 1992, giving data for both metric

tons shipped and dollar value. The estimated total weight of APC's in the U.S. market for 1992 was 7,450 metric tons at a value of $2.20 billion. Therefore, the average value of U.S. APC's calculates to $295.40 per kilogram ($134.27 per pound). An interesting observation about figure 8 is that the cost per kilogram of missile and space hardware is 1.6 times greater than the cost per kilogram of aircraft hardware, reflecting the cost of putting the maximum amount of systems into the smallest volume at the lightest-possible-weight payload. The cost to miniaturize these systems is revealed in the cost per kilogram data. Comparison of 1991 estimated data with 1992 estimated data shows little decline in total value or amount shipped. The overall market forces of the current recession apparently have not had an effect on these high-value-per-weight niche markets, especially those directly related to military and space applications. Changes will occur as most industrialized nations of the Northern Hemisphere downsize from both the end of the cold war and the current lingering recession.

World Review.—Figure 9 shows the estimated world market for APC's, by end use, for 1992, giving data in both metric tons shipped and dollar value. The estimated total weight of APC's in the world market for 1992 was 13,670 metric tons (U.S. share at 7,450 metric tons or 54%) and at a world value of $4.335 billion (U.S. share at $2.202 billion or 51%). Therefore, the average value of the world market for APC's calculates to $317.12 per kilogram ($144.14 per pound).

An overview of the world APC's industry for 1992 is given in figure 10. Figure 10 is unique in that it is in the form of a process flowsheet. This figure has both weight of materials in metric tons and the value added after each processing step in dollars. The total weight and dollar value going to the end user are the same total values presented in figure 9, 13,670 metric tons with a value of $4.335 billion or $145 per kilogram ($65 per pound). Note that processing steps include fiber weaving, prepregging, scrap, and fabrication. This schematic flowsheet gives a simplistic look at a very complex process. The challenge with APC's is to make them "user friendly" to the fabricator so that their value per weight will decrease to tens of dollars per kilogram and APC's will become very competitive in the marketplace.

In table 10, 1992 worldwide data for estimated APC shipments, by end use, are presented with emphasis on the "worldwide" segment being broken down into "U.S." and "rest of world." Additionally, projected data are listed for the year 2002 and an analytical guess put forth on the average annual growth rate(s) over this next 20 years for each of these APC market subsegments. The United States share of the world market is estimated at 54% in 1992 and projected at 58% in the year 2002. The fastest growing market sector is the automotive, with a projected growth of 26.7% worldwide and a large growth of 50% for the United States by the year 2002. The use of APC's in automobiles will lead the way to more fuel efficient and less polluting vehicles. In this automotive sector, the performance of these composites to accomplish the aforementioned goals will offset their initial high value per kilogram.

Current Research.—New Materials.— 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.[90] 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, and in increased productivity. Newer thermoplastic resins being developed as matrix materials are polyphenylene sulfide (PPS), thermoplastic polyimides, polyarylates, and polyetherimide (PEI).[91]

Liquid crystal polymers also are 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 and the resultant material becomes "self reinforcing." This self reinforcement produces 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. Although it is expected that they eventually will 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.[92]

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.[93]

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).

Owing to 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.[94] This composite offers the same structural performance and ballistic protection, has better corrosion resistance, and weighs 16% less than aluminum in the same application.[95] 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, is expected to continue to dominate the polymer composite market in the near term. The current recession may continue its no-growth-to-negative impact on 1993 shipments. The largest slump is expected in the aerospace sector, which had been holding firm in spite of poor general economic conditions. The largest gains are expected in the construction and transportation markets, which had slumped badly in 1991, and exhibited a modest gain in 1992. Gains of 6% and 7% are forecasted, respectively. Most sectors are expected to hold steady or achieve small increases for 1993. 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). An increased use of APC's is expected as they are employed to meet the demands for fuel efficiency, which is most readily achieved by weight reduction. With anticipated price reductions, due mostly to improved processing methods, polymer composites and APC's should resume penetration of the aerospace, industrial products, and electrical-type markets. The long-term outlooks for polymer composites and APC's are for 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 1995 and the year 2005, according to a Kline & Co. report.[96]

Starting in 1992, after having increased percentages annually, the DOD 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.[97]

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 constantly are 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 and right after World War II. Even though alloys originated so long ago that we use some of them to name the ages of humankind, there recently have 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. Both new alloy development and new process development on existing alloy systems have been major contributors to the current interest in advanced materials.[98]

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. Although new processing techniques have resulted in performance improvements in these alloys, they currently are 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 advanced ceramics and advanced polymer matrix composites will undoubtedly be significant members of this new family of materials, new metal-based systems also will 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 MMC application. The continued increased 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 "good grade" silicon carbide particulate, used in aluminum MMC's, is about $5 per kilogram today, compared with more than $25 per kilogram 10 years ago. Also helpful are the techniques of simply "inserting" parts made of new material into existing assemblies when the match is close enough in geometry and properties between the old and new part. These techniques give manufacturers valuable experience in the utilization of new materials.

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, B_4C), silicon and aluminum nitrides (Si_3N_4, AlN), and oxides (Al_2O_3, SiO_2), 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 used ordinarily as a continuous fiber reinforcement. Discontinuously reinforced MMC's employ particulates, whiskers, or short fibers as reinforcing components. The suitability of these materials for fabrication by standard metalworking processes has brought considerable attention to this class of MMC's in recent years.

C-C 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 800° F, they must be coated or contain oxidation inhibitors to be used long term in an oxidizing atmosphere. C-C composites have high modulus and low creep, meaning 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.

Industry Structure.—Neither MMC's nor C-C composites have reached a mature industry level. Both are still growing, not only in the number of applications but also in the amount and value of material produced. Figure 11 shows MMC producers for 1992 related to sales volume ranges. A large portion of the companies had annual revenues of less than $25 million for 1992. Figure 12, in the same data format, shows C-C producers for 1992. In the C-C composite data, small numbers of companies exist with total revenues at less than $50 million while five companies showed annual revenues greater than $250 million. These latter companies are large chemical industry corporations that were requested by DOD to increase carbon fiber/filament output so that the U.S. military needs—at least 50% capacity—could be met by U.S. fiber manufacturers. As discussed earlier in this chapter, the United States now has excess carbon fiber and C-C composite making capacity as a result of the end of the cold war. Some of this excess capacity already has been sold to foreign interests, although the physical plants still reside inside the United States. The remaining U.S.-owned companies have asked the new Clinton administration for economic assistance to convert C-C technology to civilian uses through DOD insertion-type programs. This same assistance also has been requested by the smaller entrepreneurial MMC companies. These DOD insertion programs allow higher cost technology to substitute for existing lower cost technology, with the U.S. Government paying the difference.

The concept is that companies will be able to manufacture, in limited quantities, new technological products, and, if ever needed in a new war, these same companies will be able to increase production in a timely manner. Emerging technologies are thereby nurtured by the Federal Government. This DOD concept is being considered for other types of emerging technologies as various legislative proposals are now in congressional review.

***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. These higher purity levels allow further development of the material's intrinsic properties and create "engineered materials" to achieve the highest possible performance goals. New processing methods, such as directional solidification, single crystal growth, hot isostatic pressing, mechanical alloying, and rapid solidification, are being used to fabricate alloys with refined and controlled microstructures, resulting in the achievement of tailormade properties. Knowledge of the resultant physical properties as a function of the microstructure and the processing methods for a designated metal system give today's metallurgists the ability to produce engineered materials.

Unconventional processing techniques have increased the number of alloy systems available to the metallurgist to study, delineate, and ultimately engineer. In some cases these new processes enable the production of "impossible alloys" or metastable alloys. Just as oil and water "do not mix," some metallic elements do not form liquid solutions or solid 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. By a method called Rapid Solidification Processing (RSP), many liquid solutions are rapidly cooled (through millions of degrees temperature change per second) so that the 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 solidification. There exist many different ways in which RSP can be achieved. One method is to pour hot liquid metal alloy into a very fine stream and let it drop onto a rapidly spinning disk. The individual liquid droplets are quickly splat cooled on the spinning disk and thrown off as solid particles. The powders are gathered, beneficiated, and used in the many fabrication processes amenable to metal powders.

All of the aforementioned techniques produce powders or metal feedstock that can be further processed into MMC's. MMC's are composite materials in the sense that second-phase fibers, whiskers, or particulates are added to improve one or more physical properties. For example, aluminum and magnesium alloys have low-to-moderate tensile strength but excellent fracture toughness. For many applications in aerospace and automotive, where high strength and low density is a must, these alloy systems can only be effectively strengthened by introducing a second-phase material not originally derived from precipitation mechanisms engineered into the original "matrix" alloy.

Therefore, 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 to mix in the second-phase, and/or the use of high pressure or vacuum to quickly force the molten metal into a mold bearing the second-phase preform. 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 fiber coated aluminum preforms are subsequently consolidated using hot pressing techniques. Hot rolling or hot isostatic pressing also could be used for the consolidation step.

"Compocasting" 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.[99] An upper limit of approximately 15 to 25 volume percent of second-phase particles can be added with this technique. When SiC whiskers are the second-phase additive to the liquid melt, the volumetric amount decreases slightly because the whiskers tend to ball up into lumps due to their needlelike shape. Laboratory development indicates that maximum engineered properties occur at about 50 volume percent second phase. The Duralcan process is impressive in its achieved strength enhancements and definitely has market areas were Duralcan alloys offer unique properties.

Another method of adding second-phase strengtheners that are not continuous fibers is to use powder metallurgy (PM) approaches. Second phase(s) and powder matrix are mixed, blended, and prepared for hot pressing or hot isostatic pressing. Up to the desired 50 volume percent second phase can be

added and desirable physical properties displayed. Materials under development for the High Speed Civilian Transport (HSCP) or the orbitor National Aerospace Plane (NASP) use SiC whiskers as the second phase. One of the engineering problems to be solved in the PM approach is how to sufficiently out-gas the cold pressed powder/whisker compact before pressing or rolling with temperature. Because the matrix is never melted, the micro surface area of 1 gram of powder or whisker could equal 10 to 15 meters squared per gram. The failure to remove this absorbed species on the surface does degrade the physical properties by forming undesirable grain boundary precipitates.

NASP materials development and manufacturing involves these two techniques as the NASP project attempts to scale up these processes to make skin panels and structural members for the plane. Other governmental uses for these aluminum alloy SiC materials include structural sections for the space station and the myriad of platforms involved in the Strategic Defense Initiative. The latter projects are declining in funds due to today's changing world conditions. Transferring MMC technology to civilian uses will require that the intended application(s) be extremely high-performance oriented to compete with existing commercial material system(s). Like many advanced composite systems under development today, the achievement of high-performance goals is accomplished at great cost.

Applications.—MMC's are used in many applications and have a history going back at least 20 years. The F-111 all-service fighter-bomber employed boron fiber (boron deposited on tungsten filament) as a second-phase fiber reinforcement in the U.S. Navy version of the plane to lighten the aft end of the plane for carrier landings. Spun-off from that application and others were boron-fiber-reinforced aluminum tubes used as cargo bay struts in the space shuttle. Similar type composites found utility in some sporting and recreational goods such as skis and bicycle frames. Today, R&D has evolved technically better second-phase reinforcements such as fibers; low-cost, high-purity refractory ceramic powders; and newly discovered ceramic whisker types. These reinforcement types are added to aluminum-, magnesium-, and titanium-matrix MMC's for additional applications in airframes, other aircraft applications, and industrial products. Both continuous and discontinuous reinforcements are evolving rapidly as R&D focuses on finding technically compatible metal alloys for these many reinforcement types. The ultimate goal is to develop MMC's toward maximizing their full performance capabilities.

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.

The prime mover in turbine engine development is the DOD's Integrated High Performance Turbine Engine Technology (IHPTET) program. Its goals are turbopropulsion capabilities twice that available using today's technologies. This long-range program is coupled to both the High Speed Civilian Transport (HSCT) and NASP with intermediate results scheduled for use in the High Speed Civilian Transport.[100] In addition, the Enabling Propulsion Materials (EPM) program, a joint effort of NASA and industry, has been established to develop the high-temperature composite materials technology that will increase turbine engine efficiency, resulting in a reduction of NO_x emissions and sufficient noise reductions at airports.[101]

The aircraft turbine engine companies are developing MMC's for all sections of their engines and are starting to look at intermetallic alloy systems, such as the nickel, titanium, or niobium aluminides. Although these aluminides are currently not classified as MMC's, ongoing R&D seems to point to using second-phase reinforcements to enhance the strength and/or fracture toughness. Both of these physical properties are maximized inversely as the operating temperature increases. For instance, an aircraft engine must be capable of repeatedly going from room temperature to a high-temperature stable condition and back to room temperature for aircraft take-offs, flight path, and landings. The fracture toughness property is a function of temperature, usually going from brittle fracture (unacceptable) at some low temperature to acceptably high values at the designed high-temperature stable conditions. In the case of the intermetallic MMC's, the low-temperature fracture toughness values are not acceptable for these materials. Hence, ongoing R&D using second-phase reinforcements to improve room temperature fracture toughness. Intrinsic chemical reinforcements [precipitated and/or diffusion-controlled second-phase(s)] can be optimized in most materials, but the use of extrinsic second-phase reinforcement(s) allows for the technical possibility of a versatile "engineered material."[102]

Commercial MMC applications have only just begun to be cost effective, based on certain high-performance benefits. For example, 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 MMC products include microelectronics packaging, electro-optical platforms, ballistic armor, and various structures requiring stiffness and good high-temperature properties.[103]

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.

MMC's are included in the "critical materials" lists targeted for joint partnerships between the U.S. Government and industry. The next 5 years should indicate whether this country can learn to use flexible and agile manufacturing techniques to make MMC's commercially competitive products of the U.S. economy.

Recycling.—Multialloyed metals owe their high-performance achievements to the value added by processing and postprocessing treatments, both the result of many years of R&D. These metals must be completely refabricated, commencing with remelting. Whether it is economically better to use "scrap" or virgin feedstocks depends on the individual alloy system, the current application requirements, and other technical concerns, all driven by cost. MMC's are complicated alloy systems in that deliberate, extrinsic second-phase reinforcements are added to the multialloyed matrix to achieve certain performance goals. Therefore, the recycling situation for MMC's is complex because the second-phase reinforcements could become contaminants if allowed to remain mixed with the matrix alloy(s) during remelting.[104] For example, because MMC's are engineered materials, the initial mechanical design program could call for second-phase continuous fibers. When this particular end product is scrapped, remelting to remove the multiphase alloy leaves behind a metallized continuous fiber preform of possibly little economic value. Remember that 1 kilogram of high modulus carbon fiber costs about $1,000 today, and this "feedstock material" may not lend itself to being recycled into a high-cost product. In addition, fiber-matrix reactions in a component during its "designed" elevated temperature lifetime, or at any remelt operation, could render the fibers, in any morphological form, unsuitable for reuse. The same line of reasoning holds true for other second-phase reinforcements such as ceramic particulates, whiskers, or ceramic type continuous fibers. R&D is ongoing to find technical and economic methods for reclaiming these second-phase reinforcements for reuse as value-added materials approaching the technical quality of virgin "feedstock" reinforcements.

In other recycling situations, "scrap" segregation of MMC's from nonreinforced alloys may be necessary before recycling. For example, USBM research has shown that it is possible to separate conventional Ti-6Al-4V alloy scrap from the same alloy scrap reinforced with SiC or B_4C fibers using eddy current measurements. USBM researchers have demonstrated scrap separation of 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 MMC's from unreinforced aluminum alloys.

If the metal or metal alloy and its reinforcement do not interact chemically at the melting point of the matrix, a physical separation, such as liquid or solid filtration, would be effective in separating matrix material from reinforcements. USBM has conducted preliminary research on this approach using various filter media.[105] However, if significant chemical reactions occur, the fibers usually are damaged, and often special techniques would be needed to clean up the 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. When remelted and cast to shape in the foundry, the reinforcing particles remain well distributed with only gentle stirring and there is no loss of physical properties. Theoretically, when its useful life is completed, the product could be remelted and cast still another time. Currently, most of the Duralcan process 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.

It can be generally stated that MMC use will increase rapidly in the near future. These MMC's offer superior technical performance, capable of being engineered into the MMC's. This superior performance usually cannot be achieved by conventional materials in use today. Therefore, the recycling of these complex composites becomes very important to their overall lifecycle. Because MMC's are posed for entry into commercial applications, many material designers are incorporating the concept of "design to recycle" into these future MMC applications. R&D is continuing into all lifecycle phases of MMC's, and recycling will be a significant factor in engineering MMC's.

Annual Review

Consumption and Uses.—**Metal Matrix Composites.**—The estimated 1992 U.S. market for MMC's, shown in table 11 and figure 13, is $28.9 million for 202 metric tons shipped with market subsegments or end uses identified as automotive, aerospace, recreation, and industrial/other. From table 11 (1990-92), the 1992 data show a 12% decrease in value for a 35% increase in total tons shipped when compared to 1991. This most noticeable change occurred mostly in the automotive segment where 50% more product was shipped in 1992 but at

a dollar value almost equal to 1991. The 1992 automotive market continued to be the largest segment tonnagewise, with approximately 60%, while the aerospace market is the largest segment valuewise at 83%. The aerospace market stayed the same for 1991 and 1992 for both tonnage and dollar value and is not yet reflecting the DOD cuts in military spending.

Carbon-Carbon Composites.—The estimated 1992 U.S. market for C-C composites, shown in table 13 and figure 14, is $120 million for 167 metric tons shipped with market subsegments or end uses identified as aircraft brakes, rocket nozzles, nose tips/ablatives, racing brakes, and industrial/other. From table 13 (1990-92), the 1992 data show a 2% decrease in value for a 4% decrease in total tons shipped when compared to 1991. This most noticeable change occurred with a decrease in military-type product (aircraft brakes, rocket nozzles, and nose tips/ablatives) of 9%, offset by an increase in nonmilitary product of 14%, or a net decrease in dollar value of approximately 2%. The 1992 aircraft brakes market continues to be the largest segment tonnagewise, with approximately 67%, while the nose tips/ablatives market is the largest segment valuewise at 50%. The slight decrease in 1992 for both tonnage and dollar value may be reflecting DOD cuts in military spending.

World Review.—**Metal Matrix Composites.**—The estimated 1992 world market for MMC's is $56.1 million (558 metric tons). This represents a 7% decrease in value but a 2.5% increase in weight compared with 1990 data. The world data also reflect the observation that more lower value products were shipped in 1992 than in 1991. Figure 15 shows the 1992 world market by end-use industry while table 11 compares the same categories for 3 years, 1990-92 (Both Kline & Co. data). Analysis of table 11 reveals world automotive MMC dollar value for 1992 returning to 1990 levels but the aerospace dollar value for 1992 decreased 10% compared to that in 1990. Notice that the world aerospace tonnage shipped in 1992 was lower in value than the tonnage shipped in 1990. The 1992 worldwide automotive market continues to be the largest segment tonnagewise, with approximately 79%, while the worldwide aerospace market is the largest segment valuewise at 67%.

From table 11, a comparison, for 1992, of the worldwide value per weight in the automotive category to the aerospace category yields the following: for automotive, $35 per kilogram ($16 per pound); and for aerospace, $405 per kilogram ($184 per pound). This indicates that the average cost of MMC's for aerospace applications is 10 times higher than those for automotive and other applications. These higher costs are attributed to labor-intensive fabrication and low-volume production.

The estimated 1992 worldwide and projected year 2002 worldwide MMC shipments are shown in table 12. For 1992, the U.S. share of the total MMC market is 36% and is expected to increase to 43% by the year 2002. The fastest growing market segment worldwide in the next 10 years is the automotive market in the United States with a projected 12% annual increase, while the slowest growth rate was indicated for the U.S. aerospace market at 6% annually. The rest of the world category is expected to have a total MMC growth of 7.4% annually while the United States is projected at 6.1% annually.

Carbon-Carbon Composites.—The estimated 1992 world market for C-C composites is $171 million (229 metric tons). This represents a 14.5% decrease in value and a 25% decrease in weight compared to 1990 data. The world data also reflects both lower total value and lower total shipments in 1992 than in 1991. Figure 16 shows the 1992 world market by end-use industry while table 13 compares the same categories for 3 years, 1990-92 (Both Kline & Co. data). Analysis of table 13 reveals world nose tips/ablatives dollar value for 1992 approaching the record 1991 level while the world aircraft brakes and rocket nozzles dollar values decreased approximately 5% to 10% in 1992 compared to 1991. All other end-use categories decreased in 1992 compared to 1991.

The 1992 data are a decrease over 1991; this decrease is due, in part, to an overall sluggish economy combined with current and anticipated cuts in defense spending and to the quickness of the military success in the Persian Gulf war. Table 13 reveals only worldwide growth in the areas of racing brakes and industrial/other (dollar value in the former, shipments in the latter). Furthermore, table 13 indicates the 1992 worldwide aircraft brakes market continues to be the largest segment tonnagewise, with approximately 62%, while the worldwide nose tips/ablatives market is the largest segment valuewise at 49%. The 1992 value per weight shipped for aircraft brakes segment is compared to the nose tips/ablatives segment: for aircraft brakes, $257 per kilogram ($117 per pound); and for nose tips/ablatives, $3,002 per kilogram ($1,365 per pound). Remember that the densities of C-C composites are about one-half that of typical MMC's so that a $3,000 per kilogram C-C composite structure needs only one-half the weight to carry the same structural load as an MMC. Also, C-C composites can be almost twice as strong (elastic modulus) as MMC's, therefore, only about half as much material is needed compared to an MMC. These density and strength factors help to offset the very large costs of processing C-C composites at temperatures in excess of 2,000° C. However, the higher costs of C-C composites are also attributed to labor-intensive fabrication and low-volume production that are inherent in many of today's composites.

The estimated 1992 worldwide and projected year 2002 worldwide C-C composite shipments are shown in table 14. For 1992, the U.S. share of the total C-C composite market is 72% and is expected to remain at 72% by the year 2002. The fastest growing market segment worldwide in the next 10 years is the industrial/other market in the United States, with a projected 11.3% annual increase, while negative rates were indicated for the U.S. nose tips/ablatives at -2% annually and rocket nozzles at -3% annually.

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.[106]

Advanced Composite Materials Corp. (ACMC) of Greer, SC, also is developing aluminum composites based on the wrought alloy series. Its 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.[107] ACMC also is 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.[108]

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, and more fatigue and corrosion resistant are likely to 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 experienced a drop in nearly all areas in 1992. The only bright spot was in the total tonnage shipped for the year, which increased 26% over that of 1991, mainly from the automotive market. The total dollar value decreased 12%. The aerospace market for MMC remained the same in 1992 as in 1991, a more than 80% share of total MMC dollar value, indicating that the DOD procurement cuts have not caught up with MMC's in 1992.

Because of its heavy use in defense applications, perhaps the picture for C-C 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.

SILICON INTEGRATED CIRCUITS

Background

This segment is a highly condensed version of the USBM Working Paper "Material Process/Product Flows in the U.S. Semiconductor Industry: Focus on the Silicon Integrated Circuit," by Kristin Tressler.

The semiconductor industry is divided into three distinct areas: (1) integrated circuits (IC's), (2) discrete (or individual) semiconductors, and (3) "other" semiconductors, such as light-sensitive or light-emitting devices.[109] Of these three types of semiconductor devices, integrated circuits are by far the leading devices in terms of consumption of materials and worldwide revenues. Discrete devices, which ranked second, are either transistors or diodes. Transistors are used to amplify electronic signals or to turn electrical current on or off, whereas diodes are mainly used to convert alternating-current signals to direct-current signals. The third area is light-sensitive and light-emitting diodes, which include solar cells and photodiodes. The majority of semiconductor devices end up collectively as parts for integrated circuits. An IC is merely a collection of various discrete devices built into and interconnected on a semiconducting silicon substrate. Most IC's are monolithic, meaning that all functions are performed on a single silicon wafer, and are manufactured of two basic types: bipolar or metal-oxide-silicon (MOS). Bipolar IC's are more difficult to manufacture than MOS IC's. Because bipolar IC's process information faster, they are used mainly as logic circuits in high-speed computers. MOS IC's are used primarily for data storage, but also find uses in microprocessors and microcontrollers.

Definitions, Grades, and Specifications.—IC's represent the majority of semiconductor device revenues and, in 1992, accounted for approximately 70% of total factory shipments. MOS IC's are the fastest growing group of semiconductor devices and alone accounted for 39% of total device revenues in 1992. Total factory shipments of semiconductor devices have increased approximately 53% from 1981 to 1990. IC's are categorized by trade associations in the following subgroups:[110]

- Integrated Circuits:
  - IC type:
    - MOS IC's
    - Bipolar IC's
    - Other hybrid IC's
  - IC function:
    - IC's for power control
    - IC's for signal processing
- Diodes and Rectifiers:
  - Light-emitting
  - Other
- Other Semiconductor Devices:
  - Thyristors
  - Solar Cells
  - Other

Products for Trade and Industry.—IC's are considered enabling technologies and are used in some of the United States' most important industries, including data processing, communications, industrial machinery, consumer products, military electronics and controls, and transportation systems. For example, the revenue distribution for 1992 indicates more than 40% sales generation from data processing alone, with industrial and the military accounting for 15% each. This 40% number represents a doubling of data processing revenue over this 10-year period (1983-92).[111] Except for the rapidly expanding category of data processing, revenue data from the past 10 years for all other IC uses have increased steadily while maintaining the same degree of revenue proportionality among the various categories.

Industry Structure.—Succinctly, IC's are made by first cutting thin sections or wafers from single crystal boules of ultrahigh-purity silicon metal. Then multistep processing prepares the wafer surface for the as-designed IC products; e.g., computer chips. These initial prefabrication steps are unique in that they are usually carried out by specialized companies. Major wafer suppliers to U.S. wafer-fabrication plants include MEMC Inc., Wacker Siltronic Corp., and several Japanese suppliers. It should be noted that there are currently no U.S.-owned silicon wafer suppliers. MEMC and Wacker have plants in the United States but are owned by German interests. However, IBM, a captive U.S. company (wholly owned by U.S. interests), produces extremely large amounts of silicon wafers for its own in-house use. U.S. consumption of merchant (usually imported) and captive (U.S. origin) silicon and merchant epitaxial (single crystal layer deposited) wafers has increased steadily for the period 1986-92. In 1992, the value of silicon wafers in the United States measured $1,051 million, making silicon by far the greatest revenue earner in the semiconductor materials market.[112]

The actual fabrication of the IC's in the United States is carried out by four or five large U.S. corporations and by corporations that are foreign-owned. The U.S.-owned companies are IBM, Motorola, National Semiconductor, and Intel Products Group. Foreign-owned companies in the United States include Philips Semiconductor, NEC Electronics, and Toshiba America. The fabrication of IC's requires large investments in plants and equipment plus a very astute marketing arm to ensure a good return on investment in this rapidly changing electronics market.[113] Intel announced that the plant necessary to fabricate its new "Pentium" chip in numbers large enough to satisfy estimated market demand will cost $500 million.

Technology.—**Processing.**—The semiconductor industry is constantly evolving with new advancements in processing and fabrication technology, particularly with regard to integrated circuits.[114] The technical focus is on the materials used in the processing and fabrication. IC processing and fabrication involves seven basic steps, of which several are repeated throughout the manufacturing process. The sequential order of the processing steps is by no means fixed and may not be the actual order for all IC's manufactured. Figure

18 is a schematic flowchart for IC fabrication and includes end uses and types of waste anticipated is this high-technology industry. The first step in the manufacturing process, crystal growth and wafer preparation, is not actually part of the fabrication of the IC itself. However, it is a necessary step and has a relatively high consumption of materials. Steps two through seven usually include wafer cleaning operations, photolithography, etching, doping, diffusional and/or depositional "additive" processes, and metallization. Several of these 7 steps will be discussed in general terms, as follows.

Before actual IC fabrication can begin, raw semiconducting materials must be converted into highly purified, polished wafers that must meet very stringent requirements before being used to manufacture IC's.[115] Silicon is by far the most commonly used material for the manufacture of IC's. Other semiconductor materials are gallium arsenide, gallium arsenide phosphide, and indium phosphide. These materials each have distinctive properties that separate them from silicon and make them particularly useful for specialty semiconductor devices; e.g., gallium arsenide in lightemitting diodes (LED'S), superfast computers, and realtime control circuits.

Silicon metal is extracted from ordinary sand, and this impure silicon is purified through chemical reactions to produce semiconductor-grade polycrystalline silicon. Conversion from polycrystalline silicon to single crystal silicon is usually performed using the Czochralski Method. This method involves heating the polycrystalline silicon and small amounts of a dopant to a liquid state. The dopants used usually are boron, phosphorus, arsenic, or antimony. A single crystal "seed" is placed just above the melt and selected crystal faces actually contact the liquid. As the seed is systematically raised from its initial position, heat is extracted by external means and the melt in the meniscus freezes, forming more single crystals on the seed. This method of crystal growth produces crystals that can be several feet in length and up to 12 inches in diameter. After the crystal boule is grown, it goes through a series of cutting, slicing, cleaning, and polishing procedures before the final wafers are ready for use in the fabrication of IC's. These wafers are then evaluated for surface defects and other impurities and are packaged in "clean rooms" to be shipped to various IC fabrication facilities.

IC's are designed to perform specific functions depending on what end-use products will receive the circuits.[116] The actual circuitry is designed as a series of sequential patterns that are stacked in horizontal layers and interconnected. The completed physical scheme contains all the electronic devices and electrical current pathways necessary to accomplish the IC's goals. To fabricate an IC, the individual patterns are singularly "transferred" to the wafer surface(s) at the appropriate fabrication stages through a process called photolithography. Photolithography is an extremely crucial step in IC fabrication because it determines where the devices will be positioned on the wafer and what dimensions these devices will have, two specifications that must be highly accurate for the effective operation of the IC. Coupled with the photolithography operations are wafer surface processes designed to modify selected wafer regions to achieve the IC's goals. For example, wafer surface modification processes could remove surface material to get to a sublayer; i.e., a selected region of insulating material removed to get to a metallic sublayer. Another process could remove surface silicon metal to allow deposition of a dopant, which, after thermal diffusion treatment, is a region known as an electronic junction. Further processing in this selected region could make it into a current control gate. A final example could be the selective removal of a wafer's prior deposited top insulating material layer to expose a small region of metallic sublayer. The exposed metallic sublayer, for this device, is the attachment region for a connecting wire leading to another device.

Physically, the photolithography patterns allow light and dark contrasts, similar to light shining through a 35-millimeter slide, to project the slide's contents onto a large viewing screen. However, the photolithic focusing lenses or devices miniaturize the pattern(s) to fit the wafer size. In practice, the entire wafer surface is coated with a photosensitive material. After exposure, the dark lines or dark areas on the pattern "mask" or prevent the photoresist coating on the wafer from being exposed to the radiation source. The photoresist material must have two attributes—the ability to change chemical composition in the regions exposed to the radiation and the ability of the nonradiated regions to resist being dissolved by chemicals specific to dissolving the irradiated regions. Through careful engineering of this entire process, the goals are achieved to obtaining designated regions of the wafer surface suitable for additional fabrication.

The photolithographic/wafer surface modification processes involve five basic steps: (1) applying liquid photoresist to the entire wafer surface; (2) processing the photoresist coating with radiation to produce chemically susceptible and chemically inert photoresist surface regions; (3) removing by chemical or physical (plasma) means the susceptible photoresist surface regions, thus exposing the underlying wafer surface; (4) etching or modifying these wafer surface regions to remove, deposit onto, or by diffusion change the wafer surface chemistry; and (5) stripping the remaining photoresist coating to allow the next sequential operation to commence. Step (4) is done to the wafer surface regions exposed by the removal of the chemically susceptible photoresist.

The IC is composed of a silicon wafer with thin layers of either conducting or insulating films created by deposition and dopant processes onto the wafer's surface. The initial stages of these processes, which lay down deposition and/or dopant materials, usually occur at or near room temperature. Later thermal treatments stages (diffusional treatments) at high temperatures are necessary to diffuse "dopants" into the surface film or

chemically bond one thin film to another or to the actual silicon wafer surface. All of these processes normally are repeated often in IC fabrication. The most common deposition materials are epitaxial silicon, polycrystalline silicon, silicon dioxide, and silicon nitride. These materials are deposited by an "additive" process such as chemical vapor deposition (CVD). CVD is defined as the formation of a nonvolatile solid film on a substrate by the reaction of vapor-phase chemicals (reactant gases) that contain the required constituents. These reactant gases are introduced into a chamber where they decompose and react on the heated substrate(s) surface to form the new thin film. There are other "additive" processes currently being used for the deposition of materials. However, CVD is the most common process because of the following advantages: (1) high-purity deposits can be achieved, (2) a large variety of chemical compositions can be deposited, (3) some films cannot be deposited with adequate film properties by any other method, and (4) good economy and process control are possible for many films. Thermal energy is used to enhance appropriate reactions by heating either the chamber or the wafer or both.

Almost all of the silicon wafers used today for the fabrication of IC's contain a layer of CVD-deposited epitaxial silicon. It is in this layer of the IC that the semiconductor part of the device is actually formed by using the appropriate dopants. The preferred gas for CVD deposition of epitaxial silicon is silicon tetrachloride. However, other gases also are used, including silane, dichlorosilane, and trichlorosilane. Select epitaxial silicon layers are heavily doped to make regions that are good conductors of electricity by moving either electrons or their electrical analog-holes. Which type of dopant(s) employed results in increased current flow in these regions and are designated "n-type" or "p-type" conductors. The positioning of these "n" and "p" regions and their junctions allow for the controlled movement of current through electrical "gates" that allow "go or not go" and "or and nor" situations. The "go" gate stops and starts current flow along a single pathway while the "nor" gate selects one of two pathways for current flow. The multiplexing of these two gate types allows today's complex computers to be built because they are the electrical equivalent of binary logic, when combined with Boolean algebra (the complex interactions possible with binary logic), allow today's computers not only to exist but to continue to evolve. The only IC limitations appear to be the number of gates capable of being formed in an ever-decreasing space that makes up the central processing unit of a computer.

The gates themselves are made up of gate insulating silicon oxide and current carrying polycrystalline silicon, both individually CVD deposited. These polycrystalline silicon layers replace other metals in many IC technologies because these layers have the additional advantage of being chemically compatible with epitaxial silicon. Silicon dioxide, an insulator, is deposited by either CVD, as are most other materials, or by thermal oxidation of the silicon substrate. CVD-deposited silicon dioxide films are most widely known for their use as insulators around the various gates and as a final passivation layer covering the completed wafer to protect it from the natural environment. However, oxide films also are used as insulation between polysilicon and metallization layers, between multimetallization layers, as doping barriers, as diffusion regions, and as isolation regions.

A second insulating material, silicon nitride, also is deposited by CVD and is considered to be superior to CVD-deposited silicon dioxide because it is harder, is a better moisture and sodium barrier, has a higher dielectric strength, and resists oxidation. Uses for these films include passivation layers, masks for selective oxidation of silicon, and intermetal dielectrics. Silane plus ammonia, silane plus nitrogen, and dichlorosilane are the gases most frequently used for the deposition of silicon nitride.

Metals are generally deposited onto the wafer surface by either CVD or physical vapor deposition (PVD). PVD, or sputtering, is a procedure conducted in a vacuum chamber with the appropriate electrical potentials and connections. The deposition rate of the PVD process is not directly dependent on the temperature of the wafer substrate. In most situations, the film receiving substrate is or can be at room temperature. In the sputtering chamber, the material to be deposited is called the target and is deliberately biased—electrically negative. The target material, a one piece solid, is placed in the vacuum chamber above the silicon wafer. Then, an inert gas, usually argon, is fed into the chamber through selected openings and ionized. Because the gas ions are positively charged, they gain momentum as they are electrically accelerated toward the negatively biased target. These gas ions strike the target material and cause the atoms from the target to scatter and eventually come to rest on the wafer surface. The metallic atoms freed from the target material by the ionized gas stream are deposited on the silicon wafer and form a physical bond with the wafer surface. The high vacuum in the chamber plus prior cleaning of the wafer surface allow the target atoms to atomically bond to the wafer surface and eventually form the desired thin film. PVD has become the most widely used method of metal deposition for most materials. Metals deposited include aluminum, aluminum alloys, gold, and platinum. Before the development of advanced integrated circuits, pure aluminum and aluminum alloys were the metals of choice for the interconnection of semiconductor devices. They are still widely used today in semiconductor device fabrication. However, advanced IC's require materials with extremely low resistivities and low contact resistances, two attributes of refractory metals and their silicides. Refractory metals include molybdenum, tantalum, titanium, and tungsten. These materials and their silicides can be deposited either by sputtering (PVD) or by CVD.

For metallic deposition, CVD, a process described earlier in this report, offers a less-expensive, less equipment-

intensive alternative to PVD and is the preferred method for deposition of refractory metals and/or their silicides (both used for electrical interconnections). Tungsten is the most frequently deposited refractory metal. CVD of tungsten is accomplished by using tungsten hexafluoride gas to produce tungsten silicide on the wafer surface. Titanium tetrachloride is the common source liquid used to form titanium silicide from titanium.

Etching of metals is accomplished by the same two methods as nonmetallic material etching: wet etching and dry etching. Aluminum and aluminum alloys are generally wet etched in heated solutions of phosphoric acid, nitric acid, acetic acid, and water, with phosphoric acid making up 80% of the solution. However, problems exist with this procedure because of the formation of tiny hydrogen bubbles that form on the wafer surface and inhibit etching. Therefore, dry etching is the preferred method of etching for aluminum and aluminum alloys. Refractory metals and their silicides are etched using dry methods involving both chlorine- and fluorine-containing gases. Etching of these materials is difficult but accomplished with the use of mixtures of gases.

The use of metals is crucial to the processing of IC's because the metallic attachments interconnect the many layered structures within an individual device and intraconnect the many individual devices built onto the "wafer surface." In addition, selective metallic areas of the finished wafer must provide regions to which external connecting leads can be attached. Often, there are several different layers of metal incorporated onto one wafer just as there are many layers of nonmetallic materials. The concepts of deposition and etching discussed earlier for nonmetallic materials also can be applied to metals.

These variously described processes are repeatedly carried out until the originally designed IC is completed. It is important to note that the majority of advanced integrated devices manufactured today are highly sophisticated devices. Many of them consist of multiple oxidation and metallization layers and several p-n junctions for the IC to perform very complicated operations. However, the materials and techniques used to fabricate these more advanced devices are the same as those outlined for this report. Note that millions of such devices comprise an advanced IC and that hundreds to thousands of IC's are contained on a single silicon wafer.

Environmental Issues.—Until the early 1980's, the semiconductor industry was believed to be a "clean industry" compared to the older "smokestack industries," which were noted for environmental degradation. However, the discovery of contaminated ground water at several wafer fabrication facilities in California in 1981 revealed that semiconductor manufacturing at that time was not environmentally safe. Today, after many years of State and Federal regulatory laws and suits against the industry,[117] the semiconductor industry is approaching a "clean industry" not only in the manufacturing of semiconductors devices but in maintaining environmental goals. The industry uses large quantities of solvents, gases, acids and bases, and metals. The improper technical handling of some of these materials prior to, during, and after their use in device manufacturing poses concerns about possible environmental pollution. All of the above materials occur in nature, but it is their concentration by industry for manufacturing purposes that causes possible hazards to the environment. Today, the proper handling of these materials has become more widely known to industry through governmental regulations, internal industry awareness, and the alertness of citizen environmentalists. The possible environmental implications of these four categories of materials are outlined with emphasis on proper utilization of these materials and/or eventual replacement of these materials with less harmful materials.

The first category of possible pollutants from the manufacture of semiconductor devices is solvents. Solvents are widely used in the semiconductor industry because of their ability to dissolve other materials. Perhaps, the most publicly "visible" class of solvents is chlorofluorocarbons (CFC's). In the mid-1980's, CFC's, or freon, were identified as substances that deplete the ozone shield in the upper atmosphere, which protects the earth from excessive amounts of ultraviolet light. The major use for CFC's in the electronics industry is for defluxing printed circuit boards; however, they also are used as cleaners, photoresist strippers, and etchers in the fabrication of integrated circuits. In the mid-1970's, the use of CFC's was thought to be extremely safe as they emerged as good substitutes for trichloroethylene (TCE) and 1,1,1-trichloroethane (TCA), both of which are very hazardous solvents (still used today, but in diminishing quantities). In 1985, when a hole in the ozone layer was discovered over Antarctica, scientific experts began to take a serious look at CFC use. At that time, the electronics industry consumed 20% of all CFC's used. Since then, the 1987 Montreal Protocol, calling for the reduction of worldwide CFC use, was amended in June 1990 and again in November 1992 to accelerate the phaseout of CFC's. U.S. manufacturers must now cease production of CFC's by the end of 1995. On May 15, 1993, a new law went into effect, mandating that all products manufactured using ozone-depleting chemicals (mainly CFC's and TCA) be labeled: "Warning: Manufactured with (name of substance), a substance which harms public health and the environment by depleting ozone in the upper atmosphere."[118]

For several years, researchers have been trying to find less environmentally harmful substitutes for TCE, TCA, and CFC's.[119] HCFC's (hydrochlorofluorocarbons) have been found to be less damaging to the ozone layer but also may be banned early in the next century. For wafer cleaning processes, companies are experimenting with just using surfactants (soap) and water and are having some success. Lockheed Missiles and Space Co. is experimenting with blasts of frozen

carbon dioxide pellets (dry ice) to clean wafer surfaces. Plasma-cleaning processes may prove to be the best alternatives to the use of toxic chemicals but are not effective enough for commercial use as of now.

Another group of solvents that are extremely environmentally hazardous are ethylene-based glycol ethers. These materials have been used since the 1970's to thin photoresist in the manufacture of IC's. Ongoing government research citing the possible hazards to humans and other mammals from these glycol ethers have prompted several "user" companies to begin using alternative materials. Three viable substitutes have been found to date: propylene glycol monomethyl ether acetate, ethyl-3-ethoxypropionate, and ethyl lactate.

The second category of potential pollutants includes some of the gases used in the U.S. semiconductor industry.[120] These gases range from highly toxic (arsine, phosphine, diborane, and silane) to relatively harmless (hydrogen, nitrogen, oxygen, and argon). Arsine, phosphine, and diborane are used as dopants in silicon wafer processing. Arsine is the most toxic gas used in the manufacture of semiconductor devices. Exposure to extremely small amounts may be fatal. Phosphine is pyrophoric and flammable, besides being toxic. Diborane is an extremely reactive gas and immediately damages the respiratory tract. Silane, used in the process of CVD, also is highly toxic and ignites spontaneously when in contact with air. These gases, if released into the air in very high concentrations, can be extremely harmful to the environment because they are deoxidizers to living things. Finding replacements for these highly toxic gases is a continuing quest today. For example, American Cyanamid Co. introduced two low-vapor liquid substitutes for arsine and phosphine: tertiarybutylarsine (TBA) and tertiarybutylphosphine (TBP). It is known that these liquid replacements are much less hazardous than their gaseous counterparts but cost 15 times more than the cost of the gases. Also, Lam Research in Fremont, CA, has replaced diborane with a less toxic substitute, alcohol triethylborate (TEB).

Acids and bases comprise the third category of potential pollutants. Acids and bases are widely used in the U.S. semiconductor industry for cleaning, etching, and photoresist stripping. Acids commonly used include hydrochloric acid, sulfuric acid, nitric acid, and hydrofluoric acid. Bases commonly used are sodium hydroxide, potassium hydroxide, and ammonia and ammonium compounds. Acids, in extremely high concentrations, are particularly dangerous to the environment and are designated as hazardous materials under RCRA. Of the acids currently used in the semiconductor industry, the largest contributor to the hazardous wastestream is hydrofluoric acid. Other acids usually are found in wastestreams in dilute form, but still pose a possible threat to the environment.

The fourth and final category for potential pollutants resides in the use of metals.[121] Several harmful metals are used in the semiconductor industry, including antimony, arsenic, beryllium, cadmium, and lead. Many of these are used in the actual fabrication of an IC; for example, arsenic trioxide is used as a solid dopant source and is extremely dangerous. When IC's are cleaned at various stages of the fabrication process, dissolved metals become part of the discarded solution. If this wastewater is discharged into the sewer system, the metals can be highly toxic to fish, birds, marine mammals, and humans. Today, many companies already have instituted systems to guard against contamination of ground water by toxic metals.

Annual quantities of emissions of some of the most harmful chemicals currently used in the U.S. semiconductor industry have been reported by the EPA,[122] beginning in 1987, the first year in which companies were required to publicly disclose chemical releases to the environment in the EPA's Toxic Release Inventory (TRI). The EPA has vigorously enforced compliance by conducting more than 2,300 site visits, filing approximately 550 complaints, and levying fines of more than $16 million since 1989. This data represent quantities of emissions released directly to the environment or through offsite transfers.

The term environmental release refers to discharges onsite to the air, water, underground injection, or land. Air emissions are by far the largest contributors to total releases in the U.S. semiconductor industry. However, levels of air emissions have decreased 29% from 1987 to 1990.[123] Surface water discharges from the semiconductor industry have shown the sharpest decrease for the period 1987-90, from 2,140,733 kilograms in 1987 to 94,241 kilograms in 1990. Underground injection is a disposal method by which chemical wastes are injected into deep underground wells. Underground injection releases were minimal for the U.S. semiconductor industry from 1987-90. On-site land releases refer to releases to the land on the premises of the reporting facility and fall into one of four categories: landfills, land treatment/application farming, surface impoundments, and other land disposal. For the period 1987-90, land releases have remained relatively constant, measuring approximately 400,000 kilograms. Offsite transfers include releases sent offsite for treatment, storage, or disposal and fall into two categories: publicly owned treatment works (POTW's) and other offsite transfers. POTW's are owned by a State or municipality and include any devices used in the storage, treatment, recycling, and reclamation of domestic sewage or a combination of domestic sewage and industrial wastewaters. Other offsite transfers include transfers to incinerators, underground wells, landfills, and other sites not on the premises of the reporting facility.[124]

Annual Review

U.S. semiconductor device revenues totaled approximately $23 billion for 1990 and $27 billion for 1992.[125] This 8% annual increase in revenues has been sustained since 1986 but the revenue share of IC's is increasing. *(See table 19.)* For instance, IC's represent the majority of semiconductor device revenues and, in 1992, accounted for

approximately 70% of total factory shipments, up from 45% in 1989. In fact, the Metal Oxide Semiconductor (MOS) IC segment is the fastest growing of the semiconductor devices and alone accounted for 39% of total device revenues in 1992. This reflects the rapid change in the PC market in the past 3 years. The price of a PC has been reduced twofold while the computing power of a PC has increased four times. The result has been a doubling in the number of PC's sold, therefore, the number of MOS IC's sold. Total factory shipments of semiconductor devices have increased by approximately 53% from 1981 to 1991 and are projected to continue to increase through 1994.[126] *(See figure 17.)*

Outlook

The continued increase in total IC revenues of approximately 8% per year over the past several years is different from the almost level revenues exhibited by most advanced material and technology industries. In general, a slight downturn for 1991 and 1992 is attributed to the general economic conditions rather than a real softening or leveling of demand for these industries. But, the annual revenue increases for all IC's are caused mostly by the MOS IC's revenue increases, driven by the fierce market competition in the personal computer industry over the past 2 to 3 years. The result is greatly increasing numbers of PC's being sold, each with a MOS IC as its computer processing unit.

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TABLE 1

TOTAL AMPP R&D FUNDING, BY AGENCY

(Million dollars)

Department or agency	Fiscal year 1992 actual expenditures	Fiscal year 1993 congressional appropriations	Fiscal year 1994 President's budget request
Department of Commerce, National Institute of Standards and Technology	42.6	48.4	56.7
Department of Defense[1]	530.9	557.7	421.7
Department of Energy[1]	862.5	914.0	941.5
Department of the Interior, Bureau of Mines	25.2	24.9	21.5
Department of Transportation	11.0	14.9	12.7
Environmental Protection Agency	3.5	4.5	4.5
Department of Health and Human Services, National Institutes of Health	79.6	85.9	92.9
National Aeronautics and Space Administration	76.3	102.8	131.1
National Science Foundation	265.6	303.6	328.0
Department of Agriculture	36.3	37.4	45.8
Total materials R&D funding	1,933.5	2,094.1	2,056.4
	(1,683.5)	(1,822.5)	(1,736.4)

[1]Excludes classified research.

Source: Committee on Materials, Office of Science and Technology Policy, Executive Office of the President.
Note.—Parentheses indicate total funding excluding construction and operating costs for major national user facilities.

TABLE 2

TOTAL AMPP R&D FUNDING, BY RESEARCH COMPONENT[1]

Component	Fiscal year 1992 actual expenditures		Fiscal year 1993 congressional appropriations		Fiscal year 1994 President's budget request	
	Value (million)	Percent	Value (million)	Percent	Value (million)	Percent
Synthesis and processing	$948.8	49.1	$1,032.4	49.3	$972.4	47.3
Theory, modeling, and simulation	234.3	12.1	259.6	12.4	252.7	12.3
Materials characterization	478.4	24.8	506.4	24.2	486.2	23.6
Education/human resources	22.0	1.1	24.1	1.2	25.1	1.2
National user facilities/other	250.0	12.9	271.6	12.9	320.0	15.6
Total component funding	1,933.5	100.0	2,094.1	100.0	2,056.4	100.0

[1]Excludes classified research.

Source: Committee on Materials, Office of Science and Technology Policy, Executive Office of the President.

TABLE 3

TOTAL AMPP R&D FUNDING, BY MATERIALS CLASS[1] AND FACILITY

(Million dollars)

Materials class and facility	Fiscal year 1992 actual expenditures	Fiscal year 1993 congressional appropriations	Fiscal year 1994 President's budget request
Bio/biomolecular materials	139.8	153.5	172.2
Ceramics	152.1	166.1	159.6
Composites	184.7	225.3	199.7
Electronic materials	230.5	244.2	220.6
Magnetic materials	32.0	24.1	26.2
Metals	391.9	389.5	254.7
Optical/photonic materials	138.3	162.9	153.3
Polymers	100.7	108.7	122.6
Superconducting materials	142.7	145.2	133.0
Other/nonspecific materials	170.8	203.0	194.5
Total materials R&D	1,683.5	1,822.5	1,736.4
National user facilities	250.0	271.6	320.0
Total R&D funding	1,933.5	2,094.1	2,056.4

[1]Excludes classified research.

Source: Committee on Materials, Office of Science and Technology Policy, Executive Office of the President.

TABLE 4

U.S. AND WORLD PRODUCTION OF ADVANCED MATERIALS

Year	Advanced ceramics (Ceramic Industry)[1]		Advanced ceramics (Kline)		Advanced polymer composites (Kline)		Metal matrix composites (Kline)		Carbon-carbon composites (Kline)	
	Quantity (thousand metric tons)	Value (million dollars)	Quantity (thousand metric tons)	Value (million dollars)	Quantity (thousand metric tons)	Value (million dollars)	Quantity (thousand metric tons)	Value (million dollars)	Quantity (thousand metric tons)	Value (million dollars)
U.S. PRODUCTION										
1990	—	3,800	NA	NA	9.0	2,400	0.2	36	0.2	152
1991	—	3,900	NA	NA	7.8	2,400	.2	33	.2	125
1992	NA	NA	124.5	3,173	7.4	2,200	.2	29	.2	120
2002	XX	XX	[2]177.8	NA	[2]14.5	NA	[2].5	NA	[2].3	NA
WORLD PRODUCTION										
1990	NA	13,600	NA	NA	15.0	4,000	.5	60	.3	200
1991	NA	15,300	NA	NA	14.1	4,500	.4	54	.2	175
1992	NA	[3]14,800	583.0	13,373	13.7	4,300	.5	56	.2	171
2002	XX	XX	[2]863.0	NA	[2]25.2	NA	[2]1.1	NA	[2].4	NA

NA Not available. XX Not applicable.

[1]No domestic breakdown available.

[2]Estimate—Kline & Co., Inc.

[3]Includes $1.18 billion for optical fibers not in Kline data. Ceramic Industry obtained by industry survey forms.

TABLE 5

ESTIMATED 1992 WORLD PRODUCTION OF ADVANCED MATERIALS, BY REGION

Region	Advanced materials (Kline)		Advanced ceramics (Kline)		Advanced polymer composites (Kline)		Metal matrix composites (Kline)		Carbon-carbon composites (Kline)	
	Quantity (thousand metric tons)	Value (million dollars)	Quantity (thousand metric tons)	Value (million dollars)	Quantity (thousand metric tons)	Value (million dollars)	Quantity (thousand metric tons)	Value (million dollars)	Quantity (thousand metric tons)	Value (million dollars)
Pacific Rim	355.9	8,768	353.0	7,926	2.7	817	0.2	12	([1])	14
North America	152.1	5,994	144.0	3,608	7.5	2,236	.2	29	0.2	121
Western Europe	93.9	3,137	90.0	1,839	3.4	1,247	.1	15	.1	36
Worldwide[2]	601.9	17,900	583.0	13,373	13.7	4,300	.6	56	.2	171

Note A.—Value per kilogram (value per pound) per region (all advanced materials).
Pacific Rim = $24.60 per kilogram ($11.18 per pound).
North America = $39.31 per kilogram ($17.87 per pound).
Western Europe = $33.33 per kilogram ($15.15 per pound).
Total Worldwide = $29.68 per kilogram ($13.49 per pound).
Note B.—Value per kilogram (value per pound) per technical category.
Worldwide advanced materials = $29.68 per kilogram ($13.49 per pound).
Advanced ceramics = $22.88 per kilogram ($10.40 per pound).
Advanced polymer composites = $313.24 per kilogram ($142.38 per pound).
Metal matrix composites = $100.76 per kilogram ($45.80 per pound).
Carbon-carbon composites = $746.44 per kilogram ($339.29 per pound).
[1]Less than 50 metric tons.
[2]Data may not add to totals shown because of independent rounding.

Source: Kline & Co., Inc.

TABLE 6

SURVEY OF 1992 WORLD SALES OF ADVANCED CERAMICS, BY CORPORATE RANKING

Ranking by sales	Corporation name and country	Sales (billion dollars)	Ranking by sales	Corporation name and country	Sales (billion dollars)
1	Kyocera Corp., Japan	2.787	6	Sony Corp., Japan	0.742
2	Murata Mfg., Japan	2.109	7	NGK Insulators, Japan	.600
3	Compagnie de Saint-Gobain, France	1.392	8	Cooper Industries, United States	.557
4	Philips Electronics, Netherlands	1.145	9	Noritake Co., Japan	.373
5	Corning Inc., United States	1.115	10	General Motors Corp., United States	.324

Total sales (top 10) = $11.144 billion.
Total sales (United States) = $1.996 billion.
Percentage (United States) = 18%.

Source: Ceramic Industry.

TABLE 7

ESTIMATED 1992 U.S. SALES OF ADVANCED CERAMICS, BY TECHNOLOGY

Electronic ceramics		Ceramic coating		Engineering ceramics		Total advanced ceramics	
Quantity (thousand metric tons)	Value (billion dollars)	Quantity (thousand metric tons)	Value (billion dollars)	Quantity (thousand metric tons)	Value (billion dollars)	Quantity (thousand metric tons)	Value (billion dollars)
67.0	2.324	49.0	0.654	8.3	0.195	124.5	3.173

Note.—In future years, Kline & Co. will expand study to include: optical fibers, and other hi-tech devices. Presently, no nonproprietary studies exist on U.S. advanced ceramics sales. In 1992, Ceramic Industry's annual survey expanded to worldwide because of international ownership of pertinent U.S. corporations.

Source: Kline & Co., Inc.

TABLE 8

SURVEY OF WORLD SALES OF ADVANCED CERAMICS, BY TECHNOLOGY

(Million dollars)

Year	Capacitors packaging	Other electronics	Low-voltage porcelain	Optical fiber	Engineering ceramics	Other[1]	Total
1990	6,525	2,310	1,663	1,224	1,359	513	13,594
1991	5,753	3,758	1,534	1,994	1,688	614	15,341
1992	5,334	3,408	1,778	1,185	1,185	1,926	14,816

[1]Includes ferrites and high-voltage porcelain.

Source: Ceramic Industry.

TABLE 9

U.S. POLYMER COMPOSITES SHIPMENTS[1]

(Thousand metric tons)

Markets	1987	1988	1989	1990	1991	1992	1993[2]
Aircraft/aerospace/military	16	18	19	18	18	15	15
Appliance/business equipment	64	68	68	69	61	65	68
Construction	230	225	213	212	191	219	232
Consumer products	76	77	72	75	68	73	78
Corrosion-resistant equipment	149	158	152	159	161	151	153
Electrical/electronic	97	104	104	109	105	118	124
Marine	187	205	184	170	125	138	146
Transportation	298	315	307	320	309	340	363
Other	34	36	34	36	34	38	40
Total	1,151	1,206	1,153	1,168	1,072	1,157	1,219

[1]Includes thermoset and thermoplastic resin composites, reinforcements, and fillers.
[2]Forecast released Feb. 1993.

Source: SPI Composites Institute.

TABLE 10

ESTIMATED 1992 AND PROJECTED 2002 WORLDWIDE ADVANCED POLYMER COMPOSITES SHIPMENTS, BY END USE

	Worldwide (thousand metric tons)		United States (thousand metric tons)		Rest of World (R.O.W.) (thousand metric tons)		Average annual growth rate (percent)		
	1992	2002	1992	2002	1992	2002	World	U.S.	R.O.W.
Aircraft	4.1	8.4	2.4	4.4	1.8	4.0	7.4	6.5	8.5
Missiles/space	2.6	3.2	1.7	1.9	.9	1.4	2.1	1.0	4.0
Recreation	2.2	3.5	1.2	2.2	1.0	1.4	5.0	6.0	3.5
Armor	1.9	3.1	1.1	2.0	.8	1.2	5.4	6.0	4.5
Automotive	.3	2.9	—	2.6	.2	.3	26.7	50.0	2.0
Industrial/other	2.6	4.1	1.0	1.5	1.6	2.6	4.6	4.0	5.0
Total	13.7	25.2	7.4	14.6	6.3	10.9	6.4	7.0	5.6

Source: Kline & Co., Inc.

TABLE 11

COMPARISON OF ESTIMATED U.S. AND WORLD MARKET SHIPMENTS FOR END-USE METAL MATRIX COMPOSITES

Year	Automotive		Aerospace		Recreation		Industrial/other		Total	
	Value (million dollars)	Weight (metric tons)	Value (million dollars)	Weight (metric tons)	Value (million dollars)	Weight (metric tons)	Value (million dollars)	Weight (metric tons)	Value (million dollars)	Weight (metric tons)
ESTIMATED U.S. MARKET SHIPMENTS										
1990	—	—	—	—	—	—	—	—	36.0	164
1991	4.0	77	26.0	66	2.0	5	1.0	2	33.0	150
1992	3.7	121	24.0	67	.8	8	.4	6	28.9	202
ESTIMATED WORLD MARKET SHIPMENTS										
1990	15.6	441	42.0	82	1.2	11	1.2	11	60.0	545
1991	12.0	336	39.7	87	1.0	9	1.3	11	54.0	445
1992	15.5	440	37.7	92	1.4	11	1.5	13	56.1	557

Source: Kline & Co., Inc.

TABLE 12

ESTIMATED 1992 AND PROJECTED 2002 WORLDWIDE METAL MATRIX COMPOSITES SHIPMENTS, BY END USE

	Worldwide (metric tons)		United States (metric tons)		Rest of world (R.O.W.) (metric tons)		Average annual growth rate (percent)		
	1992	2002	1992	2002	1992	2002	World	U.S.	R.O.W.
Automotive	440.0	974.2	120.7	374.8	319.3	599.4	8.3	12.0	6.5
Aerospace	92.1	117.8	67.1	90.2	24.9	27.6	2.5	3.0	1.0
Recreation	11.3	19.1	8.2	14.6	3.2	4.5	5.4	6.0	3.5
Industrial/other	13.2	20.6	5.4	8.1	7.7	12.6	4.6	4.0	5.0
Total	556.6	1,131.7	201.4	487.7	355.1	644.1	9.2	6.1	7.4

Source: Kline & Co., Inc.

TABLE 13

COMPARISON OF ESTIMATED U.S. AND WORLD MARKET SHIPMENTS FOR END-USE CARBON-CARBON COMPOSITES

Year	Aircraft brakes		Rocket nozzles		Nose tips ablatives		Racing brakes		Industrial/ other		Total	
	Value (million dollars)	Weight (metric tons)	Value (million dollars)	Weight (metric tons)	Value (million dollars)	Weight (metric tons)	Value (million dollars)	Weight (metric tons)	Value (million dollars)	Weight (metric tons)	Value (million dollars)	Weight (metric tons)
ESTIMATED U.S. MARKET SHIPMENTS												
1990	—	—	—	—	—	—	—	—	—	—	152.0	227
1991	32.2	120	21.5	11	65.6	23	3.5	9	4.2	7	125.0	170
1992	30.7	112	20.0	12	60.5	20	4.4	13	4.4	10	120.0	167
ESTIMATED WORLD MARKET SHIPMENTS												
1990	50.0	212	70.0	46	64.0	28	(1)	(1)	16.0	21	200.0	307
1991	37.5	147	35.5	22	88.0	32	6.2	18	7.8	15	175.0	234
1992	36.8	143	33.9	21	84.6	28	7.8	21	7.4	16	171.0	229

[1]Not included as end use in 1990.

Source: Kline & Co., Inc.

TABLE 14

ESTIMATED 1992 AND PROJECTED 2002 CARBON-CARBON COMPOSITES SHIPMENTS, BY END USE

	Worldwide (metric tons)		United States (metric tons)		Rest of World (R.O.W.) (metric tons)		Average annual growth rate (percent)		
	1992	2002	1992	2002	1992	2002	World	U.S.	R.O.W.
Aircraft brakes	142.4	233.6	111.6	178.3	30.8	55.2	5.1	4.8	6.0
Nose tips/ablative	27.7	25.4	19.5	15.9	8.2	9.5	-.8	-2.0	1.5
Rocket nozzles	20.9	18.6	12.2	9.0	8.6	9.5	-1.2	-3.0	1.0
Racing brakes	21.3	46.8	12.7	30.6	8.6	16.2	8.2	9.2	6.5
Industrial/other	16.3	37.4	9.5	27.8	6.8	9.6	8.6	11.3	3.5
Total	228.6	361.7	165.6	261.7	63.0	100.0	4.7	4.7	4.7

Source: Kline & Co., Inc.

TABLE 15

FACTORY SHIPMENTS OF SEMICONDUCTOR DEVICES

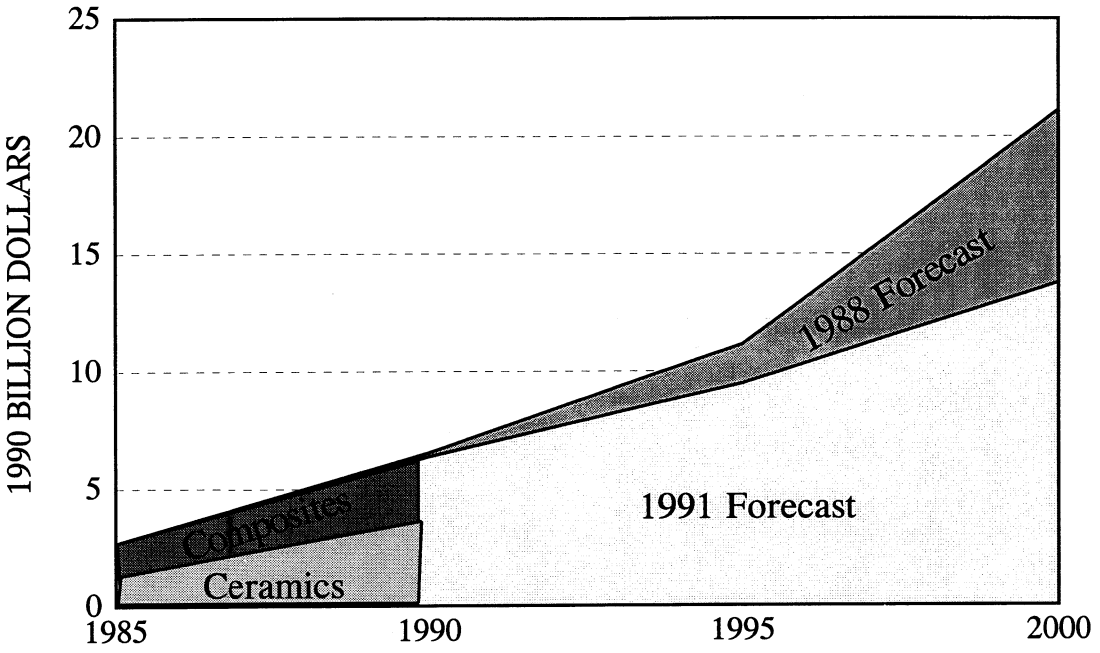
(Million dollars)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Integrated circuits										
MOS IC's	3,334.1	3,559.2	4,895.9	6,119.1	4,702.8	4,719.9	6,089.7	7,956.4	8,867.3	8,565.0
Bipolar IC's	1,989.0	2,143.8	2,746.5	5,218.1	4,710.1	4,530.7	4,896.5	4,975.8	5,353.7	5,175.0
Other IC's	1,653.3	1,618.7	1,218.3	1,622.9	1,393.1	1,565.0	1,864.3	1,932.4	1,778.6	1,725.0
Total	6,976.4	7,321.7	8,860.7	12,960.1	10,806.0	10,815.6	12,850.5	14,864.6	15,999.6	15,465.0
Signal	310.7	250.6	272.5	384.1	263.2	282.9	294.7	335.8	266.2	235.0
Power	326.9	346.2	353.3	439.6	392.1	404.7	458.4	528.3	562.8	545.0
Total	637.6	596.8	625.8	823.7	655.3	687.6	753.1	864.1	829.0	780.0
Diodes and rectifiers										
Light-emitting diodes	166.2	161.6	195.0	99.1	49.1	34.4	46.4	48.1	52.6	56.0
Other	615.5	493.5	541.1	661.6	706.2	651.1	733.6	806.9	741.1	659.0
Total	781.7	655.1	736.1	760.7	755.3	685.5	780.0	855.0	793.7	715.0
Other semiconductor devices										
Thyristors	128.5	87.0	94.1	126.2	125.4	137.6	108.9	142.6	144.4	150.0
Solar cells	36.3	46.2	47.8	48.5	33.5	36.6	48.1	47.5	35.9	35.0
Other	1,748.4	2,021.9	2,205.7	2,312.5	2,275.2	2,062.7	2,245.6	3,016.2	4,573.0	4,805.0
Total	1,913.2	2,155.1	2,347.6	2,487.2	2,434.1	2,236.9	2,402.6	3,206.3	4,753.3	4,990.0
Grand total	10,308.9	10,728.7	12,570.2	17,031.7	14,650.7	14,425.6	16,786.2	19,790.0	22,375.6	21,950.0

Source: 1991 Electronic Market Data Book.

FIGURE 1

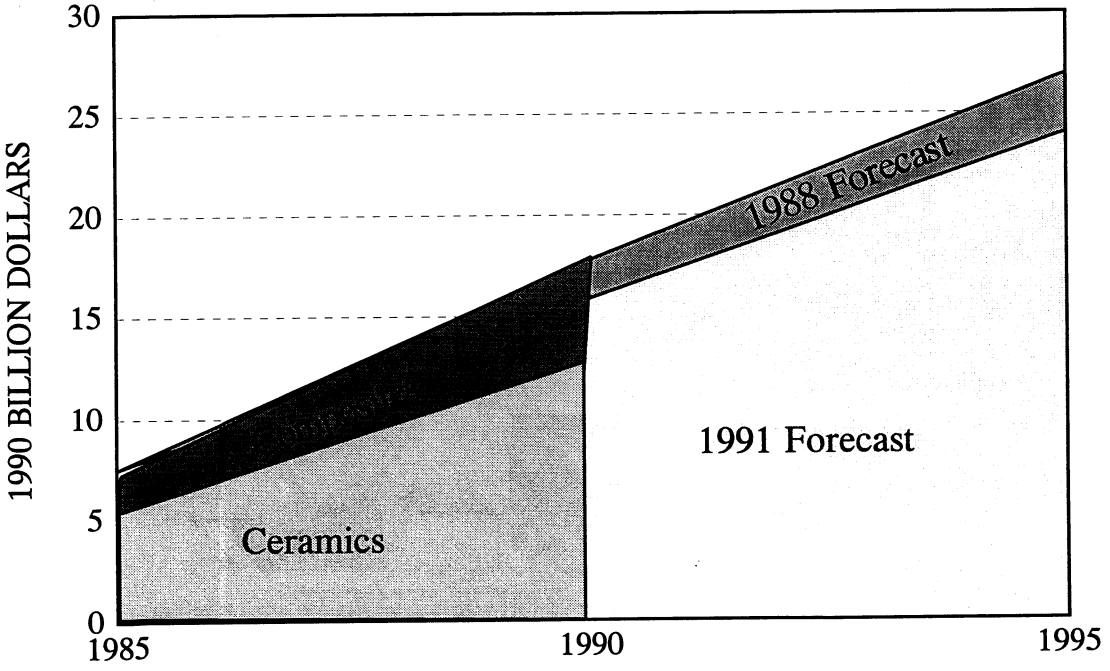
ADVANCED MATERIALS TRENDS AND FORECASTS—U.S. OUTLOOK



Source: Kline & Co., Inc.

FIGURE 2

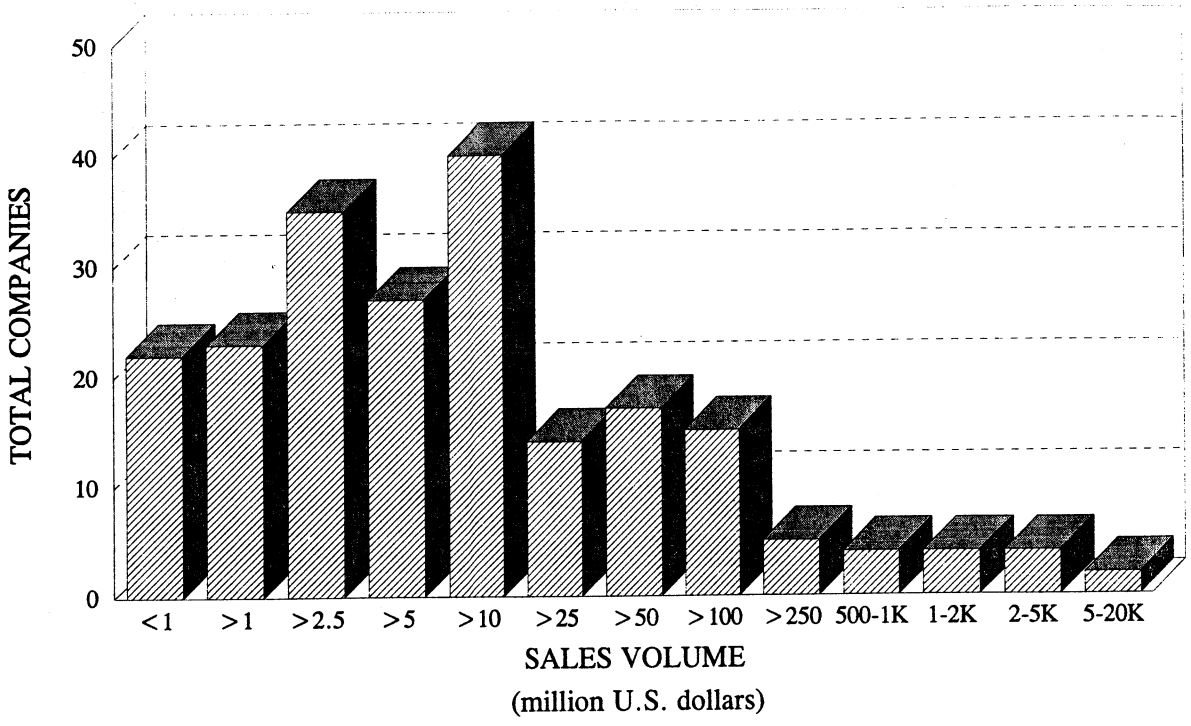
ADVANCED MATERIALS TRENDS AND FORECASTS—WORLD OUTLOOK



Source: Kline & Co., Inc.

FIGURE 3

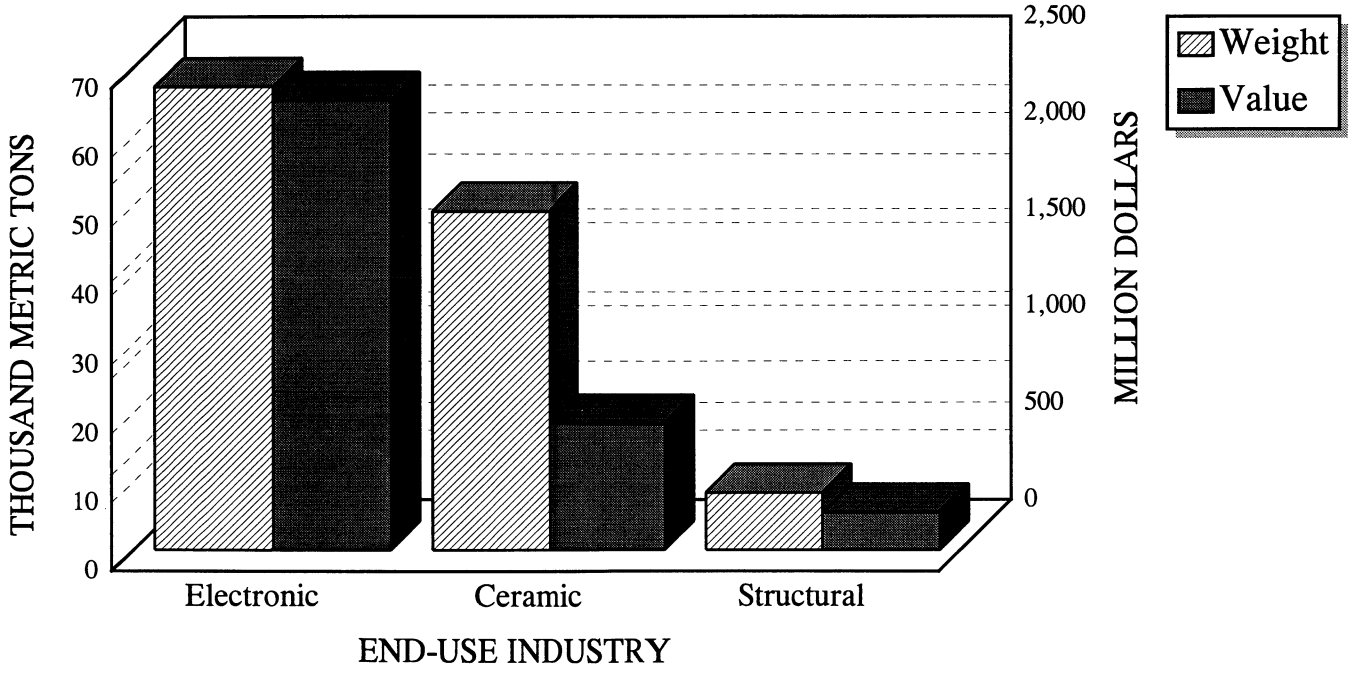
ADVANCED CERAMICS PRODUCERS, BY TOTAL ANNUAL SALES IN 1992 (UNITED STATES)



Source: CorpTech.

FIGURE 4

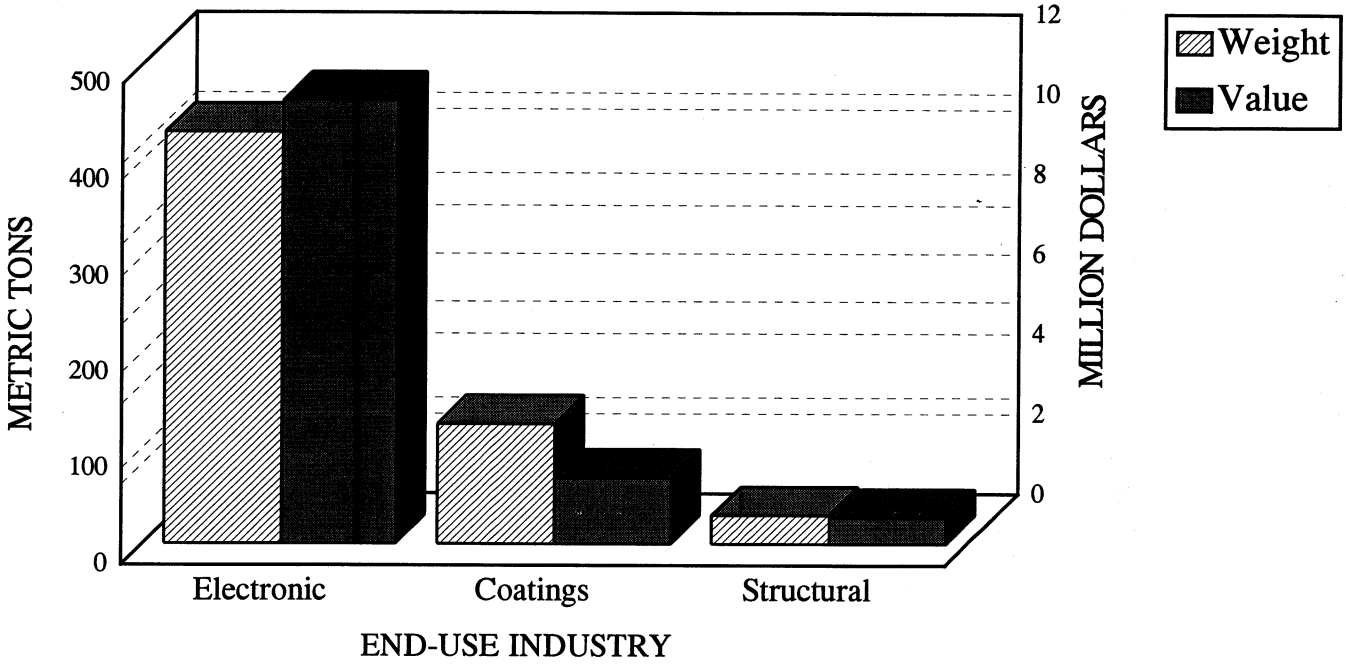
ESTIMATED U.S. MARKET FOR ADVANCED CERAMICS, BY END USE, 1992



Source: Kline & Co., Inc.

FIGURE 5

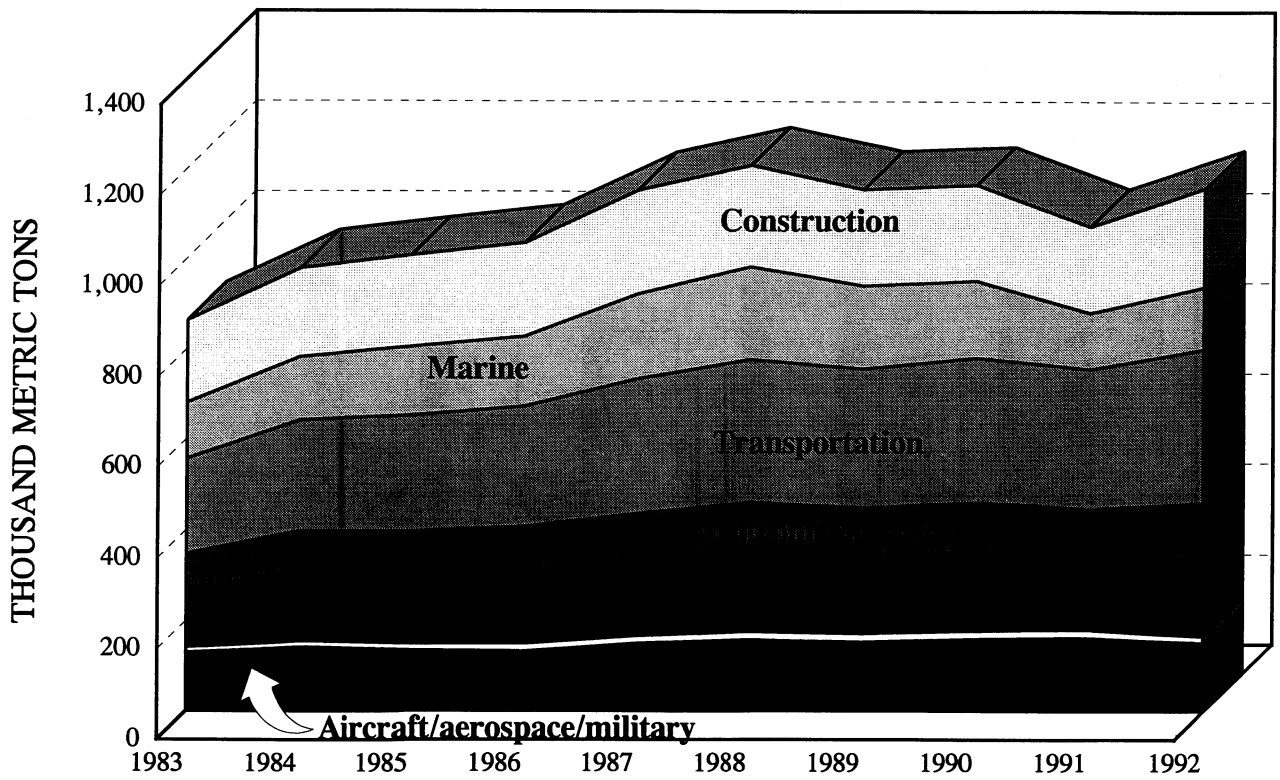
ESTIMATED WORLD MARKET FOR ADVANCED CERAMICS, BY END USE, 1991



Source: Kline & Co., Inc.

FIGURE 6

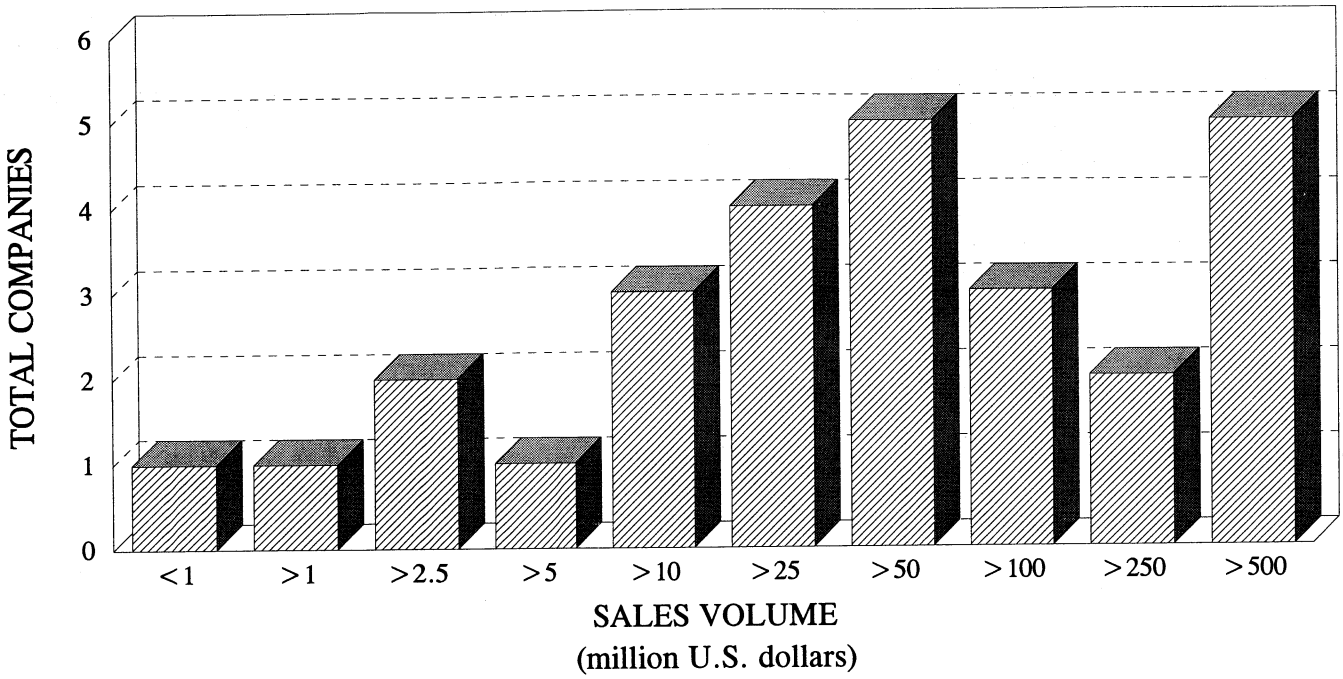
U.S. POLYMER COMPOSITES SHIPMENTS, 1983-92



Source: SPI Composites Institute.

FIGURE 7

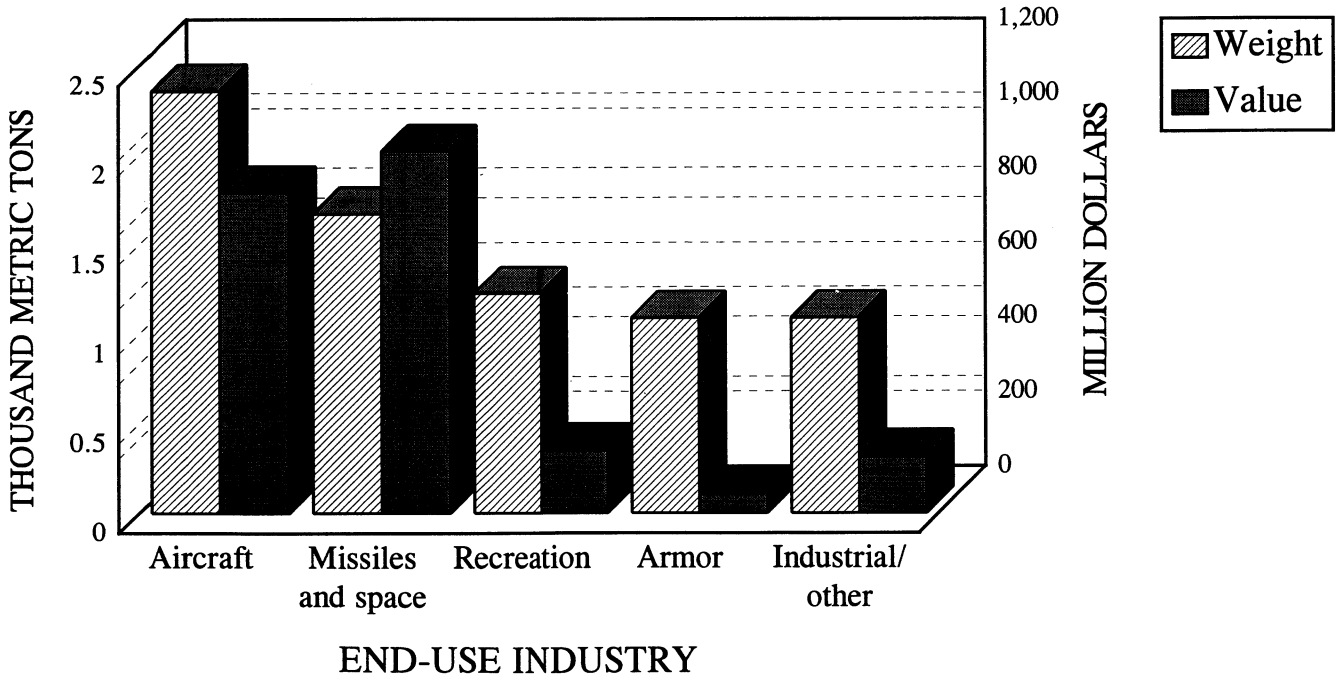
ADVANCED POLYMER COMPOSITES PRODUCERS, BY ANNUAL TOTAL SALES IN 1992 (UNITED STATES)



Source: SACMA, CorpTech.

FIGURE 8

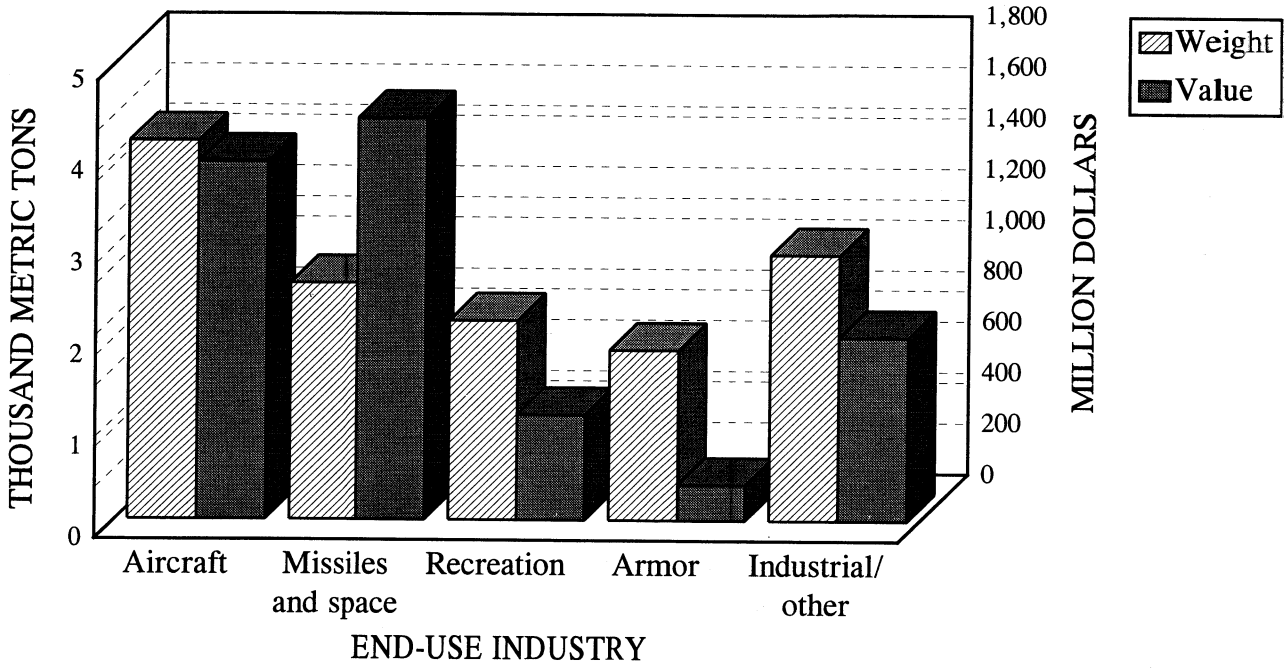
ESTIMATED U.S. MARKET FOR ADVANCED POLYMER COMPOSITES, BY END USE, 1992



Source: Kline & Co., Inc.

FIGURE 9

ESTIMATED WORLD MARKET FOR ADVANCED POLYMER COMPOSITES, BY END USE, 1992

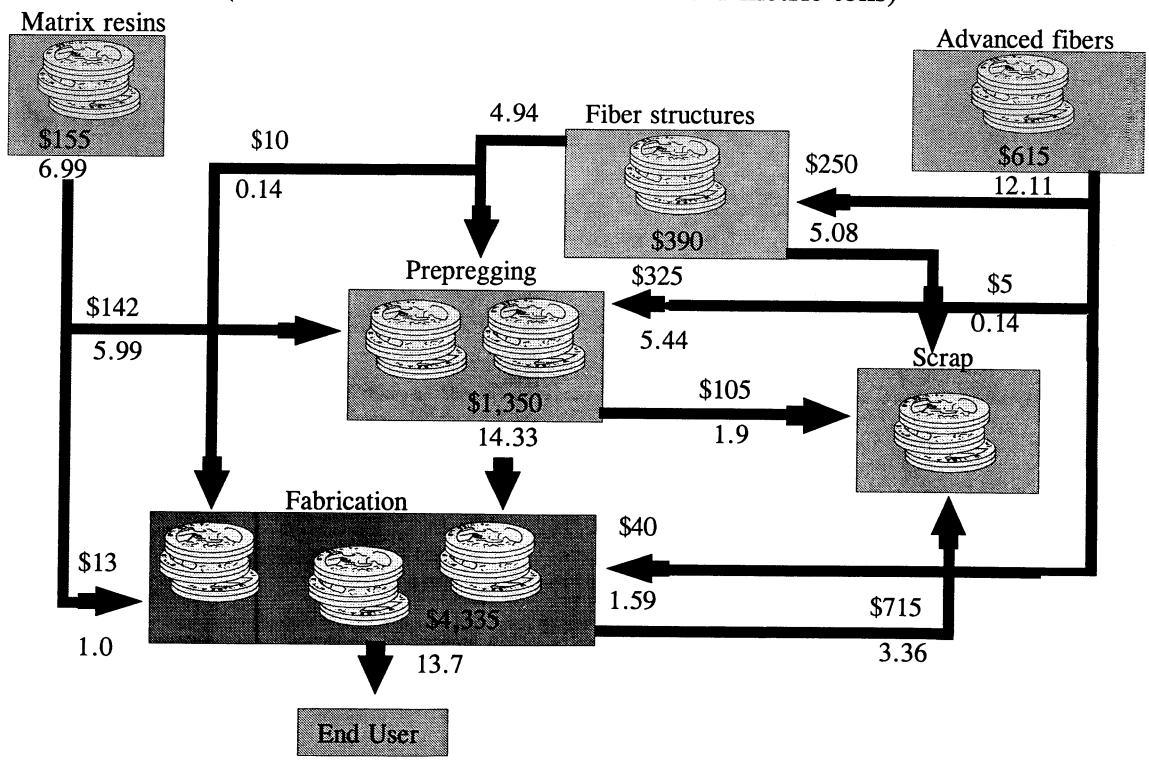


Source: Kline & Co., Inc.

FIGURE 10

OVERVIEW OF THE WORLD ADVANCED POLYMER COMPOSITES INDUSTRY, 1992

(values in million dollars and thousand metric tons)

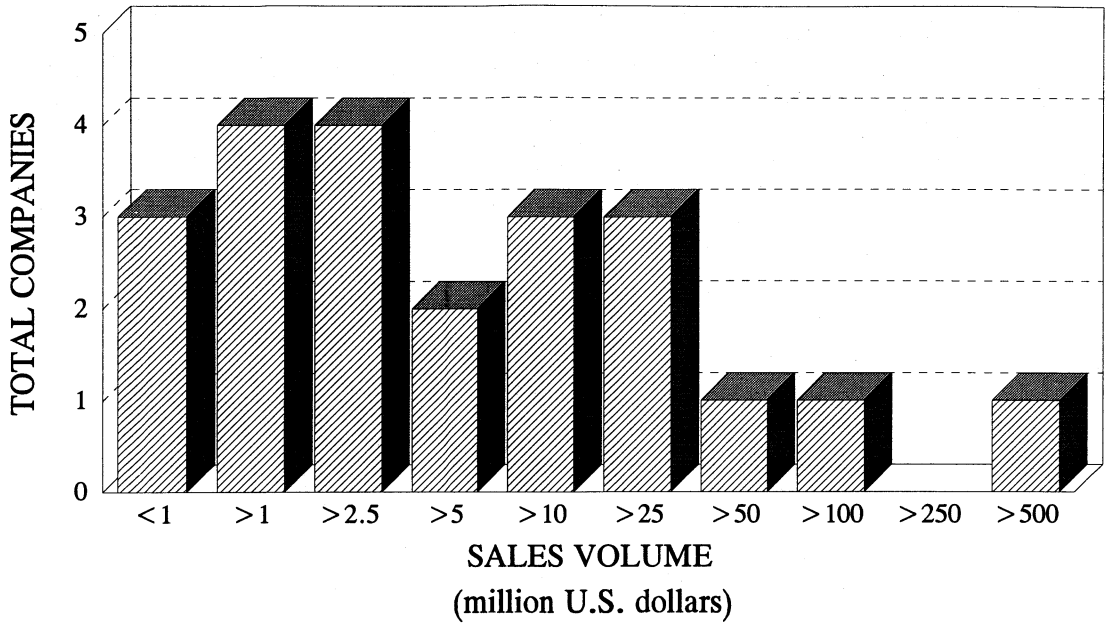


Note.--Value is added at each stage.

Source: Kline & Co., Inc.

FIGURE 11

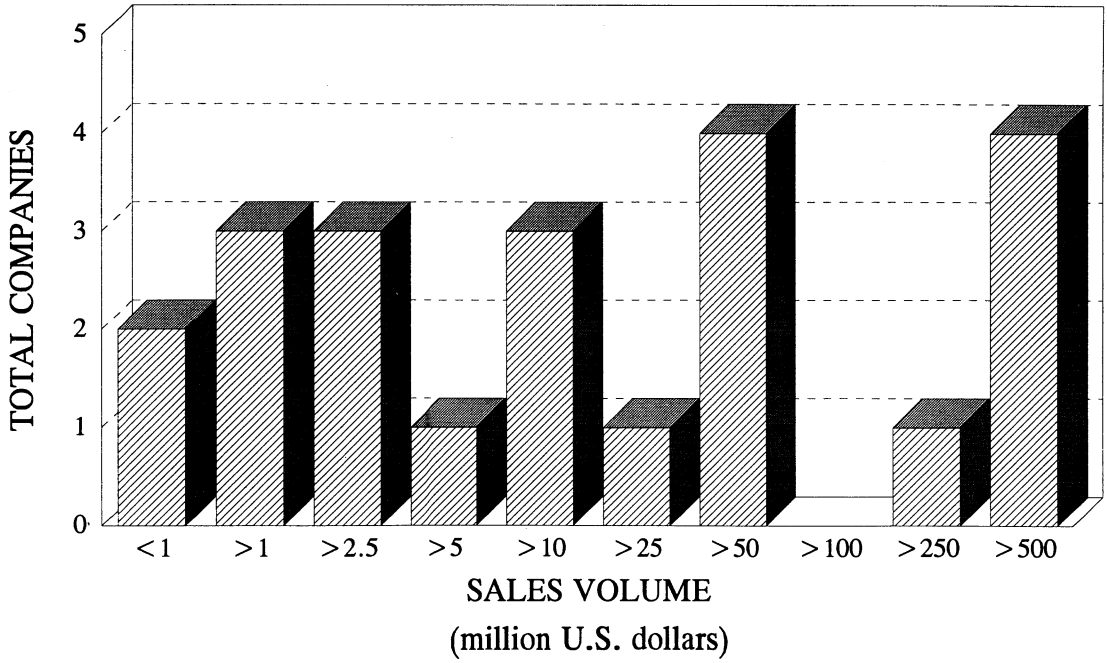
METAL MATRIX COMPOSITES PRODUCERS, BY ANNUAL TOTAL SALES IN 1992 (UNITED STATES)



Sources: CorpTech., T. Moss, and Advanced Composites.

FIGURE 12

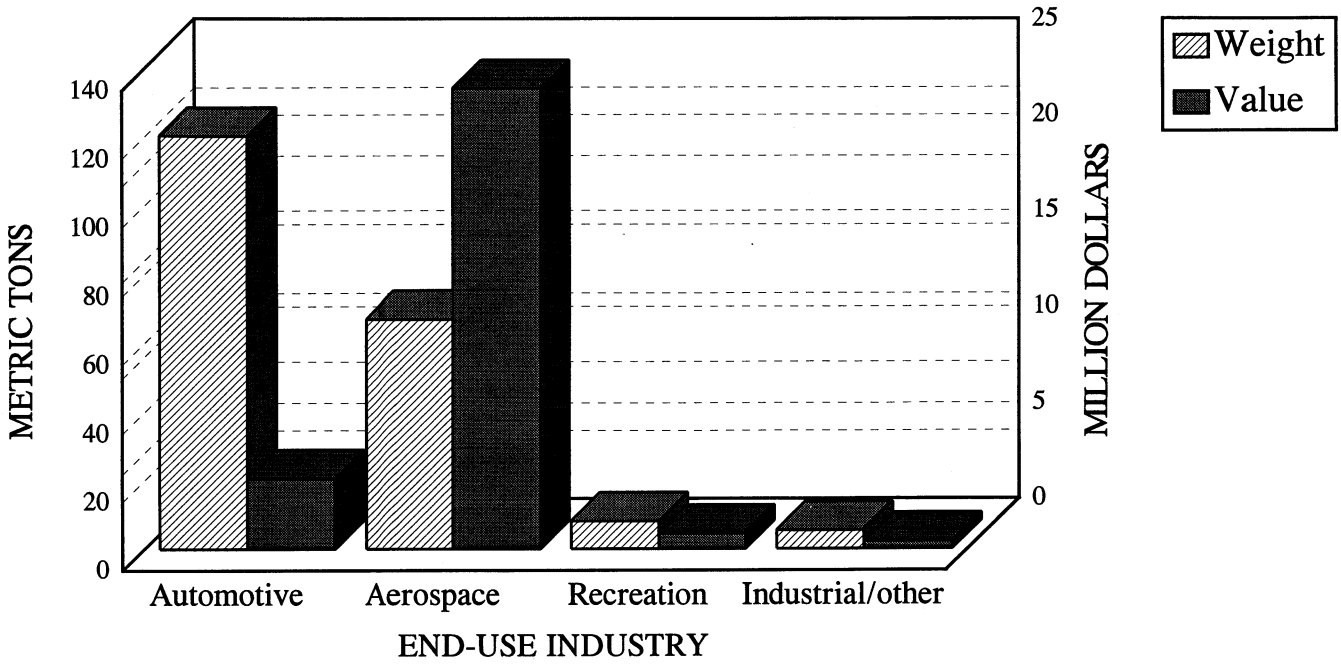
CARBON-CARBON COMPOSITES PRODUCERS, BY ANNUAL TOTAL SALES IN 1992 (UNITED STATES)



Source: CorpTech.

FIGURE 13

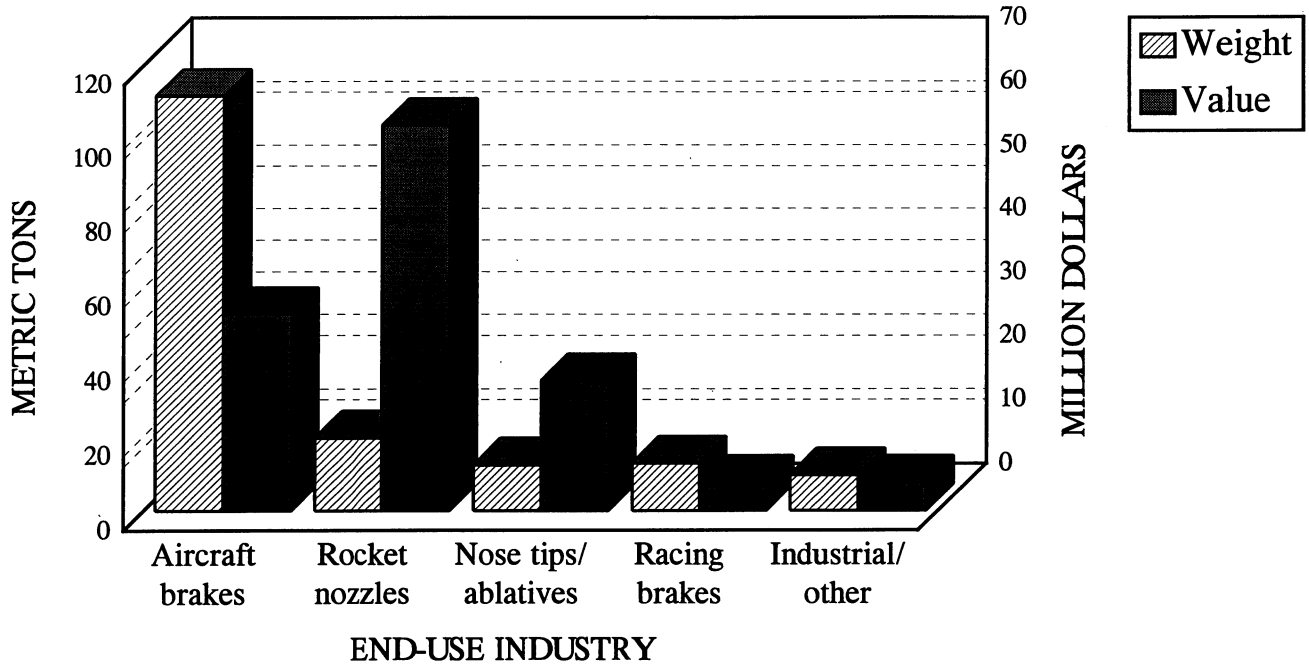
ESTIMATED U.S. MARKET FOR METAL MATRIX COMPOSITES, BY END USE, 1992



Source: Kline & Co., Inc.

FIGURE 14

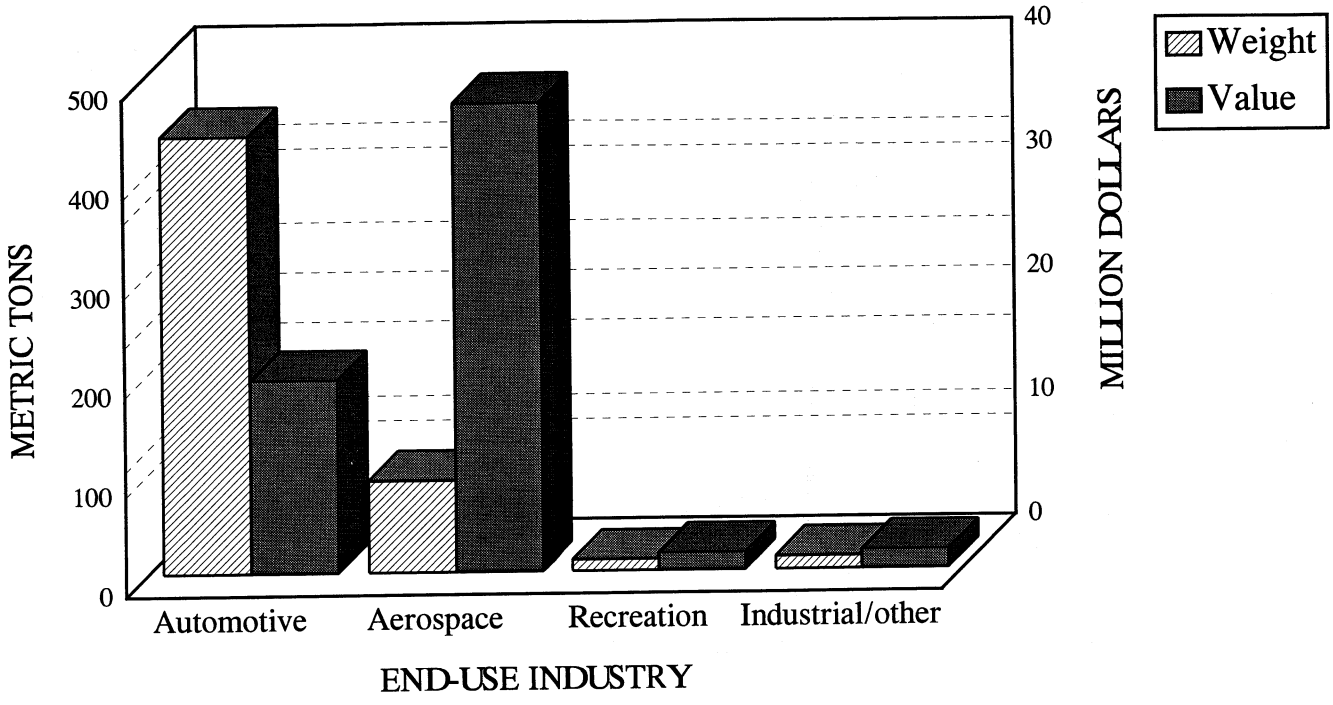
ESTIMATED U.S. MARKET FOR CARBON-CARBON COMPOSITES, BY END USE, 1992



Source: Kline & Co., Inc.

FIGURE 15

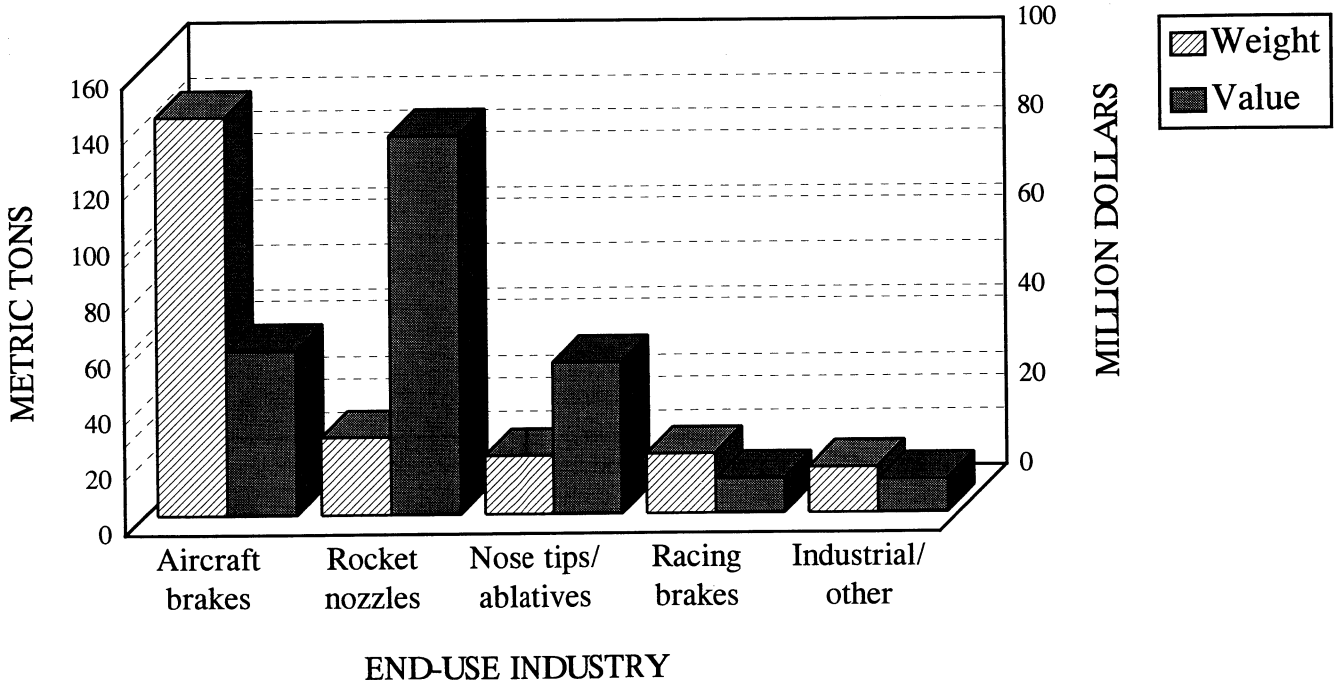
ESTIMATED WORLD MARKET FOR METAL MATRIX COMPOSITES, BY END USE, 1992



Source: Kline & Co., Inc.

FIGURE 16

ESTIMATED WORLD MARKET FOR CARBON-CARBON COMPOSITES, BY END USE, 1992



Source: Kline & Co., Inc.

FIGURE 17

USES OF INTEGRATED CIRCUITS BY INDUSTRY, 1983-92

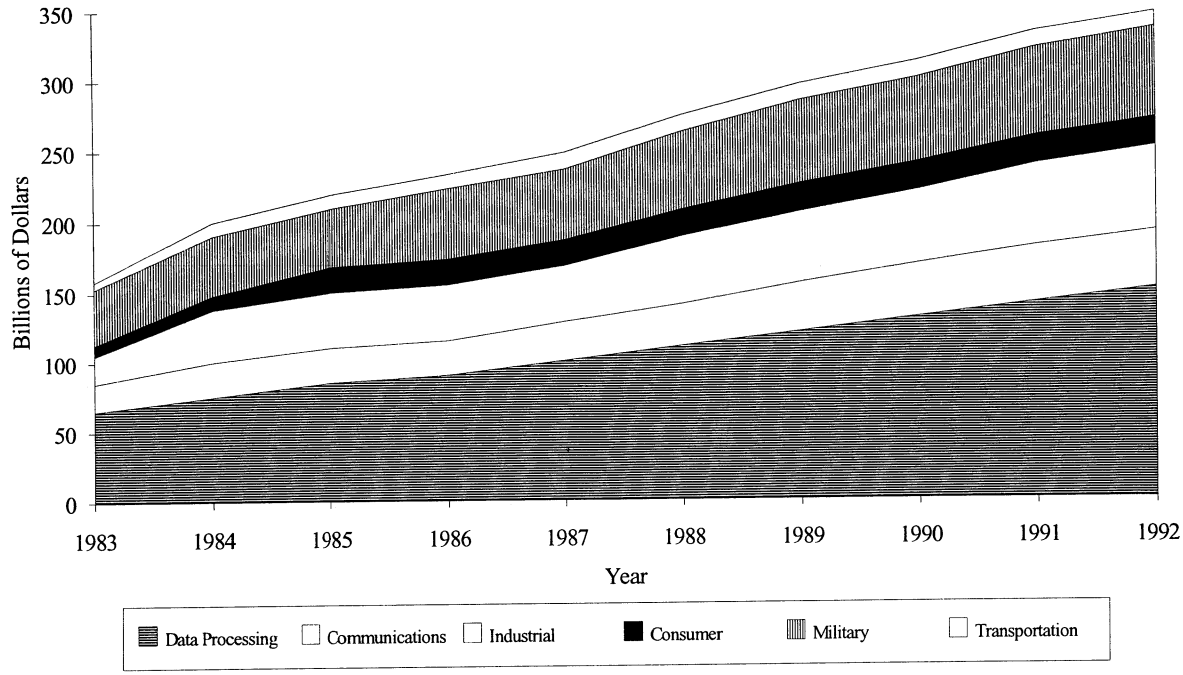
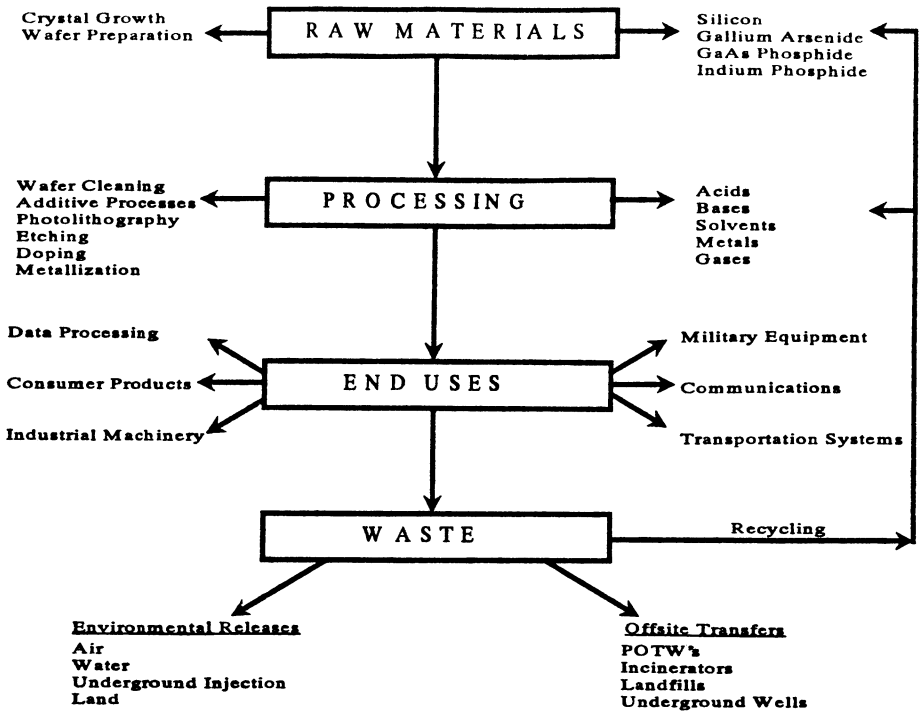


FIGURE 18

INTEGRATED CIRCUIT FABRICATION FLOW CHART



Source: U.S. Bureau of Mines

ALUMINUM, BAUXITE, AND ALUMINA

By Patricia A. Plunkert and Errol D. Sehnke

Ms. Plunkert, a physical scientist with 24 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 team leader; and international data tables were prepared by Audrey D. Wilkes, international data coordinator.

Mr. Sehnke is a physical scientist with 19 years of minerals industry and U.S. Bureau of Mines experience. Domestic survey data for bauxite and alumina were prepared by David W. Chilton, statistical assistant; and international data tables were prepared by Harold D. Willis, international data coordinator.

Aluminum is the second most abundant metal element in the Earth's crust after silicon, yet it is a comparatively new industrial metal that has been produced in commercial quantities for slightly more than 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.

World demand for aluminum remained at depressed levels throughout 1992. The increase in aluminum activity evident in the United States did not occur in most of the other areas of the world. Despite some small decreases in the production of primary metal, world inventory levels continued to rise. The United States continued to be the world leader in primary metal production, producing more than 4 million metric tons of metal with an estimated value of $5.1 billion.

World production of bauxite and alumina, feedstocks for the aluminum industry, decreased by modest amounts in response to the faltering world economy, stagnation in primary aluminum metal output, and a continued flow of aluminum exports from the newly independent republics of the former U.S.S.R. Mine production of bauxite was reported from 28 countries, and alumina was produced in 29 countries.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for aluminum, bauxite, and alumina are developed by the U.S. Bureau of Mines (USBM) 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 naturally occurring, heterogeneous material composed primarily of one or more aluminum hydroxide minerals and various mixtures of aluminosilicate (clay, etc.), iron oxide, silica, titania, and other impurities in minor or trace amounts.[1] The principal aluminum hydroxide minerals found in varying proportions within bauxites are: gibbsite, $Al(OH)_3$, the trihydrate; and the monohydrate polymorphs boehmite and diaspore, both AlOOH. Domestic bauxites and those imported from Brazil and Guyana are of the trihydrate gibbsitic type. Imports from the Sangaredi deposit of Guinea and the north coast of Jamaica are predominantly gibbistic, 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 called for in processing gibbsite.

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 13.5 kilograms (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 Inc. 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.

Industry Structure

The aluminum industry is truly a worldwide industry. It is impossible to discuss the domestic industry without relating it to the total world aluminum industry. To more fully understand the global market in which the U.S. industry is competing, it is necessary to discuss the U.S. position in each of the individual components of aluminum supply—bauxite, alumina, and aluminum metal.

World bauxite resources (reserves plus subeconomic and undiscovered deposits) are currently estimated to be 55 to 75 billion tons. These resources are mainly in South America (33%), Africa (27%), Asia (17%), and Oceania (13%). Mine production during the past 30 years has moved from North America and Europe to these bauxite-endowed regions of the world. U.S. mine production has decreased from about 2 million tons in 1960 to only 588,000 tons in 1988, the last year for which releasable data were available from the USBM.

Presently, there are only three companies conducting bauxite mining operations in the United States. Their mines are in Alabama and Georgia, and they do not produce bauxite for metal production. The bauxite produced by these operations traditionally has been used for refractory, chemical, and other specialized applications. The United States is entirely dependent on foreign sources for metallurgical-grade bauxite. What aluminum metal resources the United States does have are low-grade bauxite substitute materials, which are not currently economic to exploit. To utilize these domestic alternative sources of alumina, an entirely new processing industry would have to be designed and developed. The United States currently receives most of its metallurgical-grade bauxite from Australia, Guinea, and Jamaica.

Bauxite imports are shipped to five domestic alumina plants, which produce smelter-grade alumina for the primary metal industry. These alumina refineries are in Louisiana, Texas, and the U.S. Virgin Islands. Even if these five refineries operated at full capacity levels and sold their product exclusively to the domestic metal smelters, the U.S. supply of alumina would be inadequate to meet the demand of the country's primary metal industry. Therefore, the United States must use imported alumina to supplement its domestic requirements, and Australia has become the principal source of these imports. A developing trend in world alumina production patterns has been the construction of alumina plants near areas of bauxite mining. More and more nations with bauxite reserves are realizing the economic advantages of processing the bauxite ore closer to the mine site and exporting the higher valued alumina product. In addition to providing a value added product for the raw material-producing country, this practice also reduces the bulk transportation requirements of the aluminum industry.

In the 1960's, the United States accounted for more than 50% of the world's production of alumina. By the mid-1970's, Australia had surpassed the United States as the world's predominant alumina producer. In addition to this change in the world alumina production picture, several countries, which either did not have an alumina industry or were very minor producers in the 1950's and 1960's, have taken on a much stronger role. Some of these countries with an expanding or newly developed alumina industry are Brazil, Greece, India, Ireland, Spain, Suriname, and Venezuela.

Although the United States continues to be the leading producer of primary aluminum metal in the world, its dominance in the industry has begun to wane. As late as the mid-1960's, the United States accounted for about 40% of the world's production. However, by 1992, the U.S. share of world production

had decreased to 21%. Most of the restructuring of the world aluminum industry began in the late 1970's and continues to this day. Australia and Canada have emerged as major metal producers. Japan, which had produced more than 1 million tons of aluminum as late as 1980, today produces only about 20,000 tons of primary metal. Other countries that have recently entered the world market are Brazil, China, Norway, Venezuela, and several countries in the Persian Gulf region.

The driving force for most of these changes was the cost of energy. In the early 1980's, the price of aluminum ingot decreased, an oversupply situation existed, and energy costs increased. These factors put pressure on aluminum companies to close their plants with high operating costs and low energy efficiencies. This was especially evident in the United States and Japan. Recent smelter expansions and new plant construction have been focused on areas of the world with access to low-cost energy and labor. Brazil, Canada, and Venezuela, for example, have access to hydroelectric power sources. Countries in the Persian Gulf are planning to use their abundant natural gas reserves to generate the electricity required for their announced new smelters.

Unlike past practice, when most of the cost for new aluminum plant construction was taken on by a single company, today's new plant construction costs typically are borne by a number of different aluminum companies in joint ventures. Even though the number of different companies producing aluminum has been increasing, there are seven major companies that still control more than 40% of the total Western World primary aluminum production capacity. The leading company is the Aluminum Co. of America (Alcoa), followed by Alcan Aluminium Ltd., Reynolds Metals Co., Alumax Inc., Pechiney, Kaiser Aluminum & Chemical Corp., and Alusuisse-Lonza Holding AG. Most of these companies can be described as fully integrated, having interests in all aspects of the aluminum industry from bauxite mining through semifabricated materials and, in some cases, even end product facilities.

Beginning in 1991, additional pressure was put on an aluminum market already straining under an oversupply situation caused by a slowdown in world economic activity. The pressure came in the form of aluminum metal exports from the republics of the former U.S.S.R. Before the breakup of the U.S.S.R., very little Russian metal appeared in Western World markets. Most of this metal was traded inside the block of centrally planned economy countries. However, with the emergence of newly independent countries, many of the old trading blocks were dissolved, and the search was on for new trading partners.

The dissolution of the U.S.S.R. also has placed strains on economic activity inside these independent republics to the extent that aluminum metal exports were being used as a form of currency to barter for other goods and services. As a result, exports of metal from the former U.S.S.R. averaged about 1 million tons per year in 1991 and 1992. In a market already being hit by a slowdown in economic activity, exports to Western World markets of this magnitude have caused inventory levels to rise and prices to fall. It will take time for the world markets to adjust to this new and potentially major player in the market world economy.

Some of the most dramatic changes in the domestic aluminum industry occurred in the past 12 years. In 1980, there were 11 companies operating 33 smelters with a total annual domestic production capacity of 5 million tons of metal. By 1992, the number of operating companies had increased to 13, but the number of smelters had decreased to 23 with a total annual capacity of about 4 million tons. Low aluminum prices and high operating costs forced domestic aluminum companies to close some of their higher cost operations. Even though 10 smelters were forced to close, the number could have been even greater were it not for some newly formed companies that purchased some of the marginal plants and negotiated new contracts with labor unions and electric utilities that helped to reduce their overall operating costs.

Another new phenomenon that appeared in the domestic industry was the appearance of tolling operations, in which an aluminum plant charges an outside company a fee for converting alumina to metal. In the mid-1980's, some power companies negotiated supply contracts that tied electricity rates to the price of aluminum ingot. The Bonneville Power Administration, which provides power to 10 smelters in the Pacific Northwest, operates under such an arrangement. This pricing method provided domestic aluminum companies with a measure of relief by ensuring lower power costs during times of depressed prices. Major labor unions also provided concessions by negotiating lower hourly wage increases in exchange for a share in company profits.

Another factor that should be considered in analyzing the domestic aluminum industry is the growing importance of secondary aluminum to the domestic supply situation. Secondary aluminum is defined as aluminum recovered from both new and old purchased scrap. In 1960, almost 400,000 tons of aluminum was recovered from new and old scrap. In 1992, almost 2.8 million tons of aluminum was recovered from scrap. More than 1.6 million tons of this secondary aluminum was recovered from post consumer, or old, scrap.

Growing concerns over waste disposal have placed increased emphasis on the recycling of materials. Both in the United States and abroad, aluminum companies are promoting the fact that aluminum has a mature recycling industry. Not only does recycling of aluminum help to conserve landfill space, it also helps to save energy. It has been estimated that the recycling of aluminum consumes only about 5% of the energy required to produce aluminum metal from bauxite ore.

The United States remains the largest consumer of aluminum in the world. The container and packaging industry accounts for about 30% of domestic aluminum consumption. This industry is followed by the transportation, construction, and

electrical industries. The U.S. demand profile, however, does not reflect the demand pattern found in other parts of the world. World demand patterns, in general, show a much larger percentage of aluminum consumed by the construction and transportation industries and less by the packaging industry.

ANNUAL REVIEW—ALUMINUM

Domestic primary aluminum production decreased in 1992 for the first time since 1986. Despite this slight decrease, the United States remained the world's largest producer of primary aluminum metal. The average annual metal price decreased, continuing a trend that began in 1989, and reached its lowest level since 1986. Despite this continuation of depressed metal prices, domestic smelters, with the exception of the Troutdale, OR, smelter that was closed at the end of 1991, continued to operate at or near their rated capacity levels during most of the year.

The domestic secondary aluminum industry recovered more than 2.7 million tons of metal from purchased new and old scrap. Aluminum recovered from discarded aluminum products (old scrap) accounted for about 60% of this total. UBC scrap continued to be the major component of processed old scrap. The aluminum industry reported that the recycling rate for all-aluminum beverage cans reached a record high of 67.9%. Almost 30% of the apparent demand for aluminum was met by metal recovered from old scrap.

The domestic consumption of aluminum increased in 1992, reflecting an increase in economic activity that was not evident in other areas of the world. With the overall weakness of economic activity in the rest of the world, U.S. exports decreased for the first time since 1986. U.S. imports, however, rebounded and reached their highest level in 5 years. *(See table 1.)*

Legislation and Government Programs

In 1990, the Defense Logistics Agency (DLA) awarded a contract to Alcoa for the upgrade of bauxite to aluminum metal ingots for the National Defense Stockpile (NDS). Delivery of the metal was completed, and the metal began to appear in the published NDS stockpile listings in March 1992. The total quantity of metal delivered under this contract was 55,121 tons, all of which appeared in the NDS inventory publication by June. As of December 31, the NDS stockpile inventory was 57,010 tons of aluminum metal.

Production

Primary.—Domestic primary aluminum production decreased slightly compared with 1991 production levels. At the end of 1992, 1 smelter remained temporarily closed, and the other 22 primary metal smelters were operating at or near full capacity levels.

Ravenswood Aluminum Corp. announced plans to return its 168,000-ton-per-year primary aluminum smelter in Ravenswood, WV, to full capacity production levels at the end of September. The company reported that it would restart the remaining one-half of the smelter's fourth potline that had been out of service since an electrical storm damaged it 11 years ago.

In June, the United Steel Workers of America (USWA) and Ravenswood Aluminum announced that a new 3-year labor contract had been signed, ending a 19-month labor dispute at the primary aluminum complex in Ravenswood, WV. Workers were scheduled to report back to work on June 29. The new contract reportedly included a $2,000 payment for each worker affected by the labor dispute and a $1.25-per-hour wage increase spread over the life of the contract.

In November, the USWA also ratified a new labor contract that covered workers at Ormet Corp.'s Hannibal, OH, primary aluminum smelter. The new agreement, which replaced the old contract set to expire on May 31, 1993, covered the period through May 31, 1996. The new contract reportedly included wage increases of 25 cents per hour in 1993, 20 cents per hour in 1994, and 15 cents per hour in 1995. Officials also announced that employees would receive a signing bonus of $750 on or before December 15, 1992, plus additional unspecified bonuses in 1993 and 1994. The company also announced that the existing profit-sharing program would remain in effect and a new achievement bonus plan had been introduced, under which quarterly bonuses of up to 50 cents per hour worked reportedly would be paid when specified levels of improvement were reached.

Alcan Aluminum Corp. and the Aluminum, Brick, and Glass Workers International Union (ABGWIU) announced the ratification of a new 3-year labor contract covering workers at the 180,000-ton-per-year primary aluminum smelter in Sebree, KY. The new contract reportedly included a $1,500 signing bonus and an additional $500 bonus payable in 1993. Also, the agreement reportedly did not include a pay increase in the first year, but did include hourly increases of 25 cents and 40 cents, respectively, in the succeeding 2 years. The new contract was set to expire on October 28, 1995.

Alcoa and Reynolds announced that an agreement had been reached with the USWA and the ABGWIU to extend for 1 year the labor contract that was set to expire on May 31, 1992. Included in the extension agreement was a $1,000 cash signing bonus, some pension improvements, and the offer of another $500 bonus if a new labor agreement was reached by October 2. However, by yearend, negotiations had failed to bring about a new long-term labor contract, and this 1-year extension was set to expire on May 31, 1993.

The Bonneville Power Administration (BPA) reported that it had reduced by 25% the energy that it normally supplied to its Direct Service Industries (DSI's) on August 21. The restrictions remained in place through the rest of the year. DSI's are large electricity users that include 8 aluminum companies operating 10 smelters in the Pacific Northwest. BPA reported that the cutbacks were necessary owing to the continuation of severe drought conditions, which has lowered

water runoffs in the tributaries of the Columbia River that supply BPA's hydroelectric dams. Adding to the power supply problem was the shutdown of the Washington Nuclear Plant #2 for repairs. Despite the 25% reduction in BPA-supplied power, the affected aluminum smelters, with the exception of Reynolds' Troutdale, OR, smelter, which had been closed at the end of 1991, continued at or near their rated capacity through the end of 1992. This occurred because the DSI's, with BPA acting as agent, were able to secure replacement power, albeit at a higher cost than BPA-supplied electricity.

Logan Aluminum Inc., jointly owned by Atlantic Richfield Co. and Alcan Aluminum, announced the awarding of a $23 million contract to Fluor Daniel Inc. for the expansion of its rolling mill in Russelville, KY. The contract was for engineering, procurement, and construction services for a third melting and casting area in the plant. Fluor Daniel designed and built the original mill in the early 1980's. Since then, Fluor Daniel had performed ongoing maintenance at the facility and reportedly was continuing to work on an expansion project involving the rolling mill and finishing equipment, which was awarded in 1991 and scheduled for completion in late 1993.

Reynolds announced plans to build an aluminum fabricating plant in Auburn, IN. The company indicated that the plant should start production in late 1993 and would produce aluminum extruded products for the automotive industry, such as bumper systems, door extrusion beams, and sunroof tracks. The facility, which would include a 3,000-ton extrusion press, reportedly would have a capacity of 6,350 tons (14 million pounds) per year of extruded products.

Reynolds also reported that it was exiting the North American aluminum conductor cable business with the sale of its cable plants to BICC Cable Corp. The facilities, which were purchased in September, reportedly represented about 100,000 tons of annual capacity and were in Malvern, AR; Marshall, TX; Longview, WA; and La Malbaie, Quebec. In October, BICC announced plans to close the Longview, WA, plant by the first quarter of 1993.

Jupiter Aluminum Corp. announced that it had acquired Advanced Aluminum Products Inc. The Hammond, IN, rolling mill had moved under the protection of U.S. bankruptcy laws in August 1991. *(See table 2.)*

Secondary.—In 1992, the number of companies covered by the USBM aluminum scrap survey increased. This was partially responsible for the large increase in recovered secondary aluminum compared with that of the previous year. Also, the secondary data for 1991 were revised downward, owing to a double-counting error that did not become evident until this year.

According to a survey conducted by the Aluminum Association Inc., the Institute of Scrap Recycling Industries, and the Can Manufacturers Institute, the recycling rate for all-aluminum beverage cans reached a record high; 62.74 billion aluminum UBC's were recycled in 1992. The recycling rate was 67.9%, up from the 1991 rate of 62.4%.

The three largest domestic automakers, Chrysler Corp., Ford Motor Co., and General Motors Corp., announced the formation of the Vehicle Recycling Partnership (VRP) to research and promote the recovery and reuse of materials from junked cars. According to the companies, the partnership was expected to propose methods for increasing the amount of recycled materials used in autos and trucks as well as recovering more from the vehicles. The automakers also stated that the partnership was expected to look into developing industry guidelines in such areas as materials selection and compatibility, bonding methods and materials, painting, and design for disassembly. Research in these areas reportedly would be carried out in the laboratories of the three automakers and by other industries, universities, and research institutes.

Barmet Aluminum Corp. and IMCO Recycling Inc. announced plans to construct a $16 million, 120,200-ton-per-year (265-million-pound-per-year) aluminum recycling facility to be situated near Barmet's Urichsville, OH, rolling mill. Under the reported agreement, IMCO would have the exclusive rights to recycle Barmet-purchased scrap at this plant for a period of 10 years. As the new plant comes on-stream, Barmet's recycling plant at Urichsville will be phased out. The plant, which reportedly would recycle UBC's and dross and would increase IMCO's aluminum recycling capacity by 50%, was expected to be fully operational by mid-1993.

U.S. Reduction Co. reported that construction had begun on a new 27,220-ton-per-year (60-million pound-per-year) aluminum recycling plant in Tipton, IN. The company expected the plant to reach full capacity by the second quarter of 1993. The plant reportedly would provide specification liquid metal and ingot to aluminum automotive diecasters and foundries.

Aluminum Smelting and Refining Inc. reported that the company had closed its secondary aluminum plant. The decision to close the privately owned plant reportedly came after months of attempts to sell the company had failed. *(See tables 3, 4, and 5.)*

Consumption and Uses

The container and packaging industry remained the largest domestic consumer of aluminum products, representing about 28% of total U.S. shipments of aluminum products. The Can Manufacturers Institute reported that almost 92.8 billion aluminum beverage cans were shipped in 1992, representing about 97% of the total metal beverage can shipments.

Anheuser-Busch announced the development of a new can design that reportedly would save the company about 9,000 tons of aluminum per year. Anheuser-Busch, which filled and marketed about 17 billion aluminum cans per year, also reported that it planned to offer the new design to other soft-drink and beer companies. The new can had a lid 0.32 centimeter (one-eighth inch) smaller in diameter than lids used by most of the industry and maintained the

same label area and stackability as previous designs.

Reynolds and Ball Corp. announced the development of a new beverage can necking process and equipment that reportedly would permit the use of smaller can ends and reduce metal requirements for can bodies. The company reported that the Spin Flow machine could process more than 2,000 cans per minute and reduced metal requirements because the machine could form can necks shorter than those formed with other necking methods. The machine reportedly was also able to form a range of beverage can neck diameters with minimal downtime for size changeover. The companies announced that the first Spin Flow machine was to be installed at Ball's Tampa, FL, plant, and a second machine would be placed at Reynold's 1.2-billion-can-per-year Walkill plant in Middletown, NJ.

Automakers continued to explore increased and new applications for aluminum in their vehicles. Chrysler reported that it was developing a prototype small car with aluminum frame and body components. Cross-members, frame rails, floor pans, engine cradles, radiator supports, and many other structural components in the test car were expected to be made of aluminum, along with door frames, roof, body side panels, and probably most of the hinged components, including the hood and deck lid. In addition, the car would use aluminum in the engine cylinder head, transaxle case, and numerous other components that used aluminum casting alloys. Chrysler announced plans to introduce the model in about 2 years with an annual production rate of 200,000 to 250,000 units.

Chrysler also announced that it was developing a low-displacement aluminum V-8 engine for use in niche cars in about 3 years. According to Chrysler engineers, the engine, as designed, would contain at least 68 kilograms of aluminum. The engine reportedly was earmarked for use in special luxury or sports cars built off the company's new LH platform, and also possibly for its luxury minivans. Currently, the only aluminum-block/aluminum-head engines in Chrysler's entire line were the very-low-volume V-10's used in the Dodge Viper sports cars, which were produced in volumes of only a few hundred vehicles annually.

Ford announced that it had begun testing prototypes of its next generation of small car automatic transmissions that were expected to consume between 9,000 and 11,000 tons of aluminum alloy 380 each year once full production was reached in 1994. Ford sources said the new transmissions would go into production early next year but would not reach significant volume levels for 6 to 7 months.

Ford also announced plans to produce both aluminum blocks and heads for its next generation of V-6 engines and some of the blocks for its modular V-8 engines at its Windsor, Ontario, casting plant starting in 1995. Ford sources stated that once full production levels were reached in 1996, almost 16,000 tons of aluminum was expected to be consumed annually at this plant, and additional applications could increase consumption above 22,500 tons annually 1 or 2 years later.

GM announced that it had finalized plans to equip its first electric cars with aluminum spaceframes and plastic bodies. In addition to the structural or frame components, the company stated that the wheels, front brake calipers, rear brake drums, heat exchangers, heat pump compressor, and additional smaller components would be made of aluminum.

GM also announced plans to put aluminum driveshafts into some of its compact-size pickup trucks beginning with the 1994 models. GM sources said the shafts would be extruded and drawn from 6061 alloy and could require more than 450 tons of metal per year. GM used aluminum driveshafts in its bigger trucks, but this would be the first application for aluminum shafts in their smallest pickup trucks. *(See tables 6, 7, and 8.)*

Stocks

Inventories of aluminum ingot, mill products, and scrap at reduction and other processing plants, as reported by the U.S. Department of Commerce, increased from a revised total of 1.775 million tons at yearend 1991 to 1.875 million tons at yearend 1992.

The London Metal Exchange (LME) reported that its U.S. warehouses held a total of 213,525 tons of primary aluminum metal ingot at yearend 1992, an increase from the 167,550 tons of metal reportedly held in these warehouses at yearend 1991.

With the introduction of its secondary aluminum alloy ingot contract, the LME began storing aluminum alloy ingot in its warehouses around the world (see Market and Prices). At yearend 1992, the LME reported that its U.S. warehouses held a total of 10,120 tons of aluminum alloy ingot.

Markets and Prices

The monthly average U.S. market price of primary aluminum, as reported by Metals Week, fluctuated throughout the year without establishing any kind of a definitive trend. The monthly average prices reached a high of 61.034 cents per pound in April, and posted a low of 52.763 cents per pound in November. The average price for the year was 57.519 cents per pound, slightly less than 2 cents per pound lower than the 1991 annual average price of 59.461 cents per pound. The LME cash price for high-grade primary aluminum ingot followed the same general trend as the U.S. market price. The 1992 average annual LME cash price was 56.894 cents per pound.

Purchase prices for aluminum scrap, as quoted by the American Metal Market (AMM), fluctuated during the year and closed the year at higher 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, 45 to 46 cents per pound; old sheet and cast aluminum, 38 to 39 cents per pound; and clean dry aluminum turnings, 39 to 40 cents per pound.

Prices for UBC's also fluctuated during the year, but closed about 8 cents

per pound higher than prices at the beginning of the year. Aluminum producers' buying prices for processed and delivered UBC's, which began the year at a range of 32 to 37 cents per pound, reached a high for the year of 44 to 47 cents per pound in late April. The price range at the end of the year was 40 to 42 cents per pound.

Secondary aluminum ingot prices, as quoted by AMM, fluctuated during the year, but closed higher than prices at the end of 1991. The yearend 1992 price ranges for selected secondary aluminum ingots were as follows: alloy 380 (1% zinc content), 68 to 69.5 cents per pound; alloy 360 (0.6% copper content) and alloy 413 (0.6% copper content), 71.5 to 72.5 cents per pound; and alloy 319, 69.5 to 71 cents per pound.

Metals Week instituted an A-380 aluminum alloy price with the following specifications; 8% to 9.5% silicon, 1% iron, 3% to 4% copper, 0.5% manganese, 0.1% magnesium, 0.5% nickel, 0.35% tin, and 2.9% zinc. The price was for standard ingot in 20,412-kilogram (45,000-pound) truckload amounts delivered customer works. The price represented a range of spot transaction prices conducted by a survey of major suppliers and buyers. Weekly and monthly quotations began in July. The 1992 annual average price, based on 6 months of prices, was 57.081 cents per pound.

In May, the LME announced the introduction of a secondary aluminum alloy contract. Three-month trading began on October 6, and cash trading began on January 4, 1993. Trading was conducted in U.S. currency. The LME based its contract on three secondary aluminum alloy specifications—U.S.380-1, Japanese ADC12, and German DIN226.

Foreign Trade

Exports of all forms of aluminum from the United States decreased for the first time in 5 years. However, exports in 1992 remained at approximately twice the level of those of a decade ago. Canada and Japan remained the major recipients of U.S. aluminum materials, accounting for slightly less than 70% of total exports. Exports of UBC's, which were included in the scrap category, increased to 3,383 tons compared with 2,805 tons in 1991. Argentina, the Republic of Korea, and the United Kingdom were the principal destinations of UBC's exported, accounting for almost three-fourths of the total in 1992.

Imports for consumption of aluminum increased compared with those of 1991. Canada remained the major shipping country to the United States, supplying more than 80% of the total imports in 1992. Imports from the former U.S.S.R. increased significantly. Although the level of these imports was relatively low, it was indicative of the increasing presence of former U.S.S.R. aluminum metal in the Western World markets. UBC imports in 1992 totaled 44,089 tons compared with 31,602 tons in 1991. Mexico replaced Canada as the major source of UBC imports in 1992. Mexico and Canada combined to supply 84% of the total UBC imports for the year. *(See tables 9, 10, 11, and 12.)*

World Review

World production of primary aluminum metal decreased slightly in 1992 compared with that of the previous year. The continued slowdown in world economic activity, most notable in Europe and Japan, and high inventory levels, especially inventories held by the LME, kept world metal prices at depressed levels. For the second year in a row, exports of metal from the former U.S.S.R. were estimated to be in the area of 1 million tons. There were some announced decreases in smelter operating capacity during the year, but the quantities involved were not significant enough to provide any long-term effect on metal prices.

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 and the LME, decreased from 1.754 million tons at yearend 1991 to 1.717 million tons at yearend 1992. IPAI reported that total metal inventories, including secondary aluminum, decreased from 3.349 million tons at yearend 1991 to 3.283 million tons at yearend 1992.

Inventories of primary aluminum metal held by the LME continued to increase dramatically during the year. LME inventories at the beginning of the year totaled 987,150 tons. By the end of the year, inventories held by the LME had increased by almost two-thirds and totaled 1,578,625 tons. In addition, the LME held 15,540 tons of aluminum alloy by yearend.

Australia.—Comalco Aluminium Ltd. announced an agreement had been reached with the Queensland government for the purchase of the 1,600-megawatt (MW) Gladstone power station by a Comalco-led consortium. The sale was subject to the commercial viability of adding a third potline at the Boyne Island smelter. Comalco and its partners expected to complete the feasibility study on the addition of a 200,000-ton-per-year potline by December 31, 1993. If a decision is made to expand the Boyne Island smelter, the smelter's annual capacity would increase to 460,000 tons per year, making it one of the world's largest smelters.

The government of Victoria announced the sale of a 10% interest in the Portland aluminum smelter to the Marubeni Corp. of Japan. Upon completion of the sale, the government's share in the smelter, held through Aluminium Smelters of Victoria Pty. Ltd. (Aluvic), would be reduced to 25%. The other shareholders would remain unchanged-Alcoa of Australia (45%), China International Trade & Investment Corp. (10%), and First National Resource Trust (10%).

Austria.—Alusuisse announced the sale of Salzburger Aluminium GmbH to the company's management. Included in the sale were the 12,000-ton-per-year primary aluminum smelter at Lend, casting facilities, two power stations, and a truck parts factory. The Lend smelter, which uses Soderberg technology, was built in 1899.

Austria Metall AG reported that it had completed the permanent closure of its 80,000-ton-per-year primary aluminum smelter in Ranshofen. The plant had been phasing down operations since the intention to close was first announced in June 1991.

Bahrain.—Aluminium Bahrain B.S.C. (Alba) announced the completion of the $1.5 billion expansion program at its primary aluminum smelter. The completion of the smelter's fourth potline reportedly increased capacity at the smelter from 225,000 tons per year to 460,000 tons per year, making this one of the world's largest smelters. The expansion program also included a new 800-MW powerplant that runs on natural gas using combined cycle turbines, increasing the company's dedicated power system to 1,340 MW. At the end of the year, Alba announced that it had signed a $10 million loan agreement with 10 regional banks to finance a link between Alba's power system and Bahrain Electricity. The link, which was scheduled to be completed by June 1994, would enable Alba to provide up to 300 MW of power to the national supply grid during peak demand periods and would allow Alba to draw additional capacity from the grid to meet any unexpected shortfalls.

Brazil.—Alcan Aluminio do Brazil announced the temporary closure of 27,000 tons per year of metal capacity at its 57,000-ton-per-year Aratu primary aluminum smelter. In early November, the company reportedly began turning off one of the two potlines at the plant.

Latas de Aluminio SA (Latasa), a joint venture between Reynolds International do Brazil (35%) and two Brazilian banks, Bradesco (35%) and Credibanco (30%), announced plans to invest in canmaking facilities in Brazil and Argentina. Latasa announced plans to build a 700,000-can-per-year facility, probably in southern Rio de Janiero State, and a 500,000- to 600,000-can-per-year plant in Argentina, probably near Buenos Aires. The new facility in Brazil would be in addition to Latasa's 1.3-million-can-per-year plant currently in operation in Pouso Alegre, Minas Gerais State.

Canada.—In February, Alumax announced the start of production at its new 215,000-ton-per-year Lauralco primary aluminum smelter at Deschambault, Quebec. The company stated that the smelter, which uses Pechiney 300KA technology, would cast T-ingot only.

Aluminerie Alouette Inc. reported the start of production at its 215,000-ton-per-year primary aluminum smelter at Sept Iles, Quebec, in June. Aluminerie Alouette is owned by an international consortium—Vereinigte Aluminium-Werke AG (VAW) (20%), Austria Metall AG (20%), Hoogovens Groep BV (20%), Societe Generale de Financement du Quebec (20%), Kobe Steel Ltd. (13.33%), and Marubeni Corp. (6.67%). The company expected the plant to be operating at its full capacity at yearend.

In September, Alcan Aluminium reported that it was reactivating 67,500 tons of annual primary aluminum smelter capacity that had been idled since the autumn of 1991. The restarted potlines included a 21,000-ton-per-year potline at Shawinigan, 24,500 tons per year at Isle Maligne, and 22,000 tons per year at Arvida. The company cited improvements in water levels at its hydroelectric powerplants as one of the factors that led to this decision.

In May, Alcan Aluminium and the Federation des Syndicats du Secteur Aluminium announced the signing of a new labor contract covering about 5,000 workers at Alcan Aluminium's primary smelters at Arvida, Laterriere, Isle Maligne, and Beauharnois. The new 3-year contract reportedly included a wage increase of 8.6% spread over the life of the contract, with part of the increase retroactive to March 1991 when the previous contract expired.

Reynolds and the Confederation of National Trade Unions also announced the signing of a new 3-year labor contract covering workers at the 400,000-ton-per-year Baie Comeau primary aluminum smelter. The new contract reportedly included cost of living adjustments and increases in retirement benefits and vacation bonuses.

Chile.—Feasibility studies, at various stages of completion, were being conducted on three different joint-venture primary aluminum smelters. Noranda Aluminum Inc. and Proyectos de Aysen had completed most of the preliminary studies and were putting together the financial package for a $1.5 billion, 230,000-ton-per-year smelter in the Aysen area of southern Chile. Comalco and Geo-Estudios SA Santiago announced the completion of a prefeasibility study on a $2 billion, 240,000-ton-per-year smelter in the Punta Arenas area near the Straits of Magellan. The third potential project was led by Endesa, Chile's largest energy producer. Endesa reported that it was being joined by Bechtel Corp., Comalco, and Marubeni Corp. in commissioning a feasibility study on a $1.5 billion, 220,000-ton-per-year smelter in the Aysen area of southern Chile. All of these projects would require extensive infrastructure work, including the construction of hydroelectric plants and port facilities.

China.—The Southwest Aluminium Fabrication Plant announced plans to install an aluminum coating line, the first in China, at its facilities at Chongquing in the southern part of the country. The new coating line would apply paint and lacquer to coiled aluminum strip at a throughput rate of almost 11 tons per hour. The products produced were geared for applications in the architectural, automotive, appliance, and container industries.

Egypt.—Aluminium Co. of Egypt (Egyptalum) reported that it had begun switching from the use of Soderberg to prebaked electrodes at its primary aluminum smelter at Nag Hammadi in Upper Egypt. The switchover was expected to be gradual, at the rate of about 100 cells per year. Upon completion, in about 3 to 4 years, the smelter's capacity was expected to reach 240,000 tons per year.

France.—Pechiney announced that its new 215,00-ton-per-year primary aluminum smelter at Dunkirk reached full production levels in May. Pechiney stated that the Dunkirk smelter was the first to use its 300,000-ampere technology in a single potline to reduce capital and staffing costs. Most traditional smelters of similar size reportedly had two or three potlines.

Pechiney also announced plans to reduce production capacity, both temporarily and permanently, at other smelters. Temporary reductions of 20% of capacity were expected by January 1993 at the company's 120,000-ton-per-year St. Jean de Maurienne smelter, the 44,000-ton-per-year smelter at Auzat, and the 44,000-ton-per-year Lannemezan smelter. Pechiney also announced plans to permanently close its 31,000-ton-per-year Venthon smelter in the French Alps. The smelter was expected to be closed over a period of about 18 months with a full shutdown expected in early 1994.

Germany.—VAW announced the temporary closure of 105,000 tons per year (26%) of annual primary aluminum metal capacity at its Toging and Norf smelters. The reduction included the 33,000-ton-per-year reduction at these two plants that had been announced in October 1991. Company officials stated that the closures would probably stay in place at least through the end of 1993.

Pechiney Aluminium Presswerk (PAP) announced plans to construct a new extrusion plant at Burg, in eastern Germany. The plant, which was expected to be operational by mid-1994, reportedly would add 12,000 tons per year to PAP's aluminum extrusion capacity. The company stated that the new plant would enable it to respond to growth in demand for aluminum extrusions expected by the building and construction industries in that area of the country.

Greece.—Aluminum extruder Soulis SA announced the installation of a new 630-ton press at its plant in Lamia that will enable the company to produce thin-walled, lightweight extrusions. The 10-ton-per-day press reportedly produced extrusions with a minimum wall thickness of 0.7 millimeter (mm). The plant's other two presses, a 2,000-ton press and a 1,650-ton press, produced minimum wall thicknesses of only 1.3 mm. About 80% of the plant's production was for the export market and supplied the automotive, aerospace, machinery, and air conditioning industries.

Hungary.—Hungarian Aluminium Corp. (Hungalu) and an unnamed Ukrainian company reported the signing of a 5-year deal that would allow the 35,000-ton-per-year primary aluminum smelter at Inota, originally scheduled for closure in 1992, to continue to operate. The deal reportedly called for the Inota Aluminium Works to deliver aluminum semis to the Ukraine in return for electricity at a 30% discount.

Alcoa and Hungalu announced the signing of a joint-venture agreement involving Hungalu's subsidiary, Kofem Kft. The $165 million agreement reportedly gave Alcoa a majority interest (50.1%) in Alcoa-Kofem Kft. The Kofem plant, 56 kilometers southwest of Budapest in Szekesfehervar, produced about 110,000 tons of rolled products and 30,000 tons of extrusions per year. Alcoa stated its initial investment was $50 million, and the remaining $115 million investment would be spread over 5 years to improve product quality and to upgrade the environmental systems and safety at the plant.

Italy.—At the end of May, Alumix S.p.a., the state holding company for Italy's aluminum sector, announced the closure of its 30,000-ton-per-year Fusina II smelter.

The Italian Government decreed that electricity prices would be reduced for Alumix's primary aluminum smelter at Porto Vesme. Effective July 29, electricity rates reportedly decreased from 41.6 lire per kilowatt hour (kW•h) (33.5 U.S. mills per kW•h) to 20 lire per kW•h (16.1 mills per kW•h). The 36,000-ton-per-year Fusina I smelter did not appear to be eligible for the reductions.

In July, the Italian Government also issued a decree liquidating Efim, the state holding company that controlled a range of industrial companies, including the aluminum company, Alumix. The Government reportedly approved the establishment of a 3-year restructuring program, which would run to the end of 1995, with a view to eventual privatization.

Japan.—An independent Osaka-based aluminum fabricator (Alcut K.K.), Sumitomo Light Metal Industries Ltd. (SLM), and Mitsubishi Aluminium announced the commissioning of a new aluminum coil processing facility. The plant, commissioned in November, was operated by Alcut K.K. and had a capacity of 600 tons per month. The companies expected the first year output to be 50 tons per month, increasing to 300 tons per month by 1994 and reaching full capacity by 1995.

Kobe Steel Ltd. announced that construction had begun on a new aluminum and magnesium alloy casting and forging plant in Daian, Mie Prefecture. The company stated that it planned to move its castings and forgings operations in stages from its Nagoya plant, which lacked space for further expansions, to Daian. The new plant was expected to have 60% more capacity than the Nagoya plant. The target date for completion of the new plant was 1995.

Hokkai Can Co. reported the start of construction of a new aluminium can plant in Kora, Shiga Prefecture. The new plant, scheduled for completion in 1993, was expected to have an annual production capacity of 500 million cans.

Mitsubishi Materials Corp. announced plans to expand its aluminum can production capacity from its current level of 3 billion cans per year to 5 billion cans per year by 1995. The company stated that the expansion in capacity would be achieved by renovating and expanding its four existing can plants.

U.S.-based aluminum companies continued to enter into joint agreements with various sectors of the Japanese aluminum industry. Alumax announced the formation of Alumax Japan Inc., a

new subsidiary to handle Far Eastern sales and to seek partnership venture opportunities in Asia. Two aluminum automotive sheet joint ventures formed by Alcoa and Kobe Steel reportedly began production and marketing operations at Kobe's Moka plant and Alcoa's Davenport, IA, plant. Reynolds and SLM announced the signing of a 3-year agreement of technical collaboration on aluminum sheet for the automotive industry. Kaiser Aluminum announced that an agreement had been reached with the Kawasaki Steel, Furukawa Electric, and Furukawa Aluminium group to form a study group to assess the viability of forming a joint venture to produce aluminum sheet in Japan for the automotive industry.

Korea, Republic of.—Kaiser Aluminum announced the signing of a 5-year technology licensing and technical services agreement with Samyang Metal Co. Ltd. Under the agreement, Kaiser Aluminum reportedly would provide technology, technical expertise, and training for Samyang's new rolling mill under construction at Yongju. The new plant was expected to produce a full range of aluminum sheet and plate products, including can stock. Under a separate agreement, Kaiser Aluminum reportedly would market the Yongju rolling mill products in North America.

Malaysia.—Kobe Steel of Japan announced the formation of a wholly owned subsidiary, Kobe Precision Technology Sdn Bhd (KPT), that would begin producing aluminum substrates in April 1993 at the initial rate of 1.2 million pieces per month. Plans reportedly called for KPT to oversee the construction of a new manufacturing facility in Malaysia and to market the substrates to computer and hard disk drive manufacturers throughout Southeast Asia. Aluminum blanks, the material for substrates, would be supplied by Kobe's Moka plant in Tochigi Prefecture, Japan.

Japan's Marubeni Corp. reported the finalization of an agreement to take a 19.2% stake in Malaysia's Aluminium Industries Snd Bhd (AISB). AISB operated a plant in Johore Bahru that produced about 6,000 tons per year of rolled aluminum products, including fin-stock for use in air conditioners.

Mexico.—In February, Alcoa announced the closure of the third and last potline at its 44.3%-owned primary aluminum smelter in Veracruz. Later in the year, Alcoa announced that it had sold its 44.3% interest in Grupo Aluminio, which included the 66,000-ton-per-year Veracruz smelter, to Grupo Carso, a diversified Mexican company.

Netherlands.—Pechiney Nederland NV announced an additional 8% temporary cutback in production at its 170,000-ton-per-year primary aluminum smelter in Vlissingen. By January 1994, production at the smelter was expected to be reduced by 20%.

Alumax reported the start of production at its new facility at Kerkrade. The Kerkrade plant, owned by Alumax's subsidiary Alumax Aluminium BV, reportedly used a smelting system that produced billets from a mix of aluminum scrap and ingots. At full capacity, the plant would produce a minimum of 50,000 tons per year of aluminum extrusion billets.

New Zealand.—Severe drought conditions prompted the Electricity Corp. of New Zealand (ECNZ) to restrict the supply of electricity to Comalco's 260,000-ton-per-year Tiwai Point primary aluminum smelter. In June, Comalco temporarily closed one potline at the smelter, which reportedly reduced the smelter's monthly output from 22,000 tons to 14,500 tons. However, improved rainfall in July allowed ECNZ to restore full power to the smelter, and Comalco returned its smelter to full production status by the end of the year.

Nigeria.—Reynolds reported that construction progressed on a 180,000-ton-per-year primary aluminum smelter. Reynolds agreed to acquire a 10% equity interest in the Aluminum Smelter Co. of Nigeria (ALSCON) with the Nigerian Government and private interests holding the remaining equity. As part of the arrangement, Reynolds reportedly would purchase 140,000 tons of metal annually from ALSCON when the smelter reached full capacity. An initial capacity of 45,000 tons per year was expected to be in production in 1995.

Russia.—In September, an international aluminum conference was held in St. Petersburg. At this conference, representatives of the Russian aluminum industry presented papers that described the aluminum industry in the former U.S.S.R. and presented data on the engineered capacity of primary aluminum smelters. The Russian primary aluminum smelters and their rated annual capacities are as follows: Bogoslovsk, 162,000 tons; Bratsk, 844,000 tons; Irkutsk, 262,000 tons; Kamensk-Uralsk, 70,000 tons; Kandalaksha, 63,000 tons; Krasnoyarsk, 755,000 tons; Nadvoitsky, 68,000 tons; Novokuznetsk, 284,000 tons; Sayanogorsk, 274,000 tons; Volgograd, 168,000 tons; and Volkov, 20,000 tons. Annual capacity data for the primary smelters in the independent republics were also presented, as follows: Sumgait, Azerbaijan, 58,000 tons; Tadjik, Tadjikistan, 517,000 tons; and Zaporozhye, Ukraine, 110,000 tons.

Spain.—Industria Navarra del Aluminio, S.A., a 77%-owned subsidiary of Reynolds International Inc., announced the completion of a 4-year, $25 million expansion of its foil operations in northern Spain. Foil capacity at the Pamplona plant increased by 42% to 18,600 tons per year.

Switzerland.—Alusuisse announced the closure of its primary aluminum smelter in Chippis. Capacity at the smelter, which was built in 1908, had been decreasing gradually in recent years, from 40,000 tons per year to about 6,000 tons per year.

United Kingdom.—Coca Cola-Cadbury Schweppes UK Ltd., the bottling company, announced plans to use aluminum cans for all of its canning operations in the United Kingdom. To

accommodate the increase in demand for aluminum cans, Nacanco planned to convert three canmaking lines at its Milton-Keynes plant to aluminum, and CMB Packaging announced plans to convert one line at its Braunston plant to aluminum.

Venezuela.—The 300,000-ton-per-year Alcoven primary aluminum smelter project, announced last year, was postponed indefinitely.

Aluminio del Caroni SA (Alcasa) reported the startup of a new rolling mill, Laminacion Puerto Ordaz. The mill reportedly had an annual rolling capacity of 60,000 tons for canstock and other products.

Yugoslavia.—In an interview with Metal Bulletin in December, Slavko Ostojic, president of the bauxite, alumina, and aluminum producers association of the former Yugoslavia, gave the following assessment of the status of the primary aluminum smelters in that country.

The 75,000-ton-per-year Boris Kidric smelter in Sibenik, Croatia, was damaged during the war and was not expected to restart production until 1994 at the earliest. However, the smelter continued to operate its rolling mill and semifabrication facilities using metal imports from the former U.S.S.R.

The Energoinvest smelter in Mostar, Bosnia-Herzegovina, stopped production in April because of war damage. Although the damage was not serious, Ostojic did not think that the 92,000-ton-per-year smelter would be restarted given the port and general transport difficulties the war had created.

The 75,000-ton-per-year Unial smelter at Kidricevo, Slovenia, had not reduced production from prewar levels. However, owing to depressed market conditions, the smelter was producing at 10% to 20% below capacity.

The Podgorica smelter, formerly the Titograd smelter, in Montenegro had been disrupted by sanctions. Exports had stopped, and the smelter was suffering from a lack of raw materials that previously had been imported from the west. At the end of the year, the smelter reportedly was producing metal at 80% to 90% of its 102,000-ton-per-year capacity, but it was unclear how long this would continue. Estimates ranged from 1 to 3 months, depending on its stockpile of raw materials. *(See table 13.)*

Current Research

According to researchers at Sandia National Laboratories, aluminum implanted with a thin layer of oxygen ions in concentrations as low as five atomic-percent produced an alloy about five times stronger than other high-strength aerospace aluminum alloys. The new alloy also reportedly had greater resistance to friction and wear than other aluminum alloys and retained its strength superiority even when subjected to high temperatures. Ion implantation is a 20-year-old technique used to introduce additional elements into solid materials. It was initially used for doping semiconductors to achieve specific electrical properties. Sandia researchers bombarded the surface of 1.87-centimeter-diameter pure aluminum disks at room temperature with oxygen ions at energies between 25 and 200 kiloelectron volts. By varying the energies used, a uniform layer of implanted aluminum was produced from the surface to a depth of about 0.5 micrometers. The strength was evaluated using an ultralow load indentation test system, which probed the surface by applying a small force on a diamond-tipped pin.[2]

At the 121st Annual Meeting of The Minerals, Metals, and Materials Society (TMS) held in San Diego, CA, March 1992, more than 100 papers were presented in such topic areas as alumina and bauxite, reduction technology, carbon technology, cast shop technology, and recycling. Among the papers presented at the reduction technology sessions were several on the topic of handling spent potliner (SPL) waste. The generation and safe disposal of SPL produced through the electrolytic reduction of alumina had become one of the industry's biggest environmental concerns. SPL had been classified as hazardous in several countries because of its leachable cyanide content. Several companies had begun to seek alternatives to the practice of storing and landfilling SPL, which was becoming increasingly more difficult and expensive.

Reynolds reported the development of a process for detoxifying SPL in which the SPL was blended with limestone and an antiagglomeration agent and thermally treated in a rotary kiln. The company reported that the process was very effective for destroying cyanides and significantly reduced the concentration of soluble fluorides in the kiln residue. The cyanides were destroyed by oxidation and the majority of soluble fluoride salts were converted to stable, insoluble calcium fluoride by reaction with limestone. The process was developed and utilized for more than 2 years on an industrial scale at Reynolds idled Hurricane Creek Alumina Plant in Bauxite, AR. More than 300,000 tons of SPL reportedly was treated successfully during this period.[3]

Alcoa reported the results of tests it had conducted on the reuse of SPL in bench-scale carbon cathodes as an alternative to disposal. The studies included an effort to verify the detrimental effects of aluminum carbide and aluminum nitride, the determination of fluoride evolved at temperatures attained in cathode baking, and measurements of swelling owing to sodium absorption during electrolysis and of electrical resistivity for conventional cathodes and those produced from SPL. Alcoa researchers reported that limited plant trials confirmed that untreated SPL could be used in cathode blocks and seams without adversely affecting cell operating parameters. However, they also stated that a number of issues, including those involving industrial hygiene and the environment, baking furnace refractory deterioration, and the ability to produce consistent blocks and/or seams from a variable material would need to be addressed before commercialization.[4]

An alternative treatment known as the COMTOR process was developed at Comalco's Research Center in Melbourne, Australia. A 5,000-ton-per-year demonstration plant was constructed

in Queensland, Australia. Preliminary results from the demonstration plant and details on the process itself were presented. The company described the process as having three distinct stages—feed preparation, calcination, and fluoride recovery. Crushing the SPL before treatment reportedly improved the rate and quality of the detoxification process. The COMTOR process utilized a new type of calciner, known as a Torbed. Calcination reportedly was the most effective method for reducing the leachable cyanide content of the SPL. Ash treatment recovered the fluoride values for recycling directly to the electrolytic cell. Once the cyanide was destroyed and the fluorides either recovered or stabilized, the residue reportedly passed the standard leach tests and was no longer considered toxic.[5]

OUTLOOK—ALUMINUM

The world demand for aluminum metal continued to be weak during the first half of 1993. The oversupply of metal, the economic downturn, and the continuation of high levels of exports from the former U.S.S.R. should continue to depress the world aluminum market. This slowdown may continue well into 1994. When world economic activity does begin to recover, an oversupply condition will probably continue for an extended period of time until the inventory levels that have been building over the past few years return to a more economically acceptable level. Thereafter, the long-term growth rate for aluminum metal should average about 2% per year.

ANNUAL REVIEW—BAUXITE AND ALUMINA

World production of bauxite and alumina decreased during 1992 in response to the continued slow pace of primary aluminum metal output; bauxite production fell by 4% and alumina output was 2% below the previous year's total. Mine production of bauxite was reported from 28 countries. Domestic consumption of bauxite in 1992 fell below 1991 consumption levels, with the downward pressure driven by weak metal market requirements for primary aluminum. Within the specialty products area, consumption of abrasive-grade bauxite increased beyond 1991 usage, but bauxite consumption by the chemical and refractory industries decreased in 1992. Demand for alumina was soft throughout the year, mainly in response to reduced primary aluminum smelter operating levels. Owing to continued weak national economic conditions, U.S. production and shipments of smelter-grade alumina in 1992 declined by moderate amounts. U.S. alumina consumption moderated slightly from the high levels of 1991 and a continued softening of the alumina market developed throughout 1992 as a buildup occurred in alumina stocks. Alumina reportedly was produced in 29 countries around the world. *(See table 14.)*

Legislation and Government Programs

Early in 1992, the implementation of sanctions on U.S. imports of Chinese bauxite and other commodities was avoided when the U.S. and Chinese Governments reached agreement over the protection of U.S. copyrighted and patented property. China had been identified by the U.S. Trade Representative (USTR), under provisions of U.S. trade law, for its failure to provide adequate and effective protection of U.S. intellectual property. U.S. bauxite traders and consumers lobbied strongly to keep Chinese bauxite off the USTR's proposed list of sanctioned items.

There were no announced additions of bauxite to the NDS in 1992; however, 437,000 tons of bauxite was reportedly released in compliance with a contract to upgrade NDS metallurgical-grade bauxite to aluminum metal. An additional solicitation to upgrade a further 166,000 tons of NDS bauxite to aluminum was canceled by the DLA in light of revised NDS materials requirements. At yearend, DLA reported an inventory of 12.4 million tons of Jamaica-type and 5.0 million tons of Suriname-type metallurgical-grade bauxite in the NDS. The NDS calcined refractory-grade bauxite inventory was listed as 280,500 tons at the close of 1992.

Under a new Department of Defense Annual Materials Plan for Fiscal Year 1993, released in mid-December of 1992, DLA planned to offer for sale 762,000 tons of metallurgical-grade bauxite—508,000 tons of Jamaica-type and 254,000 tons of Suriname-type. In addition, as a part of this program, DLA intended to dispose of 51,000 tons of refractory-grade bauxite in fiscal year 1993. These were the maximum amounts recommended for disposal during the fiscal year, and the actual level of sales would depend on prevailing market conditions.

Production

The total U.S. bauxite production during 1992 was 9% less than that reported for 1991. Most of this sluggishness was attributed to general weakness in the U.S. economy. The only currently active bauxite mines remaining in the U.S. 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 refractory grogs. Demand for these domestic ores remained relatively weak during 1992, and mine output was intermittent. Within this market sector, the Harbison-Walker Refractories Div. of INDRESCO 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 refractory products.

Alusuisse-Lonza Services reportedly signed an agreement with Virgin Islands Alumina Corp. (VIALCO), a unit of Clarendon Ltd., under which Alusuisse would provide its proprietary alumina precipitation technology to VIALCO's alumina plant located at St. Croix, U.S. Virgin Islands. The technology should assist VIALCO in improving and

maintaining the quality of its alumina product, while providing the basis for increasing the plant's production capacity.

Kaiser Aluminum Corp., operating through its subsidiary Kaiser Aluminum & Chemical Corp., remained a major international producer and marketer of alumina. Its alumina plant at Gramercy, LA, set a new output record by producing 1.06 million tons of alumina in 1992. Kaiser's entire worldwide alumina production amounted to 2,939,300 tons for the year; approximately 68% of the alumina was sold to outside customers.

Reynolds Metals Co. indicated that its 1.7-million-ton-per-year capacity Sherwin alumina plant near Corpus Christi, TX, operated at a reduced production level in 1992. This was a result of the company's effort to balance its alumina supply system following the temporary closure of its primary aluminum smelter at Troutdale, OR. At the close of 1992, the Sherwin plant was reported to be operating at 77% of its annual rated capacity.

Conoco Inc. reportedly commenced shipping reclaimed fluorinated alumina from its 138,000-barrel-per-day Ponca City, OK, petroleum refinery to Kaiser Aluminum & Chemical Corp.'s aluminum smelter at Mead, WA. In July 1992, Conoco signed an agreement to sell reclaimed fluorinated alumina to Kaiser with the material to come from Conoco's 49,500-barrel-per-day Billings, MT, refinery as well as its Ponca City facility. The Ponca City petroleum refinery reportedly would be able to reclaim approximately 115 tons per year of fluorinated alumina and the Billings facility, approximately 90 tons. In the case of the Ponca City refinery, this amounts to the elimination of nearly 155 cubic meters of nonhazardous wastestream material that no longer has to be disposed of in an approved landfill. *(See tables 15 and 16.)*

Consumption and Uses

Weak demand for smelter-grade alumina lowered the consumption of crude and dried metallurgical-grade bauxite to a level below that of 1991. Consumption of bauxite by the abrasives industry increased modestly during 1992, and consumption within the chemical and refractory industries decreased by moderate amounts. Approximately 93% of the bauxite consumed in the United States during 1992 was refined to alumina, and an estimated average of 2.13 tons of dried bauxite was required to produce 1 ton of calcined alumina. Twenty-two primary aluminum smelters reported a consumption of 8.13 million tons of calcined alumina in 1992, barely down from the consumption level reported for 1991. This slightly lower level of consumption, coupled with the minimally higher rates of U.S. alumina imports, resulted in the development of a modest oversupply of smelter-grade alumina on the domestic alumina market. An estimated 91% 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 17, 18, 19, and 20.)*

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 1992, the USBM 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 $170 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 $120 per ton; and Guyanese, f.o.b. rail car, Baltimore, MD, or f.o.b. barge, Gulf Coast, $175 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.

A growing alumina surplus on world markets led to prices easing from the very high levels established during the previous 2 years. The average value of domestic calcined alumina shipments was estimated to be $205 per ton. Trade data released by the Bureau of the Census indicated the average value of imported calcined alumina was $182 per ton, f.a.s. port of shipment, and $194 per ton, c.i.f. U.S. ports. Beyond these current prices, medium-term projections support a reasonably resilient market outlook for alumina toward the mid-1990's.

For 1992, the International Bauxite Association (IBA) recommended that its members set their minimum c.i.f. price for metallurgical-grade bauxite between 2% and 2.5% of the composite reference price for primary aluminum ingot, and for metallurgical-grade alumina between 14.5% and 16.5% of the composite reference price for primary aluminum ingot. Before Australia's withdrawal from the IBA in late 1992, the organization's members accounted for approximately 77% of the total world bauxite output and about 47% of the alumina production. Following Australia's departure, IBA member countries produced 38% of the world's bauxite and 18% of its alumina. *(See table 21.)*

Foreign Trade

Dried bauxite exports from the United States totaled 54,400 tons in 1992, a moderate increase over the 1991 total of 37,800 tons; Canada received 98% of the 1992 exports. U.S. exports of calcined refractory-grade bauxite totaled 5,500 tons for 1992; Mexico received 91% and Canada 9%. Exports of all other grades of calcined bauxite (chiefly abrasive grade) amounted to 3,000 tons for the year. Mexico received 68% of this total. Specialty aluminum compounds exported included 5,100 tons of aluminum sulfate, 6,300 tons of aluminum chloride, 10,400

tons of aluminum oxide abrasives, and 15,000 tons of various fluoride-based compounds of aluminum, including synthetic cryolite and aluminum fluoride.

Imports for consumption of crude and dried bauxite decreased by 8% from the level of 1991 receipts, and the three principal suppliers, Jamaica, Guinea, and Brazil, in order of shipments, provided 82% of the total. As in previous years, China and Guyana remained the dominant suppliers of calcined bauxite to the United States. Australia continued to be the primary source of U.S. alumina imports, accounting for approximately 75% of the total receipts for the year. *(See tables 22, 23, 24, and 25.)*

World Review

World production of bauxite and alumina declined in response to a continued sluggishness in demand for primary aluminum metal and the continued flood of aluminum from the former U.S.S.R. Twenty-eight countries reportedly mined bauxite in 1992, and the total world production of bauxite declined to 103.6 million tons, a decrease of 4% below 1991 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 41.5 million tons, which was 2% below the 1991 production level. The three principal producing countries, Australia, the United States, and Jamaica, in order of volume, supplied approximately one-half of the total world production.

Capacity.—The 1992 world annual rated capacity of plants producing alumina increased by 3% above last year's level. At the same time, apparent worldwide refinery capacity utilization for 1992 was estimated at approximately 87% and represented a decrease of about 3% from that of the previous year. As has been the case in recent years, further increases in smelter-grade alumina production capacity are expected to develop primarily from incremental expansions of existing plants and only in very special situations from new greenfield refineries, which normally demand a 4- to 5-year design, engineering, and construction period, plus very significant levels of capital investment.

Argentina.—Aluminio Argentino SACI (Aluar) reportedly began to take advantage of the Mercosur Regional Trade and Integration Agreement involving Argentina, Brazil, Paraguay, and Uruguay. The regional agreement has induced Aluar to alter its longstanding policy of purchasing all of its alumina feed from Alcoa of Australia. Instead, Aluar has commenced purchasing approximately one-third of its smelter-grade alumina from Alcoa of Brazil. This exempts the company from a 5% duty on raw materials imposed by the Argentine Government in November 1991. The new Brazilian alumina supply arrangement also saves on shipping costs, and there are expectations that further accords among the Mercosur nations may result in the removal or lowering of tariff barriers between member countries, which could result in additional savings for Aluar.

Australia.—In 1992, production levels dropped in Australia, the world's largest bauxite- and alumina-producing country. Bauxite output was down by about 1.4% and alumina dropped by nearly 0.8%.

The export shipping facilities of Comalco Ltd. at Weipa, Cape York Peninsula, Queensland, were temporarily closed due to damage sustained from a tropical cyclone that struck the region on January 10, 1992. In spite of this disruption, Comalco announced that a historic landmark was achieved during its business quarter ended June 30, 1992, when the 200 millionth ton of bauxite was shipped from Weipa since mining commenced at the site in 1963.

Comalco's initial long-term contract for the supply of bauxite to the participants in the Queensland Alumina Ltd. (QAL) refinery at Gladstone, Queensland, expired at the end of 1992. Reportedly, agreement to extend these contacts with two of the QAL joint-venture participants had not been reached by yearend, and renewal terms were the subject of litigation. In the interim, existing terms were to apply for ongoing QAL bauxite requirements through 1993.

The joint Comalco-Alcan feasibility study for a new 1-million-ton-per-year alumina plant based on undeveloped bauxite deposits in northern Queensland's Weipa region reportedly was nearing completion at the end of 1992. The viability of various Queensland coastal plant sites had been assessed, and a decision on the next phase of the evaluation program was expected near the end of 1993.

In addition, Comalco indicated that significant changes to the work environment were initiated at its Weipa operations in 1992, including job redesign and the elimination of compulsory union affiliation as a condition of employment.

In further developments at Weipa, Comalco opened a new land use and environmental research center designed to provide scientific and technical support for the rehabilitation of the approximately 8,000 hectares of land that is expected to be impacted by the company's bauxite mining operations over the next 30 years.

During the latter part of 1992, Alcoa of Australia announced the completion of its expansion project at the Wagerup alumina plant in Western Australia. The expansion increased the plant's capacity by 630,000 tons to an annual 1.5 million tons. Even a further level of expansion that would raise the plant's capacity by an additional 250,000 tons per year was reportedly under consideration at yearend. This newly contemplated expansion would involve the addition of a third ball mill to the facility and, if implemented, would come on-stream in early 1994.

The new A. J. Parker Cooperative Research Centre at Curtin University in Perth, Western Australia, announced the establishment of an extensive research program devoted to the development of new hydrometallurgical techniques for use in the processing of minerals. Alumina was specifically identified as a principal focus of this work. The research effort was developed as a cooperative venture funded by Australia's Federal and State

governments in conjunction with private industry.

An International Bauxite Tailings Workshop (Bauxite Washing and Bayer Process Residues) was held in Perth, Western Australia, November 2-6, 1992. The meeting represented a continuation of an international program convened for the purpose of supporting scientific research into bauxite tailings disposal and a continuing search to develop possible commercial applications for these wastestream materials.

Effective October 1992, Australia withdrew as a member of IBA, a producers' organization that Australia helped to create in 1974. Australia indicated that its membership in the IBA was no longer warranted, particularly in light of the escalating organizational costs (estimated at approximately $295,000 per year).

Brazil.—Industry sources indicated that a formal decision by potential Japanese participants in the long stalled Alumínio do Norte do Brasil S.A. (Alunorte) alumina plant near Belém in northern Brazil continued to be delayed and any further judgement on the project would not likely be made until mid-1993.

Mineração Rio do Norte S.A. (MRN), Brazil's largest bauxite producer, exported 250,000 tons of bauxite from its Trombetas Mine in the Amazon region to alumina plants within the newly independent republics of the former U.S.S.R. Negotiations were conducted during the year to finalize export contracts for future shipments of bauxite to Kazakhstan and Ukraine. Bauxite prices for these supply agreements were expected to range between $22.50 and $23.00 per ton.

In May, the Alumínio do Maranhão S.A. (Alumar) alumina plant at São Luis, Maranhão, in the northeast of Brazil, achieved an alltime record for equipment availability—99.1%. In the following month, the Alumar facility recorded its lowest real-term costs for alumina production since the facility commenced operation in 1984.

Canada.—The two new primary aluminum smelters that were commissioned in Quebec during 1992, Alouette and Lauralco, reportedly had secured their alumina supplies through contracts with Australian alumina producers. The alumina for the Alouette smelter would initially be supplied by Gove Alumina for a period of 3 years. The smelter's six owners agreed that a single source of alumina was essential for smooth and efficient operation of the facility. In view of the fact that each of the joint-venture partners had its own alumina source and some of the contracts were with suppliers other than Gove, an interchange system was developed to ensure that all of Alouette's alumina would come from one source. Lauralco's alumina requirement reportedly would be supplied on a long-term contract from Alcoa of Australia's Kwinana refinery in Western Australia.

China.—The Chinese central Government reportedly has committed additional funds for the modernization of the 600,000-ton-per-year Zhengzhou alumina plant in Henan Province. The allocation of these funds was part of an effort by the Government to increase domestic alumina production, thereby reducing imports that were reported to have reached record levels.

Ghana.—The Ghana Bauxite Co. Ltd. projected that its total 1992 sales of washed bauxite would reach the 375,000-ton level at yearend. A modernization plan undertaken to improve the railway system used for shipment of bauxite from the Ichiniso Mine, near Awaso in western Ghana, to the port of Takoradi was completed in 1992. In addition, the wharf and loading facilities at the port were rebuilt to allow the loading of barges for the movement of bauxite to self-loading ships located off shore.

Greece.—Bauxites Parnasse Mining reportedly suspended bauxite production until February 1993 and commenced drawing down inventories in response to declining sales to the former U.S.S.R. and Romania.

In addition, the proposed 700,000-ton-per-year Greek-Russian alumina project planned for Thisvi, near Athens, remained on hold in 1992. The project's principal controlling interest, state-owned Hellenic Industrial Development Bank (ETVA), initiated a search for third party investors to participate in the $850 million project.

Guinea.—Friguia, the sole alumina producer in Africa, was scheduled to receive approximately $18.5 million from the European Investment Bank for modernization of its alumina plant at Kimbo and improvement of the railway link between the plant site and the port of Conakry. Under the plan, annual production capacity would be increased from 642,000 tons per year to more than 700,000 tons per year. The entire project was slated for completion within 2 years.

It was announced that the state-owned Office des Kindia (OBK) had been transformed into a limited company named Societe des Bauxites de Kindia (SBK). This restructuring effort was apparently designed to increase the company's operating efficiency, and there reportedly were related plans to seek sources of private business capital.

Belgium's Tractebel Industrie SA declared that it had signed an engineering services agreement to undertake the rehabilitation and expansion of the Compagnie des Bauxites de Guinee (CBG) bauxite treatment facilities in Guinea. The agreement was related to the first phase of CBG's project to upgrade its Kamsar ore treatment plant (drying and calcining kilns). The entire improvement project was designed to maintain CBG's 12-million-ton-per-year level of bauxite production and reportedly would cost $170 million, 70% of which will be financed by a loan from the African Development Bank (ADB). The expansion portion of the program provides for the development of the Bidi-Koum deposit to offset the decline in production at CBG's Sangaredi Mine. The rehabilitation elements of the ADB-supported project involve the Kamsar ore treatment plant upgrade, installation of a new power station, and renovation of the Sangaredi to Kamsar railroad system.

Guyana.—The Government of Guyana commenced restructuring the administration of its bauxite industry in an attempt to cut losses and lift productivity before the intended sale of its bauxite interests during the coming 2 years. To prepare for this privatization move, an 18-month contract for the management and reorganization of the bauxite industry was awarded to Minproc Engineering, Australia. Minproc was also assigned responsibility for marketing Guyana's metallurgical and calcined grades of bauxite.

Hungary.—Late in 1992, HungAluker, the trading arm of Hungary's aluminum group, Hungalu, signed an agreement with the Russian trading organization Raznoimport and the Russian aluminum smelter at Volgograd. The contract involved the export of 150,000 tons of alumina from Hungary by railway via Ukraine to Volgograd, in exchange for 27,500 tons of aluminum ingot that would be used as feed to produce semis at Hungalu's operations in Hungary.

The 7th International Congress of ICSOBA (International Committee for the Study of Bauxites, Alumina, and Aluminium) was held at Balatonalmádi and Tapolca, Hungary, in mid-June. Principal sponsors of the conference included the United Nations Development Program (UNDP) and Hungalu, plus its associated subsidiary companies.

India.—The Indian Government reportedly has provided its preliminary approval to three export-oriented alumina projects that were to be developed in India's eastern State of Orissa. The companies that received permission from the Government to construct the plants were: an Indian Aluminium (Indal) and Tata Industries joint venture, the engineering company Larsen & Toubro, and the R.P. Goenka Group. Each proposed plant would initially produce 1 million tons of alumina per year.

In a related matter, India's National Aluminium Co. (Nalco) reportedly signed an agreement with Norway's Hydro Aluminium A.S. to commence work on a detailed feasibility study for setting up a $600 to $800 million, 900,000-ton-per-year alumina plant in the Koraput district of Orissa.

Additionally, the Hindustan Aluminium Corp. Ltd. (Hindalco) has begun increasing the capacity of its alumina plant at Renukoot in Uttar Pradesh from 300,000 tons per year to 350,000 tons per year. This 50,000-ton expansion project should be completed by the end of 1993. The company reportedly also has retained Lurgi AG of Germany to investigate the feasibility of a further expansion of this facility, as well as methods to improve the energy efficiency of the operation.

It was announced that Bharat Aluminium Co. Ltd. (Balco) had acquired control of a new bauxite mining property at Maniper, Sarguja district, Madhya Pradesh, in central India. The mine reportedly has proven reserves of 8 million tons and it has, for the present, alleviated Balco's immediate concern regarding the depletion of its bauxite reserves. It was also expected that an additional bauxite deposit with a 6-million-ton reserve base would be leased by Balco in the near future.

Gujarat Mineral Development Corp. (GMDC) proceeded with its previously declared plans to construct a 50,000-ton-per-year bauxite calcination plant in western India. GMDC expected the plant to be in operation by mid-1993, producing both refractory- and abrasive-grade bauxite, primarily for domestic markets.

Indonesia.—In 1992, a sharp decline in bauxite exports to the United States brought Indonesia's production of washed bauxite to the lowest level in 5 years. This drop was largely attributed to a lapse in shipments to a principal U.S. bauxite customer. The outlook for 1993, however, appeared much brighter because PT Aneka Tambang, the country's only producer of bauxite, had entered into a 5-year agreement to supply approximately 500,000 tons per year to Reynolds Metals Co.

Iran.—It was reported that Iran and Bahrain had agreed to construct a joint-venture alumina plant on Iran's Persian Gulf island of Qeshm, in the Strait of Hormuz. The site selected for this planned alumina facility would be near the proposed $1.35 billion, 220,000-ton-per-year Al-Mahdi aluminum smelter project at Bandar 'Abbas that was to be constructed by Iran and the Dubai-based International Development Corp.

In another development, Iran signed an agreement with Guinea for the formation of a joint-venture company to mine Guinean bauxite. Guinea will hold 49% of the new company, and the remaining 51% will be shared between three unnamed Iranian firms. In addition, Iran has reportedly invited the Malaysia Mining Corp. Bhd (MMC) of Malaysia to participate in this and other proposed African mining ventures.

Ireland.—At the close of 1992, the Aughinish Alumina Ltd. refinery, near Limerick, achieved a previously unattained annual alumina production record of more than 1 million tons. It was through the completion of a major expansion plan, initiated in 1989, to raise the plant's annual capacity from 800,000 tons per year that Aughinish Alumina was able to reach the record breaking 1,007,000 tons produced in 1992.

In a related development, late in the year, Billiton B.V. announced that it planned to sell most of its downstream business operations, including its 35% share in Aughinish Alumina Ltd. Alcan of Canada was the holder of the remaining 65% equity share in this alumina operation.

Italy.—Eurallumina SpA, Italy's alumina producer, was to be included in the 3-year restructuring plan being developed for the country's state-owned aluminum sector, comprising Alumix SpA and its subsidiaries. The primary objective of the effort was to return the Alumix group to profitability within the next 3 years and to prepare these business entities for eventual privatization.

Jamaica.—The Jamaican Government reportedly entered into negotiations with

Russia's foreign trade organization Raznoimport in an attempt to recover about $4.5 million in payments for bauxite that Jamaica delivered under an agreement with the former U.S.S.R. in 1991.

In mid-1992, a new 2-year labor agreement was reached between Alumina Partners of Jamaica (Alpart) and its workers' unions. The contract provided Alpart's 2,000 employees with a 112% wage increase during the first year of the agreement and a 28% raise in the second. Alpart remains a joint-venture company owned by Kaiser Aluminum Corp. of the United States (65%) and Hydro Aluminium A.S. of Norway (35%).

If capacity increases currently proposed by Jamaica's alumina producers come on-stream as planned, alumina production in the country would increase by approximately 50% through 1997. Alpart has announced plans to raise its annual production capacity from a current 1.2 million tons per year to 1.5 million tons by mid-1993 at an estimated cost of $180 million. Jamalco (Government of Jamaica 50% and Alcoa 50%) planned to increase capacity at its Clarendon plant from 800,000 tons per year to an annual rate of 1 million tons. Alcan, in the meantime, proposed to boost the combined capacity available from its two Jamaican alumina plants by 200,000 tons to 1.2 million tons per year.

Additionally, the Jamaica Bauxite Institute (JBI) commenced a program to assess the feasibility of constructing a caustic soda plant to serve Jamaica's alumina industry. It has been estimated that Jamaica presently consumes about 300,000 tons per year of caustic soda, primarily imported from North America. The study was designed to examine the viability of establishing a caustic soda plant based on locally available limestone and imported soda ash. To assist the JBI with this project, the European Investment Bank of Luxembourg approved a loan of approximately $350,000 to fund the feasibility work. The loan was provided on a contract liability basis such that if the project proceeds to a commercial-scale operation then the loan would be repaid; if not, the loan would be forgiven. Work on the 6- to 7-month study was expected to commence in November with an initial market assessment that, if favorable, would be followed by a technical and engineering design study.

At the close of 1992, after about 6 months of delay, plans to reactivate the Lydford bauxite mine near Ocho Rios, Jamaica, were approved by Ukraine, and the formation of a mining joint venture awaited receipt of final financial guarantees. Under the agreements, the Nikolayev Alumina Plant in Ukraine, Jamaica Bauxite Mining Ltd., and American business interests proposed to reopen the mine, which Reynolds had closed in 1984.

Japan.—In 1992, Nippon Light Metal's Shimizu alumina plant in central Japan hosted a trial run of Alcan's new technology for alumina production. The process reportedly saves energy and materials, thereby reducing production costs. Alcan currently holds a 45.3% interest in Nippon Light Metal Co., Ltd.

Korea, Republic of.—The Korea General Chemical Corp. (KGCC), a state-owned enterprise, reportedly awarded a contract, valued at approximately $215 million, to Kaiser Engineers Australia for the design and construction of a 215,000-ton-per-year alumina plant in the Mokp'o area of southeastern Korea. KGCC officials anticipate that the plant should commence production by mid-1995. The plant's output of high-purity alumina trihyrate has been targeted to supply domestic markets for specialty aluminas, such as those used in chemical and ceramic applications.

Malaysia.—In 1992, Alcan exchanged its participation in Johore Mining and Stevedoring Co. Sdn Berhad for additional shares in Nippon Light Metal Co., Ltd. (NLM) of Japan. The mining operations at Pengerang, Johor, supply bauxite to NLM's Shimizu, Japan, alumina plant and to third parties.

Netherlands.—Billiton Marketing and Trading (BMT) commenced a 7-year contract for the supply of alumina from Suriname to the Aluminium Delfzijl aluminum smelter in the Netherlands. Under the terms of the contract, BMT was to supply 150,000 tons of alumina in 1992, and then would supply 100,000 tons per year for the remaining years of the contract.

Russia.—One of the principal issues addressed at the International Aluminum Conference held in St. Petersburg, Russia (September 15-18), was the supply of raw materials to the aluminum industry of the former U.S.S.R. It was estimated that the Russian state-owned aluminum consortium, Aluminiy, would need to import approximately 4 million tons of bauxite and about 1.7 million tons of alumina for its primary metal production facilities in 1992.

Preliminary plans were presented in 1992 to develop the Sredniy-Timan bauxite deposit in the northern Russian autonomous Komi republic. Government officials proposed that a joint stock company be set up to carry out development of this bauxite mining project.

For 1992, it was reported that the Russian Ministry of Industry allocated to Russia's primary aluminum producers export quotas totaling 930,000 tons of metal. Of that total amount, 615,000 tons was to be sold for the purchase of raw materials through the foreign trade organizations Raznoimport and Tsvetmetexport, and 315,000 tons was designated to be traded for the purpose of replenishing Russia's hard currency reserves.

At midyear, it was announced that Russia would impose a new series of mineral production levies on companies extracting mineral resources from within its territory. The taxes were retroactive to June 1 and applied to both domestic and foreign firms. In the case of bauxite production, the levy was placed at the 3% level.

Sierra Leone.—The Sierra Leone Ore and Metals Co. Ltd. (Sieromco), a wholly owned subsidiary of Alusuisse-

Lonza, reportedly continued its bauxite exploration program in the Gbonge Hills region, to the southeast of Gondama, and it was anticipated that mining operations would commence at the site in the near future.

South Africa, Republic of.—Alusaf Pty. Ltd. has developed long-term alumina supply contracts with Alcoa and Billiton to provide the 900,000 tons per year of alumina required to feed its planned 466,000-ton-per-year greenfield primary aluminum smelter at Richards Bay, Republic of South Africa.

Spain.—It was reported that Inespal's subsidiary Alumina Espanola entered into an agreement to purchase 1,404,000 tons per year of bauxite for its San Ciprian alumina plant in northwestern Spain. The supply contract with Alcan was scheduled to run until 1995.

Suriname.—Late in 1992, the Government of Suriname prepared a currency reform package to help eliminate the gridlock that had developed in new aluminum industry investments. Reportedly, the principal obstacle to bauxite-alumina-aluminum expansion in Suriname had centered on the currency exchange rates that the foreign producers were required to contend with in their daily business operations. The reform package recommended a sizable devaluation of the local currency, elimination of various price and trade control measures, plus a tighter check on the nation's budget deficit.

Venezuela.—CVG-Interamericana de Alumina, C.A. (Interalumina) reportedly set the first half of 1996 as the startup date for a third production line based on Alusuisse technology at its Puerto Ordaz alumina plant. This would result in Interalumina's total capacity being increased from 2 million tons per year to 3 million tons per year. Accordingly, to accommodate this alumina expansion, Venezuela's CVG-Bauxita Venezolana C.A. (Bauxiven) ultimately would need to increase domestic production at its Los Pijigauos bauxite mine to 8 million tons per year. *(See tables 26 and 27.)*

Current Research

In 1992, the USBM reported on research conducted as part of a previously funded program to study processes for the extraction of alumina from domestic resources.[6] In this project, a bench-scale evaporative crystallizer was operated with solutions of impure aluminum chloride hexahydrate (ACH). The primary purpose of the research was to determine the distribution of impurities in the bleedstream section of a proposed clay-HCl process for production of alumina. Phosphorus was established to be the principal contaminant that affected operation of the crystallizer. Chromium, magnesium, potassium, and sodium impurities were found to require smaller bleedstreams than would be necessary for phosphorus.

The Florida Institute of Phosphate Research (FIPR) reportedly has developed a dewatering process that may achieve promising results on red mud waste streams from Bayer process operations. The FIPR process consists of adding pulp fibers (3 to 6 mm in length) with a polyacrylamide flocculant. The fibers assist in the formation of large flocs that have the physical stability to withstand normal industrial dewatering techniques.

Biological methods of converting sodium oxalate ($Na_2C_2O_4$), a hazardous substance generated from Bayer-process production of alumina, have reportedly been tested independently at the pilot plant level by Alcan in Jamaica and Worsley Alumina Pty. Ltd. in Australia. The use of micro-organisms to dispose of sodium oxalate was said to be far simpler and cheaper than the currently employed burning and landfilling methods of disposal. It was reported that Worsley Alumina had operated a 8-ton-per-year pilot plant since early 1992 and has commenced work to optimize the process for application to its 1.6-million-ton-per-year alumina plant at Collie, Western Australia. In the Worsley Alumina process, sodium oxalate filter cake from a caustic waste liquor was slurried with water and placed in an aerated tank along with bacilli, which converted the $Na_2C_2O_4$ into sodium carbonate and bicarbonate. It was determined that this biological process operated best when the pH was between 9 and 11.

The method employed by Alcan at its Ewarton, Jamaica, alumina plant utilized the micro-organism, *pseudomonas oxalaticus*, to consume the sodium oxalate. Alcan's pilot plant work has achieved a 95% level of sodium oxalate elimination with the corresponding destruction of 2 tons per month of this hazardous waste. In the Alcan process, sodium oxalate precipitate was dissolved in water, at a concentration of about 10 to 15 grams per liter. The solution was then introduced into a biological contactor, where the bacteria, immobilized on disks, rotated between the solution and air to convert the oxalate into sodium carbonate. The pH level was maintained between 9 and 9.5, and some fertilizer was added as a nutrient. Alcan reportedly was considering plans to scale up the pilot plant in 1993.

In 1992, researchers from BHP Co. Ltd. reported on continuing investigations dealing with the use of manganese dioxide (MnO_2) for carbon removal from Bayer liquors.[7] Their work showed that the selective oxidation of alumina plant liquors by MnO_2 can result in substantial increases in alumina yield. Manganese dioxide treatment also was found to cause a beneficial decrease in the soda content of the alumina and that a small reduction in the total organic carbon levels with this treatment also may be significant in improving the viscosity of the liquor. Additionally, preliminary financial calculations developed in this BHP study demonstrated that the MnO_2 process was most economically viable when applied as a sidestream process treating a spent liquor and used in combination with a subsequent sodium oxalate removal step, at an increased level of liquor causticization.

Engineers at Southwest Research Institute (SWRI), San Antonio, TX, reportedly have developed a new series of composite materials known as MIMLC's (micro-infiltrated, macro-laminated composites). These materials are suitable for use in armored vehicle and spacecraft

shields by providing the structures with resistance to high-velocity impact and protection against multiple impacts. A SWRI developed MIMLC, consisting of alternating layers of nickel and alumina-nickel, recently was successfully tested as an armor material against tungsten heavy alloy-based penetrators.

Researchers at Yoshida Kogyo Co. (YKK) have developed a ultrafine, hexagon-shaped alumina with a grain diameter of approximately 1 micron and a thickness of approximately 0.1 micron. The newly developed alumina has fluidity characteristics similar to those of clay, offering possible applications in ceramics, papermaking, cosmetics, and coating products.

OUTLOOK—BAUXITE AND ALUMINA

Known world bauxite reserves are sufficient to meet cumulative world demand well into the 21st century. Considering the high probability of discovering additional bauxite deposits and assuming reasonable energy costs, plus the added possibility of employing lower grade bauxite deposits and other alternative sources of alumina, world resources of aluminum remain adequate to satisfy 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. If the costs of imported bauxite and alumina increase for U.S. companies, alternate domestic sources of alumina may become economically more attractive. Alternatively, high fuel prices tend to make nonbauxitic materials less competitive because the processes for treating substitute materials require considerably greater energy inputs than Bayer-processed bauxite. Therefore, it 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 the future, the continued and extended economic restructuring of Eastern Europe and the newly independent republics of the former U.S.S.R. appear to provide substantially increased market opportunities for 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 believed to be incapable of sustaining an economically sound market-based aluminum industry. To become truly competitive in the "new global economy," major amounts of imported bauxite and alumina feedstocks will be required to supply the primary aluminum production facilities of the former U.S.S.R. The most crucial element in the development of this trade pattern will be the implementation of adequate and reliable payment mechanisms for the transfer of these vital raw materials from their producers to the aluminum industry of the former U.S.S.R.

Beyond alumina's principal use as a feedstock for the production of primary aluminum metal, the future will include an increased demand for alumina in specialty markets (abrasive, ceramic, chemical, new materials, and refractory applications). Economic forecasts project that these very specialized markets will become significant profit centers for the world's principal bauxite and alumina producers.

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Metals Week.
Roskill Information Services Ltd: Aluminium 1992, 5th ed.
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TABLE 1
SALIENT ALUMINUM STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1988	1989	1990	1991	1992
United States:					
Primary production	3,944	4,030	4,048	4,121	4,042
Value	$9,572,066	$7,801,086	$6,604,398	$5,402,627	$5,125,612
Price: (average cents per pound) U.S. market (spot)	110.1	87.8	74.0	59.5	57.5
Secondary recovery	2,122	2,054	2,393	r2,286	2,757
Exports (crude and semicrude)	1,247	1,615	1,659	1,762	1,453
Imports for consumption (crude and semicrude)	1,620	1,470	1,514	1,490	1,725
Aluminum industry shipments[1]	6,851	6,761	r6,640	r6,364	p6,776
Consumption, apparent	5,373	4,957	5,264	r5,043	5,725
World: Production	r18,495	r19,104	r19,292	r19,528	e19,219

eEstimated. pPreliminary. rRevised.
[1]Shipped to domestic industry.

TABLE 2

PRIMARY ANNUAL ALUMINUM PRODUCTION CAPACITY IN THE UNITED STATES, BY COMPANY

Company	Yearend capacity (thousand metric tons)		1992 ownership (percent)
	1991	1992	
Alcan Aluminum Corp.:			
Sebree, KY	163	180	Alcan Aluminium Ltd., 100%.
Alumax Inc.:			
Ferndale, WA (Intalco)	275	275	AMAX Inc., 75%; Mitsui & Co., 11%; Toyo Sash 7%; Yoshida Kogya K.K., 7%.
Frederick, MD (Eastalco)	170	170	Do.
Mount Holly, SC	184	184	AMAX, 73%; Clarendon Ltd., 27%.
Total	629	629	
Aluminum Co. of America:[1]			
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:			
Hawesville, KY	186	186	Southwire Co., 100%.
Noranda Aluminum Inc.:			
New Madrid, MO	204	215	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	168	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	116	116	Vanalco Inc., 100%.
Grand total	4,133	4,163	

[1]Individual plant capacities are U.S. Bureau of Mines estimates based on company reported total.

[2]Northwest Aluminum Corp. signed a lease-purchase agreement for The Dalles smelter with Martin Marietta Corp. in 1986.

TABLE 3

U.S. CONSUMPTION OF AND RECOVERY FROM PURCHASED NEW AND OLD ALUMINUM SCRAP,[1] BY CLASS

(Metric tons)

Class	Consumption	Calculated recovery	
		Aluminum	Metallic
1991[r]			
Secondary smelters	673,531	553,068	594,744
Intergrated aluminum companies	1,292,168	1,081,616	1,152,520
Independent mill fabricators	402,651	337,043	359,713
Foundries	77,500	64,496	69,464
Other consumers	10,476	10,476	10,476
Total	2,456,326	2,046,699	2,186,917
Estimated full industry coverage[2]	2,568,000	2,139,000	2,286,000
1992			
Secondary smelters	945,627	760,064	815,548
Intergrated aluminum companies	1,365,751	1,139,971	1,215,115
Independent mill fabricators	553,318	473,818	505,679
Foundries	85,529	70,298	75,555
Other consumers	10,449	10,449	10,449
Total	2,960,674	2,454,600	2,622,346
Estimated full industry coverage[2]	3,113,000	2,580,000	2,757,000

[r]Revised.

[1]Excludes recovery from other than aluminum-base scrap.

[2]Rounded.

TABLE 4

U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF PURCHASED NEW AND OLD ALUMINUM SCRAP[1] AND SWEATED PIG IN 1992

(Metric tons)

Class of consumer and type of scrap	Stocks, Jan. 1	Net receipts[2]	Consumption	Stocks, Dec. 31
Secondary smelters:				
New scrap:				
Solids	r5,274	97,340	97,836	4,778
Borings and turnings	r6,618	105,144	107,435	4,327
Dross and skimmings	r2,852	59,497	59,793	2,556
Other[3]	r3,830	86,091	88,884	1,037
Total	r18,574	348,072	353,948	12,698
Old scrap:				
Castings, sheet, clippings	r14,648	437,927	439,286	13,289
Aluminum-copper radiators	r828	7,341	7,232	937
Aluminum cans[4]	r1,018	97,964	97,775	1,207
Other[5]	r456	45,503	45,592	367
Total[6]	r16,950	588,735	589,885	15,800
Sweated pig	628	1,395	1,794	229
Total secondary smelters[6]	r36,152	938,202	945,627	28,727
Integrated aluminum companies, foundries, independent mill fabricators, other consumers:				
New scrap:				
Solids	r12,536	562,819	562,435	12,920
Borings and turnings	(7)	31,317	30,932	385
Dross and skimmings	r12	10,332	10,305	39
Other[3]	r8,269	234,145	235,121	7,293
Total	r20,817	838,613	838,793	20,637
Old scrap:				
Castings, sheet, clippings	r5,432	337,387	334,244	8,575
Aluminum-copper radiators	r12	3,773	3,424	361
Aluminum cans	r34,606	810,384	821,285	23,705
Other[5]	—	8,187	7,963	224
Total	r40,050	1,159,731	1,166,916	32,865
Sweated pig	1,197	8,409	9,338	268
Total integrated aluminum companies, etc.	r62,064	2,006,753	2,015,047	53,770
All scrap consumed:				
New scrap:				
Solids	r17,810	660,159	660,271	17,698
Borings and turnings	r6,618	136,461	138,367	4,712
Dross and skimmings	r2,864	69,829	70,098	2,595
Other[3]	r12,099	320,236	324,005	8,330
Total new scrap	r39,391	1,186,685	1,192,741	33,335
Old scrap:				
Castings, sheet, clippings	r20,080	775,314	773,530	21,864
Aluminum-copper radiators	r840	11,114	10,656	1,298
Aluminum cans	r35,624	908,348	919,060	24,912
Other[5]	r456	53,690	53,555	591
Total old scrap[6]	r57,000	1,748,466	1,756,801	48,665

See footnotes at end of table.

TABLE 4—Continued

U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF PURCHASED NEW AND OLD ALUMINUM SCRAP[1] AND SWEATED PIG IN 1992

(Metric tons)

Class of consumer and type of scrap	Stocks, Jan. 1	Net receipts[2]	Consumption	Stocks, Dec. 31
All scrap consumed—Continued:				
Sweated pig	1,825	9,804	11,132	497
Total of all scrap consumed[6]	r98,216	2,944,955	2,960,674	82,497

rRevised.
[1]Includes imported scrap. According to reporting companies, 3.87% of total receipts of aluminum-base scrap, or 112,286 metric tons, was received on toll arrangements.
[2]Includes inventory adjustment.
[3]Includes data on foil, can stock clippings, and other miscellaneous.
[4]Used beverage cans toll treated for primary producers are included in secondary smelter tabulation.
[5]Includes municipal wastes (includes litter) and fragmentized scrap (auto shredder).
[6]Data may not add to totals shown because of independent rounding.
[7]Data revised to zero.

TABLE 5

PRODUCTION AND SHIPMENTS OF SECONDARY ALUMINUM ALLOYS BY INDEPENDENT SMELTERS IN THE UNITED STATES

(Metric tons)

	1991		1992	
	Production	Net shipments[1]	Production	Net shipments[1]
Die-cast alloys:				
13% Si, 360, etc. (0.6% Cu, maximum)	r60,126	r59,338	41,921	44,666
380 and variations	r299,071	r300,202	466,137	465,256
Sand and permanent mold:				
95/5 Al-Si, 356, etc. (0.6% Cu, maximum)	r10,207	r10,345	78,089	67,146
No. 12 and variations	W	W	W	W
No. 319 and variations	r46,045	r48,273	52,876	52,929
F-132 alloy and variations	13,770	r12,385	52,652	51,483
Al-Mg alloys	723	719	645	644
Al-Zn alloys	2,761	2,789	3,086	2,881
Al-Si alloys (0.6% to 2.0% Cu)	8,608	r8,413	10,680	10,705
Al-Cu alloys (1.5% Si, maximum)	1,195	1,249	1,664	1,588
Al-Si-Cu-Ni alloys	1,278	1,272	1,352	1,326
Other	r901	r1,017	1,684	1,647
Wrought alloys: Extrusion billets	67,922	r67,824	72,509	66,985
Miscellaneous:				
Steel deoxidation	6,690	6,690	3,345	3,413
Pure (97.0% Al)	117	r96	59	69
Aluminum-base hardeners	100	r101	93	97
Other[2]	29,060	r27,491	34,262	33,433
Total	r548,574	r548,204	821,054	804,268
Less consumption of materials other than scrap:				
Primary aluminum	15,881	—	65,351	—
Primary silicon	r27,213	—	35,573	—
Other	1,888	—	3,620	—
Net metallic recovery from aluminum scrap and sweated pig consumed in production of secondary aluminum ingot[3]	r503,592	XX	716,510	XX

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Sand and permanent mold: Other." XX Not applicable.

[1]Includes inventory adjustment.

[2]Includes other die-cast alloys and other miscellaneous.

[3]No allowance made for melt-loss of primary aluminum and alloying ingredients.

TABLE 6
U.S. APPARENT ALUMINUM SUPPLY AND CONSUMPTION

(Thousand metric tons)

	1988	1989	1990	1991	1992
Primary production	3,944	4,030	4,048	4,121	4,042
Change in stocks:[1]					
Aluminum industry	+11	+61	+2	r+45	-100
LME stocks in U.S. warehouses	—	—	—	-168	-46
National Defense Stockpile	—	—	—	—	-55
Imports	1,620	1,470	1,514	1,490	1,725
Secondary recovery:[2]					
New scrap	1,077	1,043	1,034	r969	1,145
Old scrap	1,045	1,011	1,359	r1,317	1,612
Total supply	7,697	7,615	7,957	r7,774	8,323
Less total exports	1,247	1,615	1,659	1,762	1,453
Apparent aluminum supply available for domestic manufacturing	6,450	6,000	6,298	r6,012	6,870
Apparent consumption[3]	5,373	4,957	5,264	r5,043	5,725

rRevised.
[1]Positive figure indicates a decrease in stocks; negative figure indicates an increase in stocks.
[2]Metallic recovery from purchased, tolled, or imported new and old aluminum scrap expanded for full industry coverage.
[3]Apparent aluminum supply available for domestic manufacturing less recovery from purchased new scrap (a measure of consumption in manufactured end products).

TABLE 7
DISTRIBUTION OF END-USE SHIPMENTS OF ALUMINUM PRODUCTS IN THE UNITED STATES, BY INDUSTRY

Industry	1990		1991		1992p	
	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	2,157	r27.7	2,210	r28.6	2,259	28.2
Building and construction	1,208	r15.5	1,052	r13.6	1,144	14.3
Transportation	r1,457	r18.7	r1,383	r17.9	1,558	19.5
Electrical	r596	r7.6	579	r7.5	587	7.3
Consumer durables	509	r6.5	472	r6.1	523	6.5
Machinery and equipment	452	r5.8	426	r5.5	448	5.6
Other markets	261	3.4	241	r3.1	256	3.2
Total to domestic users[1]	r6,640	r85.2	r6,364	r82.4	6,776	84.6
Exports	r1,157	r14.8	1,357	r17.6	1,235	15.4
Grand total	r7,797	100.0	r7,721	100.0	8,011	100.0

pPreliminary. rRevised.
[1]Data may not add to totals shown because of independent rounding.

Source: The Aluminum Association Inc.

TABLE 8

U.S. NET SHIPMENTS[1] OF ALUMINUM WROUGHT AND CAST PRODUCTS, BY PRODUCERS

(Metric tons)

	1991	1992[p]
Wrought products:		
Sheet, plate, foil	[r]3,783,066	4,097,009
Rod, bar, pipe, tube, and shapes	[r]1,100,977	1,185,893
Rod, wire, cable	[r]301,250	303,475
Forgings (including impacts)	[r]63,074	61,705
Powder, flake, paste	[r]43,740	43,035
Total	[r]5,292,107	5,691,117
Castings:		
Sand	97,038	NA
Permanent and semipermanent mold	167,925	NA
Die	575,179	NA
Other	23,794	NA
Total	863,936	NA
Grand total	[r]6,156,043	NA

[p]Preliminary. [r]Revised. NA Not available.

[1]Net 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 9

U.S. EXPORTS OF ALUMINUM, BY CLASS

Class	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Crude and semicrude:				
Metals and alloys, crude	792,794	$1,274,285	603,818	$843,261
Scrap	460,820	541,702	295,239	299,598
Plates, sheets, bars, strip, etc.	488,950	1,383,928	533,905	1,416,160
Castings and forgings	7,336	90,288	5,348	54,904
Semifabricated forms, n.e.c.	12,387	65,862	14,383	66,279
Total	1,762,287	3,356,065	[1]1,452,695	2,680,202
Manufactures:				
Foil and leaf	35,373	116,975	41,751	128,389
Powders and flakes	4,494	18,291	4,246	16,406
Wire and cable	22,314	65,739	28,758	86,395
Total	62,181	201,005	74,755	231,190
Grand total	1,824,468	3,557,070	1,527,450	2,911,392

[1]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10

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)
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]	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]	792,794	1,274,285	508,673	1,540,078	460,820	541,702	1,762,287	3,356,065
1992:								
Brazil	96	230	5,293	17,203	966	1,243	6,355	18,676
Canada	78,651	120,799	288,983	671,018	45,615	50,867	413,249	842,684
France	5,396	7,885	3,359	19,312	1,975	2,111	10,730	29,308
Germany	316	1,264	10,511	32,028	411	657	11,238	33,950
Hong Kong	7,685	10,248	4,906	17,505	8,845	6,471	21,436	34,224
Italy	60	337	2,481	19,624	533	533	3,073	20,495
Japan	416,122	547,661	24,673	86,404	139,835	144,919	580,630	778,984
Korea, Republic of	18,828	25,877	16,332	47,509	17,138	18,714	52,298	92,100
Mexico	30,112	60,338	73,552	232,295	26,010	28,409	129,675	321,041
Netherlands	1,249	2,199	2,493	15,236	524	598	4,266	18,033
Philippines	3,034	4,129	187	941	126	144	3,348	5,215
Saudi Arabia	163	413	20,557	48,114	125	179	20,846	48,706
Singapore	167	384	3,016	8,534	386	262	3,569	9,180
Taiwan	21,289	29,865	12,545	40,341	30,855	23,663	64,689	93,869
Thailand	10,965	14,407	4,360	9,045	1,992	1,590	17,317	25,042
U.S.S.R.[3]	409	242	85	489	—	—	495	730
United Kingdom	3,866	6,151	10,946	50,812	2,035	2,185	16,847	59,148
Venezuela	16	63	23,629	61,429	557	547	24,203	62,039
Other	5,393	10,770	45,727	159,505	17,312	16,505	68,431	186,779
Total[2]	603,818	843,261	553,637	1,537,343	295,239	299,598	1,452,695	2,680,202

[1]Includes castings, forgings, and unclassified semifabricated forms.

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

[3]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

Source: Bureau of the Census.

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM, BY CLASS

Class	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Crude and semicrude:				
Metals and alloys, crude	1,024,732	$1,428,420	1,155,515	$1,500,777
Plates, sheets, strip, etc., n.e.c.[1]	243,492	564,548	283,960	622,865
Pipes, tubes, etc.	3,345	27,650	4,538	30,683
Rods and bars	9,647	28,118	15,305	40,375
Scrap	208,384	219,558	265,306	267,372
Total[2]	1,489,600	2,268,296	1,724,624	2,462,070
Manufactures:				
Foil and leaf[3]	27,488	108,318	28,136	111,349
Flakes and powders	1,057	3,116	1,885	3,985
Wire	14,742	31,539	17,183	32,232
Total	43,287	142,973	47,204	147,566
Grand total[2]	1,532,886	2,411,269	1,771,827	2,609,636

[1]Includes plates, sheets, circles, and disks.
[2]Data may not add to totals shown because of independent rounding.
[3]Excludes etched capacitor foil.

Source: Bureau of the Census.

TABLE 12

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)
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.[3]	—	—	—	—	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
Yugoslavia[4]	—	—	9,980	19,864	—	—	9,980	19,864
Other	383	489	11,455	39,146	10,005	6,752	21,844	46,387
Total[2]	1,024,732	1,428,420	256,484	620,317	208,384	219,558	1,489,600	2,268,296
1992:								
Argentina	5,301	6,832	216	573	—	—	5,517	7,405
Australia	487	660	1,322	2,454	19	12	1,829	3,126
Bahrain	—	—	5,925	11,618	—	—	5,925	11,618
Belgium	63	76	6,705	15,420	678	606	7,445	16,101
Brazil	10,369	13,474	2,631	5,313	330	368	13,330	19,155
Canada	1,056,011	1,372,463	168,939	312,046	168,792	183,677	1,393,742	1,868,186
France	222	1,691	9,835	34,498	3,252	2,386	13,310	38,575
Germany	640	3,644	17,213	69,694	4,816	5,554	22,669	78,892
Italy	22	1,326	2,100	5,600	—	—	2,122	6,926
Japan	61	122	17,273	68,061	85	372	17,419	68,554
Korea, Republic of	50	189	119	862	(5)	8	169	1,059
Mexico	160	399	3,864	10,653	43,632	37,997	47,656	49,049
Netherlands	—	—	4,728	14,456	2,243	2,821	6,970	17,277
Norway	126	904	891	1,719	69	87	1,086	2,710
South Africa, Republic of	199	672	6,216	11,226	20	7	6,435	11,905
Spain	—	—	6,873	12,441	63	174	6,936	12,615
U.S.S.R.[3]	16,384	16,684	391	518	5,919	4,808	22,694	22,010
United Arab Emirates	2,110	2,870	—	—	—	—	2,110	2,870
United Kingdom	7,081	10,429	8,674	30,479	1,639	1,737	17,395	42,645
Venezuela	55,554	67,663	15,223	23,537	20,721	16,464	91,499	107,664

See footnotes at end of table.

TABLE 12—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)
1992—Continued:								
Yugoslavia[4]	80	$120	7,676	$14,382	10	$10	7,767	$14,512
Other	595	558	16,987	48,373	13,017	10,284	30,600	59,215
Total[2]	1,155,515	1,500,777	303,802	693,922	265,306	267,372	1,724,624	2,462,070

[1]Includes circles, disks, rods, pipes, tubes, etc.

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

[3]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

[4]Dissolved in Apr. 1992.

[5]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 13

ALUMINUM, PRIMARY: WORLD PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1988	1989	1990	1991	1992[e]
Argentina	154	[e]162	166	[e]165	165
Australia	1,150	1,244	1,234	1,235	[2]1,216
Austria	95	93	89	80	34
Azerbaijan[3]	—	—	—	—	25
Bahrain	183	187	213	[r]227	290
Bosnia and Herzegovina[4]	—	—	—	—	40
Brazil	874	890	931	1,140	1,200
Cameroon	87	92	93	[r]83	82
Canada	1,534	1,555	1,567	[r]1,822	[2]1,950
China[e]	710	850	850	860	950
Croatia[4]	—	—	—	—	50
Czechoslovakia[e]	67	69	70	68	68
Egypt	173	180	179	178	177
France	328	335	326	286	417
Germany					
Eastern states	61	54	[r]20	—	—
Western states	753	734	715	—	—
Total[e]	814	788	[r]735	690	600
Ghana	161	169	174	175	178
Greece	[r]148	145	150	152	153
Hungary	75	75	75	[r]63	26
Iceland	82	88	[r]87	89	89
India[3]	375	423	433	[r e]504	500
Indonesia[3]	185	197	186	[r]187	175
Iran[e]	40	[r]54	[r]60	[r]80	100
Italy	226	219	232	[r]206	180
Japan[6]	35	35	34	32	20
Korea, North[e]	10	10	—	—	—
Korea, Republic of[3]	18	18	2	2	2
Mexico[3]	68	72	68	51	10
Netherlands	278	[r]274	270	264	235
New Zealand	264	[r]260	[r]260	[r]259	[2]242
Norway	864	863	845	833	[2]813
Poland[7]	48	48	46	[r]46	45
Romania[8]	265	269	168	158	110
Russia[3]	—	—	—	—	2,700
Serbia and Montenegro[4]	—	—	—	—	60
Slovenia[4]	—	—	—	—	65
South Africa, Republic of	170	166	[r]159	[r]171	172
Spain	323	352	355	355	350
Suriname	10	28	[r]32	[r]29	30
Sweden	99	97	96	97	74
Switzerland	72	71	72	66	55
Tajikistan[3]	—	—	—	—	300
Turkey	57	62	61	56	59
U.S.S.R.[e 9]	[r]3,350	[r]3,300	[r 2]3,523	[r 2]3,251	—

See footnotes at end of table.

TABLE 13—Continued

ALUMINUM, PRIMARY: WORLD PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1988	1989	1990	1991	1992[e]
Ukraine[3]	—	—	—	—	90
United Arab Emirates: Dubai	162	168	174	239	240
United Kingdom	300	297	290	294	240
United States	3,944	4,030	4,048	4,121	[2]4,042
Venezuela	437	540	590	[r]601	600
Yugoslavia[5 10]	260	331	349	315	—
Total[11]	[r]18,495	[r]19,104	[r]19,292	[r]19,528	19,219

[e]Estimated. [r]Revised.

[1]The 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 June 2, 1993.

[2]Reported figure.

[3]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[4]Formerly part of Yugoslavia; data were not reported separately until 1992.

[5]Primary ingot.

[6]Excludes high-purity aluminum containing 99.995% or more as follows, in metric tons: 1988—13,628; 1989—15,696; 1990—16,292; 1991—19,652; and 1992—20,000 (estimated).

[7]Primary unalloyed ingot plus secondary unalloyed ingot.

[8]Primary unalloyed metal plus primary alloyed metal, thus including weight of alloying material.

[9]Dissolved in Dec. 1991.

[10]Dissolved in Apr. 1992.

[11]Data may not add to totals shown because of independent rounding.

TABLE 14

SALIENT BAUXITE STATISTICS

(Thousand metric tons and thousand dollars)

	1988	1989	1990	1991	1992
United States:					
Production: Crude ore (dry equivalent)	588	W	W	W	W
Value	[e]$10,566	W	W	W	W
Exports (as shipped)	63	44	53	51	71
Imports for consumption[1]	9,944	10,893	[r]12,144	[r]11,871	10,939
Consumption (dry equivalent)	10,074	11,810	12,042	12,204	11,860
World: Production	[r]97,428	[r]103,848	[r]108,609	[r]108,157	[e]103,625

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.

[1]Excludes calcined bauxite. Includes bauxite imported to the U.S. Virgin Islands.

TABLE 15

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:[e]				
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
1992	4,740	640	5,380	5,185
Shipments:[e]				
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
1992	4,805	650	5,455	5,260

[e]Estimated.

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

[2]Trihydrate, activated, tabular, and other aluminas. Excludes calcium and sodium aluminates.

[3]Includes only the end product if one type of alumina was produced and used to make another type of alumina.

TABLE 16

CAPACITIES OF DOMESTIC ALUMINA PLANTS,[1] DECEMBER 31

(Thousand metric tons per year)

Company and plant	1990	1991	1992
Aluminum Co. of America: Point Comfort, TX	1,735	1,735	1,735
Kaiser Aluminum & Chemical Corp.: Gramercy, LA	1,000	1,000	1,000
Ormet Corp.: Burnside, LA	545	545	600
Reynolds Metals Co.: Corpus Christi, TX	1,700	1,700	1,700
Virgin Islands Alumina: St. Croix, VI	635	635	635
Total	5,615	5,615	5,670

[1]Capacity may vary depending on the bauxite used.

TABLE 17
U.S. CONSUMPTION OF BAUXITE, BY INDUSTRY

(Thousand metric tons, dry equivalent)

Industry	1990	1991	1992
Alumina	11,064	11,383	11,066
Abrasive[1]	276	204	223
Chemical	212	218	190
Refractory	387	328	321
Other	103	71	60
Total	12,042	12,204	11,860

[1]Includes consumption by Canadian abrasive industry.

TABLE 18
PRODUCTION AND SHIPMENTS OF SELECTED ALUMINUM SALTS IN THE UNITED STATES IN 1991

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_2O_3)	75	1,075	1,035	$125,997
Iron-free (17% Al_2O_3)	21	123	124	15,753
Aluminum chloride:				
Liquid and crystal	3	W	W	W
Anhydrous (100% $AlCl_3$)	5	W	W	W
Aluminum fluoride, technical	4	W	W	W
Aluminum hydroxide, trihydrate [100% $Al(OH)_3$]	9	781	776	215,159
Aluminates	18	110	101	39,592
Other aluminum compounds[1]	XX	XX	XX	154,793

W Withheld to avoid disclosing company proprietary data. XX Not applicable.
[1]Includes light aluminum hydroxide, cryolite, etc.

Source: Data are based on Bureau of the Census 1991 Current Industrial Reports, Series MA-28A, "Inorganic Chemicals."

TABLE 19
STOCKS OF BAUXITE IN THE UNITED STATES,[1] DECEMBER 31

(Thousand metric tons, dry equivalent)

Sector	1991	1992
Producers, processors, and consumers	r2,620	2,319
Government	18,477	17,805
Total	r21,097	20,124

rRevised.
[1]Domestic and foreign bauxite; crude, dried, calcined, activated; all grades.

TABLE 20
STOCKS OF ALUMINA IN THE UNITED STATES,[1] DECEMBER 31

(Thousand metric tons, calcined equivalent)

Sector	1991	1992
Producers	582	492
Primary aluminum plants	1,315	1,219
Total	1,897	1,711

[1]Excludes consumers' stocks other than those at primary aluminum plants.

TABLE 21
AVERAGE VALUE OF U.S. IMPORTS OF CRUDE AND DRIED BAUXITE[1]

(Per metric ton)

Country	1991		1992	
	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	$19.48	$31.25	$17.55	$30.55
Brazil	32.11	38.65	29.40	40.51
Guinea	32.44	39.64	28.65	35.88
Guyana	30.48	39.14	30.13	40.38
Jamaica	29.57	34.83	28.13	33.63
Weighted average	r30.36	r37.28	28.58	36.25

rRevised.
[1]Computed 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 22

U.S. EXPORTS OF ALUMINA,[1] BY COUNTRY

(Thousand metric tons, calcined equivalent, and thousand dollars)

Country	1990		1991		1992	
	Quantity	Value	Quantity	Value	Quantity	Value
Argentina	(2)	440	1	837	1	726
Belgium	5	5,365	2	3,562	6	8,079
Brazil	123	31,445	186	r38,334	215	36,794
Canada	709	197,889	753	205,810	729	155,863
Finland	(2)	278	77	17,615	43	8,314
France	1	3,523	1	2,526	1	6,595
Germany	3	12,702	1	8,460	3	5,592
Ghana	83	20,770	98	22,298	41	7,820
Japan	12	15,573	22	13,300	18	11,429
Mexico	170	66,215	125	47,388	37	22,503
Netherlands	19	9,972	13	7,817	20	7,717
Norway	27	8,521	—	—	—	—
Sweden	62	18,553	12	2,933	(2)	241
U.S.S.R.[3]	29	8,828	35	10,181	(2)	776
United Kingdom	2	4,249	2	4,723	5	8,613
Venezuela	3	2,789	4	3,865	2	2,066
Other	15	18,600	19	22,460	22	23,385
Total	1,263	425,712	1,351	r412,109	1,143	306,513

rRevised.

[1]Includes exports of aluminum hydroxide (calcined equivalent) as follows: 1990—34,124 tons; 1991—35,105 tons; and 1992—31,287 tons.

[2]Less than 1/2 unit.

[3]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual successor countries.

Source: Bureau of the Census.

TABLE 23

U.S. IMPORTS FOR CONSUMPTION OF BAUXITE, CRUDE AND DRIED,[1] BY COUNTRY

(Thousand metric tons)

Country	1990	1991	1992
Australia	1,430	408	179
Brazil	1,812	1,905	1,617
China	47	93	75
Guinea	3,669	3,609	3,223
Guyana	546	r1,184	1,500
India	—	105	—
Indonesia	413	135	88
Jamaica[2]	3,886	4,261	4,128
Malaysia	r131	r94	91
Sierra Leone	159	—	—
Other	51	75	37
Total[3]	r12,144	r11,871	10,939

rRevised.

[1]Includes bauxite imported to the U.S. Virgin Islands from foreign countries.

[2]Dry equivalent of shipments to the United States.

[3]Data may not add to totals 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: 1990—12,628,163 tons; 1991—11,174,990 tons; and 1992—11,111,732 tons.

Source: Bureau of the Census and the Jamaica Bauxite Institute.

TABLE 24
U.S. IMPORTS FOR CONSUMPTION OF CALCINED BAUXITE, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1991				1992			
	Refractory grade		Other grade		Refractory grade		Other grade	
	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]
Australia	—	—	16	1,247	—	—	8	607
China	104	6,492	96	5,951	174	9,903	88	4,616
Guyana	69	7,271	(2)	(2)	54	6,485	—	—
Malaysia	—	—	(2)	(2)	—	—	—	—
Other	7	440	5	219	9	997	13	681
Total[3]	181	14,203	r117	r7,417	238	17,385	108	5,904

rRevised.
[1]Value at foreign port of shipment as reported to U.S. Customs Service.
[2]Revised to zero.
[3]Data 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 25
U.S. IMPORTS FOR CONSUMPTION OF ALUMINA,[1] BY COUNTRY

(Thousand metric tons, calcined equivalent, and thousand dollars)

Country	1990		1991		1992	
	Quantity	Value[2]	Quantity	Value[2]	Quantity	Value[2]
Australia	3,413	949,280	3,639	792,056	3,500	585,791
Brazil	86	26,515	92	20,520	51	12,394
Canada	123	56,021	74	39,790	82	43,660
France	5	13,428	7	15,537	6	18,031
Germany	23	37,550	20	36,752	20	34,025
India	(3)	15	72	19,376	109	16,207
Italy	(3)	531	(3)	489	(3)	646
Jamaica	173	100,762	394	102,126	507	85,383
Japan	8	13,424	8	13,557	9	17,742
Suriname	173	45,424	242	47,784	242	38,626
Venezuela	1	382	(3)	41	150	24,273
Other	64	25,640	44	13,979	26	10,835
Total[4]	4,069	1,268,973	4,592	1,102,008	4,701	887,613

[1]Includes imports of aluminum hydroxide.
[2]Value at foreign port of shipment as reported to U.S. Customs Service.
[3]Less than 1/2 unit.
[4]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 26

BAUXITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992[e]
Albania	[e]38	[e]35	26	8	4
Australia	36,192	38,583	41,391	40,503	[2]39,950
Bosnia and Herzegovina[3]	—	—	—	—	900
Brazil	8,083	8,665	[r]9,700	[r]10,414	10,800
China[e]	2,300	2,388	2,400	2,600	3,000
Croatia[3]	—	—	—	—	200
Dominican Republic[4]	168	151	85	7	—
France	978	720	[r]490	[r]9	—
Ghana	285	347	381	[r] [e]380	400
Greece	2,433	2,602	2,504	[r]2,133	2,100
Guinea[4]	[r]15,624	[r]15,362	[r]15,340	[r] [e]14,899	13,773
Guyana[4]	[r]1,339	1,321	1,424	2,204	2,300
Hungary	2,593	2,644	2,559	2,037	1,721
India	3,961	4,768	4,852	[r]4,738	4,475
Indonesia	513	862	1,206	[r]1,406	804
Italy	17	12	([5])	9	2
Jamaica[4 6]	7,305	9,601	10,921	11,552	11,302
Kazakhstan[7]	—	—	—	—	500
Malaysia	361	355	398	376	331
Mozambique	7	6	7	8	9
Pakistan	2	2	3	[r]4	5
Romania[e]	500	[2]313	204	200	150
Russia[7]	—	—	—	—	4,000
Serbia and Montenegro[3]	—	—	—	—	850
Sierra Leone	1,379	1,562	1,430	1,288	1,246
Spain[e]	3	3	3	3	1
Suriname	3,434	3,530	[r]3,283	3,198	3,250
Turkey[8]	269	[r]562	779	[r]489	500
U.S.S.R.[e 9]	[r]5,500	[r]5,500	[r]5,500	[r]5,000	—
United States[4]	588	W	W	W	W
Venezuela	522	702	771	1,992	1,052
Yugoslavia[10]	3,034	3,252	2,952	[e]2,700	—
Total	[r]97,428	[r]103,848	[r]108,609	[r]108,157	103,625

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]Table includes data available through June 15, 1993.

[2]Reported figure.

[3]Formerly part of Yugoslavia; data were not reported separately until 1992.

[4]Dry bauxite equivalent of crude ore.

[5]Less than 1/2 unit.

[6]Bauxite processed for conversion to alumina in Jamaica plus kiln-dried ore prepared for export.

[7]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[8]Public-sector production only.

[9]Dissolved in Dec 1991. In addition to the bauxite reported in the body of the table, two of the former Republics of the U.S.S.R. produce nepheline syenite concentrates and alunite ore as sources of aluminum. Nepheline syenite concentrate produced in Russia was as follows, in thousand metric tons: 1988—1,639; 1989—1,697; 1990—1,650 (estimated); 1991—1,500 (estimated); and 1992—1,000 (estimated). Estimated alunite ore produced in Azerbaijan was as follows, in thousand metric tons: 1988—625; 1989—600; 1990—550; 1991—500; and 1992—300. 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.

[10]Dissolved in Apr. 1992.

TABLE 27

ALUMINA: WORLD PRODUCTION,[1] BY COUNTRY[2]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992[e]
Australia	10,511	10,800	11,231	11,713	[3]11,623
Azerbaijan[4]	—	—	—	—	300
Bosnia and Herzegovina[5]	—	—	—	—	250
Brazil	1,488	1,632	1,655	[r]1,739	1,700
Canada	993	1,048	1,087	1,131	1,104
China[e]	1,300	1,350	[r]1,460	1,600	1,900
Czechoslovakia	138	205	[e]175	[e]150	150
France	563	480	464	[r]538	508
Germany:					
Eastern states	64	[r]69	[r]27	—	—
Western states	[r]939	[r]964	[r]922	—	—
Total	[r]1,003	[r]1,033	[r]949	[r]863	865
Greece	515	521	[r]587	[r]625	611
Guinea	589	619	[r]631	632	[3]561
Hungary	803	882	826	[r]653	548
India	1,188	1,947	1,601	[e]1,700	1,700
Ireland	843	891	[e]885	[r]981	1,007
Italy[6]	708	722	752	[r]805	800
Jamaica	1,514	2,221	2,869	3,015	[3]2,917
Japan[7]	415	466	481	438	420
Kazakhstan[4]	—	—	—	—	1,000
Romania	620	611	440	[e]400	400
Russia[4]	—	—	—	—	2,500
Serbia and Montenegro[5]	—	—	—	—	200
Slovenia[5]	—	—	—	—	90
Spain[6]	880	949	1,002	[r]1,004	1,000
Suriname	1,632	1,567	1,532	1,510	[3]1,576
Turkey	182	201	177	159	160
Ukraine[4]	—	—	—	—	1,000
U.S.S.R.[e 8]	[r]5,800	[r]5,700	[r]5,900	[3]5,277	—
United Kingdom	114	116	120	[e]110	110
United States[e]	4,770	5,000	5,230	5,230	5,185
Venezuela	1,284	1,212	1,293	1,295	1,308
Yugoslavia[9]	1,051	1,170	1,086	[e]900	—
Total[10]	[r]38,901	[r]41,344	[r]42,432	[r]42,468	41,493

[e]Estimated. [r]Revised.

[1]Figures represent calcined alumina or the total of calcined alumina plus the calcined equivalent of hydrate when available; exceptions, if known, are noted.

[2]Table includes data available through June 15, 1993.

[3]Reported figure.

[4]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[5]Formerly part of Yugoslavia; data were not reported separately until 1992.

[6]Hydrate.

[7]Data presented are for alumina for metallurgical use. Gross weight of aluminum hydrate for all uses was as follows, in thousand metric tons: 1988—778; 1989—863; 1990—890; 1991—864; and 1992—718 (estimated).

[8]Dissolved in Dec. 1991.

[9]Dissolved in Apr. 1992.

[10]Data may not add to totals shown because of independent rounding.

ANTIMONY

By Thomas O. Llewellyn

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Reported consumption of primary antimony products increased slightly in 1992 compared with that of 1991. Production of primary antimony increased considerably. Exports and imports of antimony products were also up from those of the previous year. The U.S. International Trade Commission (ITC) unanimously determined that imports of refined antimony trioxide from China did not materially injure or threaten to injure the U.S. antimony trioxide industry, as claimed by a coalition of five domestic antimony trioxide producers.

DOMESTIC DATA COVERAGE

Domestic primary production data for antimony are 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, all responded, representing 100% of the primary smelter production shown in table 1. *(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

In 1992, 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, diorite, and monzonite. 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 former 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 aforementioned. 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 1992, 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-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 affluents 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-base products filed an antidumping petition with the U.S. ITC and the U.S. Department of Commerce (DOC), 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 February 28, 1992, the DOC announced its final determination that Chinese antimony trioxide entering the United States should be assessed the following weighted-average dumping margins: China National Metals & Minerals Import Corp. (Minmetal), 80%; China National Nonferrous Metals Import & Export Corp. (CNIEC), 13.05%; and all others, 33.10%.[5] However, in April 1992, the ITC unanimously determined that imports of refined antimony trioxide from China did not materially injure this particular U.S. industry.[6]

Strategic Considerations

Antimony was included in the National Defense Stockpile because of its strategic uses in flame-retardant compounds, friction bearings, and batteries. Under the 1992 Annual Material Plan, Public Law 102-484 of October 23, 1992, the Department of Defense was authorized to sell about 1,820 metric tons of antimony metal in addition to about 1,690 metric tons that was previously authorized on September 30, 1992. No inventory acquisitions or sales were made during the year, and, as of December 31, 1992, 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.

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 2.)*

Consumption and Uses

Reported domestic consumption of primary antimony products increased slightly in 1992 compared with 1991. 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 a 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, 72%; transportation, including batteries, 10%; chemicals, 10%; ceramics and

glass, 4%; and other, 4%. *(See tables 3, 4, and 5.)*

Markets and Prices

The New York dealer antimony metal price, published by Metals Week, started the year ranging from $0.82 to $0.84 per pound, held steady during the first quarter, but by the end of the second quarter the price range was at $0.78 to $0.88 per pound, and remained constant at that level for the rest of 1992. 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 1992.

The European price range quotation for clean antimony sulfide concentrate (60% antimony content), published by Metal Bulletin (London), held steady at $14.50 to $16.50 per metric ton unit for the first 9 months of 1992 and decreased to a range of $14.00 to $15.50 per metric ton unit by yearend. The European price range quotation for lump antimony sulfide ore (60% antimony content) held steady at $15.50 to $17.00 per metric ton unit for the first three quarters of 1992; it decreased during the fourth quarter and closed at $14.50 to $16.00 per metric ton unit.

Foreign Trade

Total imports of antimony materials increased about 8% from those of 1991. China supplied about 61% of the total imported materials in 1992. Exports of antimony oxide were about 28% higher than those of the previous year. *(See tables 6, 7, 8, and 9.)*

World Review

Antimony was produced from ores and as a byproduct of the smelting of base metal ores in about 26 countries. China, the world's leading producer, accounted for about 60% of the total world estimated mine production during 1992. China, together with the other five major producing countries, Bolivia, Kyrgyzstan, Mexico, Russia, and the Republic of South Africa, accounted for about 93% of the total world estimated mine antimony production. *(See table 10.)*

The Confederation of European Chemical Industries filed an antidumping petition with the European Commission, charging that imports of Chinese refined antimony trioxide were being dumped in Europe. The Commission determined that there was reasonable evidence to initiate an antidumping proceeding. Antidumping procedures take more than 1 year to be completed; therefore, a report of this investigation is expected to be completed by mid-1993.[7]

Capacity.—Rated annual production capacity for mines and refineries 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 total world antimony mine production capacity for 1992 was estimated at about 100,000 metric tons of content antimony, and the refinery capacity for the same year was estimated at 110,000 metric tons.

Bolivia.—Empresa Nacional de Fundiciones (ENAF), the state-owned smelting company, increased crude antimony trioxide production at its Vinto smelter by about 25% during 1992. The entire ENAF crude oxide production is shipped to Laurel Industries' plant in La Porte, TX, for a final refining stage.

Japan.—Antimony trioxide production, mainly from imported materials, was estimated at 11,227 tons, a decrease of about 6% compared with 1991 production. Antimony metal production also decreased from 262 tons in 1991 to about 165 tons in 1992.

OUTLOOK

Antimony metal prices remained steady at a low level during 1992, and all indications are that the market will probably not change much within the next 2 years. Domestic antimony trioxide producers struggled to compete with cheaper foreign imports.

The oversupply of antimony products from China that has saturated the market in the past 4 years will continue during 1993, 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 not improve.

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[2]Carapella, Jr., S. C. Antimony and Antimony Alloys. Ch. in Encyclopedia of Chem. Technol. Kirk-Othmer, 3d ed., v. 22, 1983, pp. 96-105.

[3]Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 6-Energy Data and Flowsheet, Low- Priority Commodities) (contract 0144093). BuMines OFR 117(1)-76, 1976, pp. 8-14; NTIS PB 261150/AS.

[4]Federal 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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[5]———. Department of Commerce, International Trade Administration, Import Administration. Final Determination of Sales at Less Than Fair Value: Refined Antimony Trioxide From the People's Republic of China. V. 57, No.40, Feb. 28, 1992, pp. 6801-6808.

[6]———. United States International Trade Commission. Refined Antimony Trioxide From the People's Republic of China. V. 57, No. 73, Apr. 15, 1992, p. 13118.

[7]Industrial Minerals. World Minerals—Europe. No. 296, May 1992, p. 18.

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TABLE 1
SALIENT ANTIMONY STATISTICS

(Metric tons of antimony content unless otherwise specified)

	1988	1989	1990	1991	1992
United States:					
Production:					
Primary:					
Mine (recoverable antimony)	W	W	W	W	W
Smelter	17,616	18,954	20,070	16,032	19,675
Secondary	16,172	19,501	20,351	r19,294	17,736
Exports of metal, alloys, waste and scrap	624	293	588	694	947
Exports of antimony oxide	1,227	1,850	7,142	e3,752	e4,817
Imports for consumption	30,027	25,165	29,403	28,833	31,204
Reported industrial consumption, primary antimony	12,067	13,424	12,766	r11,864	12,221
Stocks: Primary antimony, all classes, December 31	6,498	6,270	8,175	r10,170	8,743
Price: Average, cents per pound[1]	103.9	94.3	81.8	82.0	79.0
World: Mine production	r95,421	r105,462	r98,432	r80,379	e75,659

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.
[1]New York dealer price for 99.5% to 99.6% metal, c.i.f. U.S. ports.

TABLE 2
SECONDARY ANTIMONY PRODUCED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons of antimony content unless otherwise specified)

	1991r	1992
KIND OF SCRAP		
New scrap: Lead- and tin-base	1,271	1,043
Old scrap: Lead- and tin-base	18,023	16,693
Total	19,294	17,736
FORM OF RECOVERY		
In antimonial lead	18,744	NA
In other lead- and tin-base alloys	550	NA
Total	19,294	NA
Value millions	40	NA

rRevised. NA Not available.

TABLE 3

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	
1988	2,121	9,438	42	466	12,067
1989	2,523	10,640	27	234	13,424
1990	r2,148	r9,961	25	632	12,766
1991	r2,542	r9,296	26	W	r11,864
1992	2,451	9,741	29	W	12,221

rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

TABLE 4

REPORTED INDUSTRIAL CONSUMPTION OF PRIMARY ANTIMONY IN THE UNITED STATES, BY PRODUCT

(Metric tons of antimony content)

Product	1988	1989	1990	1991	1992
Metal products:					
Ammunition	W	521	602	W	W
Antimonial lead	1,538	r1,901	r1,985	r1,698	1,642
Bearing metal and bearings	178	129	90	r77	36
Cable covering	W	W	W	W	W
Castings	13	8	8	8	9
Sheet and pipe	181	157	123	W	W
Solder	256	245	208	223	248
Type metal	6	4	3	W	W
Other	609	80	106	r915	1,362
Total	2,781	r3,045	r3,125	r2,921	3,297
Nonmetal products:					
Ammunition primers	34	20	23	23	25
Ceramics and glass	1,221	1,050	991	r872	929
Fireworks	4	5	3	2	3
Pigments	179	196	246	207	314
Plastics	916	r1,137	r1,171	r1,112	717
Rubber products	29	r71	r29	W	W
Other	147	159	151	r101	115
Total	2,530	r2,638	r2,614	r2,317	2,103
Flame-retardants:					
Adhesives	251	219	189	r200	300
Paper	W	W	W	W	W
Pigments	104	926	502	W	W
Plastics	5,469	5,851	5,678	r4,982	5,108
Rubber	282	166	181	r250	241
Textiles	643	558	460	513	444
Other	7	21	17	681	728
Total	6,756	7,741	7,027	r6,626	6,821
Grand total	12,067	13,424	12,766	r11,864	12,221

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

TABLE 5
INDUSTRY STOCKS OF PRIMARY ANTIMONY IN THE UNITED STATES, DECEMBER 31

(Metric tons of antimony content)

Stocks	1988	1989	1990	1991	1992
Metal	2,360	1,873	2,934	3,598	2,450
Ore and concentrate	W	W	W	(1)	(1)
Oxide	3,840	4,079	4,380	r3,338	2,954
Residues	274	302	844	(1)	(1)
Sulfide	24	16	17	(1)	20
Total	6,498	6,270	8,175	r10,170	8,743

rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total."
[1]Data withheld to avoid disclosing company proprietary data; included in "Total."

TABLE 6
U.S. EXPORTS OF ANTIMONY METAL, ALLOYS, WASTE AND SCRAP, BY COUNTRY

Country	1991		1992	
	Gross weight (metric tons)	Value (thousands)	Gross weight (metric tons)	Value (thousands)
Belgium	594	$815	267	$396
Canada	45	130	71	188
Chile	—	—	14	33
Colombia	—	—	35	79
Dominican Republic	—	—	8	33
El Salvador	—	—	5	9
Guatemala	5	27	—	—
Japan	—	—	17	20
Mexico	12	42	409	505
United Kingdom	2	29	13	50
Venezuela	34	68	97	211
Other	(1)	27	12	95
Total[2]	694	1,138	947	1,619

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 7
U.S. EXPORTS OF ANTIMONY OXIDE, BY COUNTRY

Country	1991			1992		
	Gross weight (metric tons)	Antimony content[e] (metric tons)	Value (thousands)	Gross weight (metric tons)	Antimony content[e] (metric tons)	Value (thousands)
Belgium	28	23	$127	65	54	$178
Brazil	12	10	39	33	27	123
Canada	450	374	1,336	584	485	1,595
Colombia	56	46	182	175	145	452
Egypt	10	8	24	—	—	—
France	3	2	8	25	21	65
Germany	121	100	409	180	149	481
India	8	7	26	—	—	—
Indonesia	5	4	17	—	—	—
Israel	17	14	47	90	75	217
Italy	71	59	105	45	37	62
Japan	222	184	625	356	295	1,017
Korea, Republic of	24	20	75	—	—	—
Mexico	2,707	2,247	2,814	3,244	2,693	3,743
Netherlands	15	12	56	18	15	19
Singapore	279	232	422	551	457	1,051
Spain	53	44	127	36	30	85
Sweden	5	4	5	5	4	5
Taiwan	83	69	269	167	139	673
Turkey	48	40	158	53	44	180
United Kingdom	40	33	49	47	39	117
Venezuela	11	9	41	10	8	32
Other	253	211	443	121	99	349
Total[1]	4,521	3,752	7,404	5,804	4,817	10,443

[e]Estimated.
[1]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF ANTIMONY, BY CLASS AND COUNTRY

Country	1991			1992		
	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	197	134	$149	267	91	$505
Canada	81	40	33	893	243	478
Chile	165	164	231	69	67	94
China	2,742	2,294	3,515	1,079	1,015	1,572
France	—	—	—	103	49	328
Guatemala	29	4	16	—	—	—
Hong Kong	172	163	236	147	123	188
Mexico	428	209	258	388	277	388
Other	581	374	811	83	59	157
Total[2]	4,395	3,381	5,250	3,029	1,923	3,710
Antimony oxide:						
Belgium	763	633	2,283	704	584	1,973
Bolivia	1,633	1,355	2,685	4,025	3,341	5,775
China	5,277	4,380	7,249	5,925	4,918	7,454
France	248	206	550	242	201	557
Germany	92	77	954	118	98	1,272
Guatemala	—	—	—	42	35	78
Hong Kong	164	136	272	384	319	585
Kyrgyzstan	—	—	—	124	103	157
Mexico	3,871	3,213	3,551	3,306	2,744	3,149
Netherlands	55	46	187	28	23	87
Russia	—	—	—	163	136	190
South Africa, Republic of	2,176	1,806	740	1,794	1,489	647
Switzerland	—	—	—	57	47	63
United Kingdom	93	77	370	122	101	361
Other	26	21	100	52	43	271
Total[2]	14,397	11,950	18,941	17,085	14,181	22,619

[1]Antimony ore and concentrate content reported by Bureau of the Census. Antimony oxide content estimated by the U.S. Bureau of Mines.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF ANTIMONY METAL, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Bolivia	183	$274	113	$156
Chile	89	124	36	50
China	11,900	18,831	13,066	20,875
Hong Kong	558	831	1,424	2,400
Japan	84	2,532	137	1,825
Mexico	400	121	171	79
Russia	—	—	41	72
Taiwan	14	123	8	87
Thailand	220	353	40	63
Other	53	652	64	469
Total[1]	13,502	23,841	15,100	26,077

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

Source: Bureau of the Census.

TABLE 10
ANTIMONY: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1988	1989	1990	1991	1992[e]
Australia[2]	1,320	1,360	1,420	[e]1,500	1,500
Austria	228	350	352	—	—
Bolivia	9,943	[r]9,189	8,454	[r]7,287	6,500
Canada[3]	3,171	[r]2,821	[r]658	[r]469	[4]327
China[e]	[r]46,000	[r]61,000	[r]57,800	[r]45,000	45,000
Czechoslovakia[e]	[4]2,921	600	1,270	1,000	1,000
Guatemala	[r]1,335	1,343	[e]1,050	[r]609	600
Honduras	19	[r]10	[5]—	—	—
Italy	[r]60	—	—	—	—
Kyrgyzstan[6]	—	—	—	—	3,000
Macedonia[7]	—	—	—	—	50
Mexico[8]	2,185	1,906	2,614	[r]2,753	1,760
Morocco (content of concentrate)	250	142	192	[r]90	90
Namibia (content of sodium antimonate)	73	34	[r]2	[r]10	10
Pakistan	—	8	9	[r]11	12
Peru (recoverable)[e]	420	[4]519	560	[r]400	400
Russia[6]	—	—	—	—	10,000
Serbia and Montenegro[7]	—	—	—	—	500
South Africa, Republic of (content of concentrate)	6,264	5,201	4,815	[r]4,485	4,000
Spain[e]	20	5	—	—	—
Tajikistan[6]	—	—	—	—	500
Thailand	445	495	[r]326	[r]60	65
Turkey[e]	[4]1,877	[r]1,471	400	[r]195	195
U.S.S.R.[e 9]	[r]18,000	[r]18,000	[r]18,000	[r]16,000	—
United States	W	W	W	W	W
Yugoslavia[10]	725	798	409	[e]350	—
Zimbabwe (content of concentrate)	165	210	101	[r]160	150
Total	[r]95,421	[r]105,462	[r]98,432	[r]80,379	75,659

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."
[1]Antimony content of ore unless otherwise indicated. Table includes data available through May 24, 1993.
[2]Antimony content of antimony ore and concentrate, lead concentrates, and lead-zinc concentrates.
[3]Partly estimated on basis of reported value of total production.
[4]Reported figure.
[5]Revised to zero.
[6]Formerly part of the U.S.S.R.
[7]Formerly part of Yugoslavia.
[8]Antimony content of ores for export plus antimony content of antimonial lead and other smelter products produced.
[9]Dissolved in Dec. 1991.
[10]Dissolved in Apr. 1992.

BARITE

By James P. Searls

Mr. Searls, a physical scientist and economist with 16 years of institute, Government, and U.S. Bureau of Mines experience, has been the commodity specialist for barite since 1991. Domestic survey data were prepared by Maria Rosa Arguelles, statistical assistant; and international data were prepared by Virginia Woodson, international data coordinator.

Domestic sales of barite decreased 27% to 326,000 metric tons while apparent consumption decreased 49% to about 637,000 tons. A different measure of domestic consumption, which is referred to as "shipments from crushers and grinders" of both domestically produced and imported barite, indicated a less drastic trend. These operations reported a decline in sales of 21% to 999,000 tons. Exports fell strongly to 12,000 tons, 1989 and 1990 levels, while imports declined very strongly, about 62%, to 323,000 tons.

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 47 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.

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, the principal end use. 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.[1]

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 89% of total U.S. consumption in 1992. 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 3 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 after about 2,100 m of depth. The added weight of the barite in the column of mud in the drill string is used to counteract the dangerous pressures when deep reservoirs of hydrocarbons are encountered. High-pressure hydrocarbons, if uncontrolled, can cause extremely dangerous pressure releases and/or fires at the drilling rig.

The use of barite as a filler or extender and other uses accounted for about 11% of total U.S. consumption in 1992. 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 coat where 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 also is used as a filler or extender in some plastic and rubber products. Processors of polyurethane foam use barite in manufacturing such

products as floormats 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. In glass manufacture, barite reduces seeds and annealing time and increases toughness and brilliancy.

Minor uses include ballast for ships, heavy concrete aggregate for radiation shielding and pipe-weighing in low-lying areas, friction products, and applications in foundries.

Barite also is a raw material for barium chemical manufacturing. The major barium chemicals are 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 also is used in brick and tile manufacturing to control scum caused by gypsum or magnesium sulfate in the clay (the barium combines with the sulfate to form the insoluble barium sulfate) 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. Barium-base glass (using barium carbonate) is considered to be more brilliant than lime glass and more durable than lead glass. Barium carbonate is replacing lead oxide in television tube faceplates to stop X-ray radiation. The same amount of strontium carbonate will be used with the barium as was used with the lead. The X-rays occur when the high voltage electrons from the "gun" that excite the phosphors have been stopped quickly at the faceplate.

Blanc fixe, chemically precipitated barium sulfate, is used as a white filler in paints, rubber, inks, and other material 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 metal also is 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.

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 prevent scumming in ceramics, to make soap for lubricating oils and greases, and to recover sugar from molasses by the barium saccharate process. Barium titanate finds use in miniature electronic and communication equipment.

Uses and Products for Trade and Industry

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. (Chicago Copper & Chemical Co., closed since the 1970's) 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.

Industry Structure

Currently, much of the barite industry, which supplies the drilling mud industry, is supplied by barite from India and China. Many U.S. firms import barite and grind the barite to size in plants along the gulf coast instead of producing it from U.S. mines. Seven mining firms continue to compete in the industry, down from eight in 1991. Only two mining firms continue to compete in the barium chemical industry using domestically mined barite. Several have shut down owing to imported semipure barite.

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 3 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 60 to 180 kg of barite per cubic meter is required in a commercial deposit. In Washington County, MO, the residuum is 3 to 5 meters thick, while in Cartersville, GA, the ore is 45 meters 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 a few centimeters to more than 15 meters, 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. If 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 loaded into dump trucks that haul the ore 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.

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 also is 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 from black ash is also a precursor of a number of barium chemicals. The 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 International Trade Administration/Import Administration (ITA/IA) of the U.S. Department of Commerce made a determination not to

revoke the antidumping duty against precipitated barium carbonate from Germany.[2] The same agency also made a determination that China National Chemicals Import and Export Corp. (SinoChem) had no shipments of barium chloride (2827.38.00) during the period October 1, 1990, through September 30, 1991. The ITA/IA continued the deposit rate previously established of 60.84%.[3]

The Occupational Safety and Health Administration preliminarily concluded "...that exposure to the soluble compounds of barium causes eye, skin, and mucous membrane irritation and respiratory, gastrointestinal and central nervous system effects."[4]

This does not include barium sulfate, which is quite insoluble and becomes soluble only with an unusual alternating series of anaerobic and aerobic conditions whereby certain micro-organisms can reduce sulfate to sulfite, mobilizing the Ba^{++} ion.

Sales

Of the 47 operations that were surveyed, 6 were idle during the year and 3 were closed, although 1 operation is in the process of being moved, for a total of 38 operating mines, beneficiating plants, and crushing and grinding operations.

Run-of-mine barite sales, the lowest cost primary barite sold or used by producers, dropped to less than 10% of last year's sales as a Nevada firm converted to beneficiation of its mine production. *(See table 1.)*

For 1992, beneficiated product was 96% of total sales. Shipments from crushers and grinders of both domestically produced and imported barite declined 21% to nearly 1.0 million tons. The difference between "shipments by crushers and grinders" and "apparent consumption" may be a drawdown of importers' stocks. Sales from Nevada were about 73% of the U.S. total from barite-producing States. One mining and beneficiation operation closed during the year, and the remaining operations produced less barite for a slightly higher average price. The barite sales for the principal end use, as a weighing agent in oil- and gas-well-drilling fluids (muds), declined 24% and accounted for 89% of U.S. shipments by crushers and grinders. *(See tables 2 and 3.)*

For end of year 1992, week-average oil futures prices rose by less than 1% relative to the same week of 1991 while the natural gas price rose by about 17.5% on the same basis.[5] The price increase in natural gas occurred later in the year. By October, the Baker Hughes monthly average active U.S. rig count (of 803 rigs) was above the previous year's monthly average for the first time in 18 months. More than one-half of the rigs were drilling for natural gas. For the last full week of the year the Baker Hughes rig count was 928 rigs. The average depth of wells drilled and completed increased from 1,506 m in 1991 to 1,625 m in 1992. There were 10,301 wells deeper than 1,524 m completed in 1992. Deep gas drilling completions (below 1,524 m) were 860 wells in the first quarter, increasing from 866 wells in the second quarter to 1,004 wells in the third quarter and to 1,229 in the fourth quarter. Total gas wells declined from 9,230 in 1991 to 7,145 in 1992. The total number of wells completed (oil, gas, or dry) deeper than 1,524 m was rather stable through the year at 2,534 for the first quarter, 2,498 for the second quarter, 2,690 for the third quarter, and 2,579 for the fourth quarter.

Standard Slag, Inc. idled its Nevada mine and mill and did not sell any barite in 1992. In September, the Baroid Drilling Fluids Inc. announced plans to reopen the Rossi Mine near Dunphy, NV.

Consumption and Uses

The consumption of crushed and ground barite decreased about 21%, from 1.3 million tons in 1991 to nearly 1.0 million tons in 1992. The apparent consumption, as calculated by "sold or used by producers" minus exports plus imports, fell by 49%. The difference could be explained by sales from "crusher's and grinder's stocks." The oil- and gas-well-drilling industry completed fewer than 21,800 wells and drilled nearly 35.4 Mm of hole;[6] these figures were 25% lower and 19% lower, respectively, than the revised figures for 1991. *(See table 4.)*

Prices

Price quotations in Industrial Minerals for American Petroleum Institute grade remained unchanged at $93.70 per ton throughout the year while the Chemical Marketing Reporter showed a significant price rise ($0.20 per kg to $0.31 per kg) in the southern United States in September for offcolor dry ground barite. These 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. A representative of the drilling mud barite industry felt that the price had stayed constant throughout the year.

The reported average value per ton of domestic barite, based on reported value of direct-ship, beneficiated, and floated material, increased nearly 27%, f.o.b. plant, from $47.57 to $60.22. The average value of crushed or ground barite, sold or used by processors, was $84.49 per ton, a 4% increase from the $81.24 per ton reported in 1991. Within this group, the average value of barite for well-drilling end use was $74.55 per ton, down 1% from $75.45 per ton, while the average value for barium chemicals, filler and extender, and glass, was $163.22 per ton, up 10% from $140.08 per ton. The average customs value of exported barite was $144.84 per ton, up 90% from that of 1991. The average c.i.f. value of imported crude barite was $40.09 per ton, while the c.i.f. value of imported ground barite was $141.99 per ton.

Foreign Trade

Exports of natural barium sulfate or barite fell to just above 1990 levels, from about 43,300 tons to about 12,500 tons. Export data provided by the Bureau of the Census did not indicate the grades of barite traded; however, based only on the per-ton value of individual shipments, which varies from about $40 to nearly $2,000 per ton, drilling-, filler-, glass-,

chemical-, and pharmaceutical-grade were all exported. *(See table 5.)*

Imports for consumption of crude barite declined about 62% from those of 1991 to less than 323,000 tons. The principal source countries, in descending order, were China, which fell 69% to 216,000 tons of crude barite; India, which fell 19% to 100,000 tons of crude barite; and Mexico, which fell 44% to 19,600 tons of ground barite. The higher priced material was chiefly crude filler and extender-quality barite. Most of the crude barite entered through customs districts along the gulf coast for delivery to grinding plants in the area. *(See tables 6 and 7.)*

World Review

Little change in overall barite production around the world occurred because production has occurred more in the areas of petroleum drilling. The former U.S.S.R. and Asia are the areas of present and future petroleum exploration and development. It is less likely that barite will be hauled long distances to these areas given barite's worldwide distribution. Some areas will produce more barite in the near future and some, probably including the United States, will produce less as drilling becomes less profitable in those countries. The forecast for the United States is not perfectly clear as gas exploration may be profitable due to the environmental friendliness of gas consumption according to the new administration.

Brazil.—The Government of Brazil imposed a 92% tax on imports of barium carbonate from China for 5 years.

Italy.—A new firm has reportedly started up in Sardinia.[7] Compagnia Mineraria Sarda (Cominsar), near the village of Desulo, plans to produce about 20,000 tons per year of pigment-grade barite.

Turkey.—Etibank, a state-owned mining, metallurgy, and banking company, invited participation in the barite, fluorite, and rare-earth deposit near Eskisehir in the Sivrihisar province. It would be an open pit mine with 31% $BaSO_4$ ore. *(See table 8.)*

OUTLOOK

With several countries moving away from socialist beliefs and toward greater acceptance of international development of petroleum resources for expertise and financial backing, the petroleum exploration and development effort has moved away from North America and into the former U.S.S.R. and countries in the Pacific Basin. The large volume of barite that will be needed for exploration will more likely be supplied from mines and mills nearby to those regions and not from the United States. Drilling will continue in the United States, albeit at a slower pace, and for gas.

The domestic barite industry may change its production away from drilling mud barite, dominated by China and India, and toward higher valued products, planning to displace imports from several countries.

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[1]Thrush, P. W. (ed.). A Dictionary of Mining, Mineral, and Related Terms (Dep. of Interior). U.S. GPO, Washington, DC, 1968, p. 1049.

[2]Federal Register. International Trade Administration/ Import Administration (Dep. of Commerce). V. 57, No. 152, p. 34761.

[3]———. U.S. International Trade Administration/ Import Administration (Dep. of Commerce). V. 57. No. 128, July 2, 1992, p. 29467.

[4]———. U.S. Occupational Safety and Health Administration (Dep. of Labor). V. 57, No. 114, June 12, 1992, pp. 26244-26245.

[5]The Oil and Gas Journal. V. 90, No. 51, PennWell Publ., Tulsa, OK, Dec. 21, 1992, p. 3.

[6]American Petroleum Institute. Quarterly Completion Report. 4th Quarter, v. VIII, No. 4, Jan. 1993, pp. 7-8.

[7]Loughbrough, R. Italy's Industrial Minerals. Ind. Miner. (London), No. 301, 1992, pp. 43-45.

TABLE 1
SALIENT BARITE AND BARIUM CHEMICAL STATISTICS

(Thousand metric tons and thousand dollars)

	1988	1989	1990	1991	1992
United States:					
Barite, primary:					
Sold or used by producers	404	290	430	448	326
Value	$15,512	$12,625	$16,000	$21,310	$19,633
Exports	(1)	10	9	43	12
Value	$353	$1,622	$1,675	$3,304	$1,806
Imports for consumption (crude)	1,132	987	988	841	323
Value	$43,438	$39,768	$40,103	$35,883	$12,941
Consumption (apparent)[2]	1,536	r1,267	1,409	1,246	637
Crushed and ground (sold or used by processors)[3]	1,612	1,277	1,434	1,267	999
Value	$127,373	$103,759	$99,562	$102,934	$84,404
Barium chemicals (sold or used by processors)	27	e30	W	W	W
Value	$15,284	e$17,000	W	W	W
World: Production	r5,561	r5,720	r5,633	r5,685	e5,436

eEstimated. rRevised. W Withheld data to avoid disclosing company proprietary data.
[1]Less than 1/2 unit.
[2]Sold or used plus imports minus exports.
[3]Includes imports.

TABLE 2
U.S. PRIMARY BARITE SOLD OR USED BY PRODUCERS, BY STATE

State	Number of operations	Run of mine		Beneficiated material[1]		Total	
		Quantity (thousand metric tons)	Value (thousands)	Quantity (thousand metric tons)	Value (thousands)	Quantity (thousand metric tons)	Value (thousands)
1991:							
Nevada	5	288	$5,449	87	$6,485	374	$11,933
Other States	5	3	162	71	9,215	74	9,377
Total[2]	10	290	5,611	157	15,699	448	21,310
1992:							
Nevada	4	W	W	229	8,120	[3]229	[3]8,120
Other States	5	W	W	85	10,850	[3]85	[3]10,852
Total[2]	9	12	664	314	18,970	326	19,633

W Withheld to avoid disclosing company proprietary data; included in totals.
[1]Includes flotation concentrate.
[2]Data may not add to totals shown because of independent rounding.
[3]Data excludes run of mine.

TABLE 3
CRUSHED AND GROUND BARITE[1] SOLD OR USED BY PROCESSORS IN THE UNITED STATES, BY STATE

State	1991			1992		
	Number of plants	Quantity (thousand metric tons)	Value (thousands)	Number of plants	Quantity (thousand metric tons)	Value (thousands)
Louisiana	7	655	$47,450	7	516	$39,618
Nevada	3	216	15,401	3	180	12,427
Texas	6	276	24,755	4	185	13,684
Other[2]	12	118	15,328	12	118	18,675
Total	28	[3]1,267	102,934	26	999	84,404

[1]Includes imports.
[2]Includes California, Georgia, Illinois, Missouri, New Jersey (1991), Oklahoma, and Utah.
[3]Data do not add to total shown because of independent rounding.

TABLE 4
CRUSHED AND GROUND BARITE[1] SOLD OR USED BY PROCESSORS IN THE UNITED STATES, BY USE

(Thousand metric tons and thousand dollars)

Use	1991		1992	
	Quantity	Value	Quantity	Value
Barium chemicals, filler and/or extender, glass	100	14,808	112	18,281
Well drilling	1,168	88,126	887	66,123
Total	[2]1,267	102,934	999	84,404

[1]Includes imports.
[2]Data do not add to total shown because of independent rounding.

TABLE 5

U.S. EXPORTS OF NATURAL BARIUM SULFATE (BARITE), BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Angola	—	—	103	$12
Argentina	—	—	7	5
Australia	—	—	20	5
Barbados	338	$38	—	—
Brazil	19,375	829	—	—
Canada	6,196	969	7,025	912
China	—	—	5	6
Colombia	4,044	300	—	—
Cote d'Ivoire	—	—	6	12
Equatorial Guinea	—	—	1,688	200
Italy	—	—	1	10
Japan	324	51	207	162
Liberia	9	18	—	—
Mexico	3,535	492	305	78
Philippines	6	6	—	—
Venezuela	9,469	602	3,102	402
Total[1]	43,296	3,304	12,469	1,806

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

Source: Bureau of the Census.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF BARITE, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Crude barite:				
Australia	92	$19	—	—
Canada	1,006	99	5,901	$224
China	710,760	31,445	216,826	9,450
Denmark	299	16	—	—
Hong Kong	5,209	489	—	—
India	123,400	3,798	100,031	3,252
Japan	—	—	1	2
Mexico	71	3	20	6
Netherlands	24	12	18	7
United Kingdom	81	2	—	—
Total	840,942	35,883	322,797	12,941
Ground barite:				
Canada	10,986	2,830	10,994	2,819
Germany	178	90	162	76
Japan	172	175	36	37
Mexico	34,833	2,283	19,649	1,437
Netherlands	94	43	27	14
Total	46,263	5,421	30,868	4,383

[1]C.i.f. value.

Source: Bureau of the Census.

TABLE 7
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)
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
1992	—	—	550	277	4,730	5,076

	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)
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	—	—
1992	2,413	2,326	12,891	6,608	11,589	10,035

[1]C.i.f. value.

Source: Bureau of the Census.

TABLE 8

BARITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Afghanistan[e 3]	2,000	2,000	2,000	2,000	2,000
Algeria	43,000	49,000	53,078	r44,361	40,000
Argentina	48,972	57,558	e50,000	e50,000	50,000
Australia[e]	410,970	r11,000	11,000	11,000	11,000
Belgium[e]	35,000	40,000	r35,000	35,000	30,000
Bolivia	—	—	300	1,277	700
Bosnia and Herzegovina[5 6 7]	—	—	—	—	10,000
Brazil (beneficiated)	78,842	51,407	55,576	r46,784	50,000
Burma[8]	12,678	11,278	r9,468	e9,000	10,000
Canada	51,000	39,000	48,000	r50,000	45,000
Chile	43,135	59,873	3,038	r2,901	3,000
China[e]	1,500,000	1,750,000	1,750,000	1,800,000	1,800,000
Colombia	4,550	5,460	5,380	r5,342	5,300
Czechoslovakia[e]	460,794	50,800	87,000	85,000	80,000
Egypt	5,651	7,295	6,197	r5,943	5,900
Finland	10,993	1,614	—	—	—
France	104,400	111,800	92,500	e90,000	80,000
Germany:					
Eastern states	r12,100	r89,400	25,000	—	—
Western states	165,317	144,106	147,776	—	—
Total	r177,417	r233,506	172,776	r163,691	160,000
Greece	1,316	r1,247	r1,617	r1,309	1,000
Guatemala	5,064	3,995	r400	r—	—
India	445,604	548,103	r633,000	r615,000	620,000
Iran[3]	44,309	59,660	77,423	r191,238	200,000
Ireland	83,000	82,000	101,000	r80,000	80,000
Italy	r77,273	r60,331	r44,345	r88,486	85,000
Kenya	48	210	105	e100	100
Korea, Republic of	2,573	3,735	2,923	r1,014	1,000
Malaysia	38,766	36,526	48,291	16,600	11,300
Mexico	534,954	324,739	304,996	r203,975	200,000
Morocco	321,562	370,000	363,580	r433,325	433,000
Pakistan	22,198	29,718	23,329	r28,751	29,000
Peru	r162,625	r e150,000	r e150,000	r150,200	130,000
Philippines	349	348	500	e500	500
Poland	63,100	57,900	25,316	e25,000	25,000
Portugal	1,740	1,729	1,220	e1,400	1,200
Romania[e]	40,000	425,250	20,000	26,000	25,000
South Africa, Republic of	8,735	8,570	2,490	4,790	43,570
Spain	6,585	6,745	r11,285	r9,000	9,000
Thailand	40,587	76,422	107,707	e100,000	100,000
Tunisia	18,868	33,104	30,885	r22,366	22,000
Turkey	405,017	r425,519	r271,296	r278,827	280,000
U.S.S.R.[e 9]	540,000	540,000	500,000	450,000	400,000

See footnotes at end of table.

TABLE 8—Continued

BARITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
United Kingdom	76,253	70,026	67,551	[r]85,505	80,000
United States[10]	404,000	290,000	439,000	448,000	[4]316,000
Yugoslavia[6 7 11]	23,350	30,509	23,601	[e]20,000	—
Zimbabwe	3,400	1,900	[r]320	[r]866	900
Total	[r]5,560,678	[r]5,719,877	[r]5,633,493	[r]5,684,551	5,436,470

[e]Estimated. [r]Revised.

[1]Table includes data available through June 1, 1993.

[2]In addition to the countries listed, Bulgaria also produces barite, but available information is inadequate to make reliable estimates of output levels.

[3]Data are for fiscal year beginning Mar. 21 of that stated.

[4]Reported figure.

[5]Formerly part of Yugoslavia; data were not reported separately until 1992.

[6]All production in Yugoslavia from 1988-91 came from Bosnia and Herzegovina.

[7]Barite concentrates.

[8]Data are for fiscal year beginning Apr. 1 of that stated.

[9]Dissolved in Dec. 1991. This commodity is believed to be mainly produced in Georgia and Kazakhstan; however, information is inadequate to formulate reliable estimates of individual country production.

[10]Sold or used by producers.

[11]Dissolved in Apr. 1992.

BORON

By Phyllis A. Lyday

Mrs. Lyday has covered boron for 14 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, and soaps and detergents.

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 8. A Bureau canvass of the three U.S. producers also collected data on domestic consumption of boron minerals and compounds shown in tables 3 and 4. *(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. Government documentation concerning boron fuels projects begun after the Korean War were declassified and included in a book that describes the pilot plant production at the Malta Rocket Test Station. The chemical and engineering challenges involved in the work are detailed.[1]

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 hardness of diamond.

Boron carbide, produced by reacting carbon and boric acid at 2,300° 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.

Geology

At the Kramer borate deposit of the Boron open pit mine, tincal consists of more than 80% of high-grade beds, with claystone only between the crystals. In low-grade beds, tincal is less than 50% of the beds and is disseminated in a claystone matrix. The lower portions of the beds consist of kernite, a secondary mineral formed by the dehydration and recrystallization of borax resulting from high temperature and pressure. Probertite is found radiating prismatic crystals, or rosettes, commonly within claystone and exclusively where kernite is the dominant sodium borate. The sodium borate facies is enveloped by ulexite, colemanite, and barren claystone facies.

The barren facies contain calcareous nodules but are barren of borates.[2]

Technology

Problems with the discovery, processing, and transporting of boron minerals and compounds from remote and hostile locations became a part of the history of the borax industry. The location of the ore and the methods of production remained a guarded secret for many centuries. It was not until the end of the 17th century when Amsterdam had replaced Venice as the center of borax production that the mineral source and methods of process were commonly known. Producers of boric acid from the steam vents of Tuscany, Italy, prospered because of a lack of competition in the world market. Large reserves of borates were found in Turkey in 1865 and in the Western United States in 1856. With the discovery of new minerals, new processes were developed. The history of boron production and processing has continued for thousands of years because of the benefits derived from using the product. The use and processing have varied little over the past 100 years. Modern changes in processing are a result of improved equipment and processing controls.[3]

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.

Owens-Corning Fiberglas began using purchased cullet in the late 1970's and has raw material specifications for cullet for fiberglass manufacturing. Cullet, broken or refuse glass, is added to fiberglass in the melt. Sulfate is used to remove the carbon dioxide formed from the carbonates. Cullet contains low amounts of carbonates. Therefore, no sulfur dioxide formation occurs with the use of 100% cullet. Fiberglass is a technically sophisticated product that demands consistent and high-quality raw material. For instance, a 2% shift of sodium oxide in a cullet comprising 25% of a fiberglass batch would cause a shift in glass viscosity of 11° C. A shift of this magnitude could cause significant effects in fiberizing and is well beyond the target control of ±3° C for glass viscosity. ASTM has written a specification for cullet used in the container industry. Owens-Corning and other fiberglass manufacturers are working within the ASTM Committee on Waste Disposal to develop a standard for cullet used in making insulation fiberglass.[4] On the basis of data, the effect of each 10% increase in cullet level can decrease gas heat by 114,000 Btu/metric ton of glass.[5]

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.

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. United States Borax & Chemical Corp. (US Borax) submitted a Toxic Substance Control Act Section 8(e) risk report (No. 2002) to the U.S. Environmental Protection Agency. Results of a teratology study of boric acid reported no observed adverse effects.[6]

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 Hygienists. 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.[7]

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.

Owens-Corning detailed the results of four new studies on fiberglass and human health, which were completed during the past year. One of the four studies was an extensive animal inhalation study. The studies, in conjunction with epidemiology, provided strong evidence that working with fiberglass does not pose

a significant human health risk.[8]

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 (1.8 million hectares) of public land would be designated wilderness. In addition to the wilderness designation, the bill would add 1.3 million acres (0.5 million hectares) of Federal lands to the existing Death Valley National Monument and 200,000 acres (83,000 hectares) 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 U.S. Bureau of Mines published OFR 62-92 (NTIS:PB 92-238237/AS) in May of 1992 that presents nine case histories to highlight the diversity of deposits, commodities, and markets represented in the California Desert Conservation Area.

The Department of Commerce published in the November 25, 1992, Federal Register that national security-based validated licensing requirements to export pyrolytic boron nitride (PBN) were removed by the publication of the Commerce Control List effective September 1, 1991, following multilateral review by the Coordinating Committee for Multilateral Export Controls. Foreign policy controls continue to apply to PBN articles, including those PBN articles covered by the foreign availability finding.

The National Institute of Standards and Technology (NIST) was organizing a consortium of producers of plastics and rubber products and instrument makers interested in improving products by developing technology. The consortium will be based on improving uses of fluorescence spectroscopy to monitor processing steps in advanced polymers.[9]

The California Occupational Health and Safety Administration established a permissible exposure limit of 1 milligram per cubic millimeter for sodium borate dust. Sodium or calcium are the most frequent forms of boron-containing minerals. The best known commercial inorganic borates are boric acid and disodium tetraborate decahydrate, commonly referred to as borax. Owing to the powdered nature of many products, inhalation of sodium borate particulate dust is the predominant route of exposure in the work environment. There are an estimated 420,000 workers in the United States who have potential occupational exposure to sodium borates. Seven hundred and ninety-eight volunteers participated in a chronic effects study. Much of the data were collected in 1988, but the study continued over a 2-year period. The final report was issued in January 1991. The study confirmed that borate dust is, at most, a very mild nose and throat irritant. The results suggest no serious respiratory health consequences from borax dust exposures. Based on preliminary results OSHA decided to maintain the borate dust standard at 10 mg/m^3. Mine Safety and Health Administration was using the dust study to revise the borate standards.[10]

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, was sold in December 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 used two lines to supply brines to the plant. The first line fed lake brine to the Argus plant where sodium carbonate was produced. The effluent borax-rich brine then is pumped to the Westend plant where it supplied about two-thirds of the brine feed. The effluent was blended with fresh lake brine from a second feed line that supplied about one-third of the brine feed. The blended brine was then cooled to 18° C to precipitate decahydrate borax. The effluent was cooled to 8° C and the precipitated Glauber's salt was used to produce sodium sulfate.

US Borax, 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.

US 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 US 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 US Borax's storage in Wilmington, CA. Products made at Wilmington included ammonium borates, potassium borates, sodium metaborates, and zinc borate.

Consumption and Uses

U.S. consumption of borates increased. 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.

Owens-Corning will enter the specialty fabrics market through a 50-50 joint venture with Hexcel Corp. Specialty fabrics are composed of single or multiple layers of woven or nonwoven fiberglass and other reinforcements that are either knitted, woven, stitched, or bonded together. The joint venture will be based in Seguin, TX. Specialty fabrics are widely used in marine and aerospace industries and have potential applications in bridge overwraps, reinforcements road systems, and automotive parts.[11]

As a result of nearly four decades of developing, fiberglass reinforced plastics (FRP) have been widely used in flue gas desulfurization (FGD) processes. Usage is expected to grow. Fabrication of essentially the entire FGD system of FRP composites for new large central station units is being considered. This will represent the largest single use of FRP composites in the world. Field fabrication techniques now permit construction of FRP vessels in excess of 100 feet (30 meters) in diameter.[12]

FRP was compared for installation cost for 33 corrosion-resistant piping systems. Many engineers look only at material cost because the figures are relatively simple to estimate. Installation cost can account for more than one-half of the total investment made in a piping system. Pipeline construction costs can be broken into material, line schedule and diameter, complexity of the layout, fabrication and erection, and labor. Three FRP systems were evaluated and were less expensive than 21 of the other materials evaluated.[13]

Consumption of borates in borosilicate glasses remained the third major end use, and demand decreased. Boron added in amounts of between 4% and 15% to glass reduced the viscosity of the melt, assisted with fiber formation during processing, 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.[14]

Special glasses can be divided into five types, as follows: borosilicate glass (10% to 13% boron oxide); opal glasses (0% to 13% boron oxide); potassium glasses (0% boron oxide); glass ceramics (0% boron oxide); and fiberglass for reinforcing (0% to 9% boron oxide). Alumina contained in glass contact refractories can have a positive effect to prevent corrosion, but in specialty glasses can generate bubbles. The use of zircon refractories can present an alternative in the manufacturing process if crystallographic stability is considered.[15]

Glassman America '92, the fifth International Glass Manufacturing Exhibition, attracted 100 suppliers at its New Orleans, LA, meeting June 9-10. Twenty-one organizations provided exhibits. Since first staged in 1986, more than 200 separate firms have participated, representing the primary glassmaking sector's core supplier base. Of particular relevance to glass scientists, 58 papers were presented, including an invited plenary lecture by Rolf Bruckner, Technical University of Berlin, Germany.[16]

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 of Atlanta, GA, recommended one-half pound (0.9 kilogram) of boron for every ton of expected yield of alfalfa in the spring 1992 Agi-Briefs. The brief recommended that micronutrient levels in the soil be monitored by soil testing. The Tennessee Valley Authority published Commercial Fertilizer 1992 that listed total boron compounds consumed as secondary and micronutrients by region in the United States for 1991 and 1992.

A growing and important use of zinc borate, ammonium pentaborate, and boric oxide is as fire retardants in the plastics industry. Zinc borate is of commercial importance because it is water insoluble and does not release water until heated to 290° C. There are advantages in partially replacing alumina trihydrate (ATH) used as a halogen-free fire retardant in ethylene-vinyl acetate polymers with zinc borate. Partial replacement of ATH with zinc borate results in a tenfold increase of char and a changeover from the glowing to smoldering combustion mode.[17]

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 ferroboron were constituents of certain nonferrous alloys and specialty steels, respectively.

Boron nitride solids have been produced by The Carborundum Co. of Amherst, NY, since 1954. The advanced synthetic ceramic material is available in solid, powder, liquid, and aerosol spray for use in thermal, electrical, and mechanical applications.

Boron is also used as a bleaching agent in detergents and cleaning products, such as compact washing powders. Perborates are used more frequently in Europe where wash temperatures are higher. Procter & Gamble Co. introduced the first laundry detergent with perborates after developing and patenting a low-temperature activator.[18] During 1992, a second company incorporated a perborate bleach. E. I. du Pont de Nemours & Co. stated that a second production line was added in 1992 for the production of

sodium perborate monohydrate. The use of compact powders has had a significant impact on the increased use of the perborate.[19]

Sodium borohydride is used in the removal of color and metals from solutions of dyes used for textiles. Reduction methods were developed for the treatment of six paper dyes for which other reductive methods were found to be ineffective. The processes developed involve bisulfite catalyzed borohydride reduction in combination with precipitation and removal of the reduced species by addition of a cationic agent and a flocculent. These processes are done at a pH 6 and ambient temperature. Decolorization indicated metal removal was complete within 15 minutes. The dyes were azo dyes that included metallized azo, copper phthalocyanine, and stilbene dyes.[20] *(See tables 3 and 4.)*

Prices

Prices for anhydrous boric acid and technical borax remained the same. All other reported prices increased. *(See table 5.)*

Foreign Trade

The majority of material from the US 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 6 and 7.)*

PPG Industries Inc. announced that four wholly owned fiberglass manufacturing plants have been registered as meeting the requirements of International Standards Organization (ISO) 9002. ISO registration is a quality standard recognized around the world, but is especially important for companies doing business in Europe. Two of the four plants are in North Carolina.[21]

World Review

Argentina.—Boroquimica SA continued production of tincal from the Salar del Hombre Muerto and boric acid from Tincalayu. In addition, Minera del Boro also produced borates.

Bolivia.—During March 1992, Boron International Inc. entered into an agreement with Teck Corp. to finance an $8 million expansion at Capina for the production of 60,000 tons per year of calcium borate manufactured from ulexite. Current mining in the area of 30,000 tons annually resulted in 8,000 tons of ulexite (40% boron oxide), 4,000 tons of boric acid, and 1,500 tons per year of sodium ocataborate.[22]

Compania Minera Tierra Ltd., a small company formed in 1988 for producing borates in an area of the Department of Potosi, 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 that 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.

Various borate deposits are in the southwestern part of the Altiplano. Llipi Llipi, in the south of Salar de Uyuni, contains an estimated 12 million tons of ulexite. Copla Ltda. was mining ulexite for export. Production of ulexite in 1989 was 9,609 tons.[23]

Chile.—Boratom Quimica Processes Ltda. had operated in Chile since 1986 by providing technology and sales support to producers. In 1986, Boratom shipped 3,000 tons of ulexite to the United States in connection with Borichem Inc. Ulexite mines are in the I and II Regions of Chile, and Ulexite operates a refining plant near Iquique. In March 1992, Boratom's assets and technology were sold to Boron International Inc. (Canada). In November, Boron entered into an agreement with Teck Corp. called Boron Chemicals Processes Chile S.A. A $1.4 million upgrade of the plant was expected to be completed by yearend.[24]

Quimica & Industrial del Borax (Quiborax) was the main producer of boric acid and concentrated ulexite. The second stage of an expansion was completed in 1992. Included in the expansion were about 70,000 square meters of evaporation ponds, a ulexite washing plant, water purification osmosis plant, and boric acid plant. Quiborax operated a mine at Surire, Parindacta, with a crude annual output of 1,000,000 tons per year of ulexite. The ulexite is washed and upgraded from 30% to 40% boron oxide by centrifugal action and flotation prior to filtration. Calcium borate is produced by adding calcium hydroxide to the washed ulexite.[25] Beginning in 1993 the boric acid production was estimated to be 20,000 tons and calcium borate production was expected to be 20,000 tons. The plant facilities are at El Aguila, Arica.[26]

The National Boraxx Corp. (Cleveland, OH) packages and distributes boric acid in the United States for Quimica E Industrial del Borax Ltda. (Quiborax Ltda.)[27]

Compania Minera Salar de Atacama (Minsal) is a joint-venture project between AMAX of the United States, Molibdenos Y Metales (Molymet) of Chile, and Corporacian 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 II 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. Sociedad Quimica y Minera del Chile (SQM) acquired the 63.75% stake held by AMAX. Plans were to limit the production to about 300,000 tons per year of potassium chloride and possibly lithium. SQM planned to finalize contracts by May 1993 and has indicated a target date of mid-1995 for production.[28]

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 to the north side of the Gangdisi-Tanggula mountains.

Former U.S.S.R.—Several distributors were marketing boron compounds produced in the former U.S.S.R. Among the materials listed were boric acid, borax decahydrate, anhydrous borax, sodium perborate, and calcium borate.[29]

Primorsky Industrial Amalgamation, in Dalnegorsk, has been in production since 1953. Amalgamation produced a range of boron minerals and compounds from datolite containing 20% boron oxide. The complex has about 10,000 people. Employment includes 1,000 persons in mining, 2,000 persons in manufacturing, and 7,000 persons in support operations. Amalgamation is part of the Russian Agricultural Joint Stock Co. known as ROSAGROCHIM. ROSAGROCHIM coordinates the activities of about 100 companies.

Mining is by open pit. The ore is about 9% boron oxide content. The ore is calcined to 18% boron oxide content. The calcining is to conserve the use of sulfuric acid. About 75% of the ore is treated with sulfuric acid to create boric acid, calcium sulfate, and silica. The sulfur is imported from Poland and Canada. About 18% of the ore is used to manufacture calcium borate of 43% to 44% boron oxide content. The Dalnegorsk plant supplied about 85% of the boron oxide market in the former U.S.S.R. The nearest railway station is about 200 kilometers from the plant. The products are trucked in loads of 15 to 17 tons. To ship the product to Europe, the product is transferred at the Black Sea.

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.[30]

Peru.—The boron concessions in Arequipa, including Cia. del Boro y Derivados S.A., were merged into Compania Minera Ubinas S.A. as well as the chemical processing company Quimica Oquendo S.A., which produces boric acid at Callao.[31]

Sweden.—Owens-Corning announced that it would close its plant at Falkenberg and increase the capacity of its other European facilities by 25%. The company stated that it planned to spend $110 million in reorganizing its European facilities over the next 3 years. The changes are a result of structural changes in the industry and cyclical changes in the economy. The world economy has changed, and the dollar has declined and continues to trade at a low level. In certain major market segments, products are selling at 1982 prices.[32]

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.

United Kingdom.—Borax Consolidated, a subsidiary of RTZ Corp., planned to build a 60,000-square-foot (5,580-square-meter) technical center at the University of Surrey Research Park, near Guildford. The move will involve a total of 120 people from the research, technical, and development functions and the technical marketing operations.[33] *(See table 8.)*

Current Research

Owens-Corning introduced a new fiberglass insulation concept that can increase the energy efficiency of refrigerators and freezers. Unlike urethane foam insulation, the fiberglass insulation requires no chlorofluorocarbons (CFC's) for blowing. CFC's are to be phased out by 1995. The new fiberglass insulation is contained within a steel foil container and has a heat insulation ability six times that of urethane foam insulations used in today's refrigerators. Owens-Corning is seeking a joint-venture partner that would market and produce the product on a commercial scale.[34]

A consortium was formed to study the feasibility of building an earthquake-resistant highway bridge from advanced composites made of glass, carbon, and polymer fibers. The materials are lighter, stronger, and more durable than steel and concrete. If constructed, the bridge would be the first structure of its kind.[35]

A silicon-base agent was developed from the reaction of a boron acid with sodium silicate. With the addition of borax, the pH range for gel forming becomes alkaline, and the boron changes its geometry from triangular to tetrahedral ions that are precipitated easily by hydroxides and base salts of metals and are absorbed by dispersed aluminum silicates, such as those used in well-drilling muds. This resulted in gel strength and improved water loss characteristics and a decrease in sticking characteristics, thus improving the flow of the drilling mud.[36]

OUTLOOK

Production and consumption of boron minerals and compounds have decreased between 1983 and 1992. 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 has 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 until 1992. 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 increased during 1992.

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 end during 1992. Fiberglass is closely related to construction and transportation.

Coatings and Plating

Primarily used as a protective coating for steel products and as a glazing on ceramic tiles, usage increased during the year.

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.

Soaps and Detergents

This usage declined primarily as chlorine bleaches and coldwater washes replace boron soap powders. Recent concern for environmental effects of chlorine has reversed 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)

	1988	1989	1990	1991	1992
United States:					
Sold or used by producers:					
Quantity:					
Gross weight[1]	1,149	1,114	1,094	1,240	1,009
Boron oxide (B_2O_3) content	578	562	608	626	554
Value	$429,667	$429,806	$436,175	$442,532	$338,700
Exports:					
Boric acid:[2]					
Quantity	56	42	39	47	80
Value	$35,301	$32,613	$31,679	$35,457	$53,652
Sodium borates:					
Quantity	[3]546	[3]646	[3]585	[4]554	[4]489
Value[e]	[e]240,800	[e]361,000	[e]208,433	[e]205,722	[4]159,492
Imports for consumption:[4]					
Borax:					
Quantity	8	7	5	10	16
Value	$2,304	$2,114	$1,570	$3,260	$5,328
Boric acid:					
Quantity	3	3	6	5	6
Value	$2,020	$2,197	$3,921	$3,784	$4,337
Colemanite:					
Quantity	17	15	12	18	30
Value	$7,790	$4,202	$3,310	$4,389	$8,408
Ulexite:					
Quantity	31	27	29	16	42
Value	$7,480	[r]5,940	$7,360	$4,060	$10,306
Consumption: Boron oxide (B_2O_3) content	356	315	319	[r]262	345
World: Production	[r]2,994	[r]2,988	[r]3,018	[r]2,965	[e]2,600

[e]Estimated. [r]Revised.

[1]Minerals and compounds sold or used by producers, including both actual mine production and marketable products.

[2]Includes orthoboric and anhydrous boric acid.

[3]The Journal of Commerce Port Import/Export Reporting Service.

[4]Bureau of the Census.

TABLE 2
BORON MINERALS OF COMMERCIAL IMPORTANCE[1]

Mineral	Chemical composition	B_2O_3 weight percent
Boracite (stassfurite)	$Mg_6B1_4O_26Cl_2$	62.2
Colemanite	$Ca_2B_6O_11 \bullet 5H_2O$	50.8
Hydroboracite	$CaMgB_6O_{11} \bullet 6H_2O$	50.5
Kernite (rasortie)	$Na_2B_4O_7 \bullet 4H_2O$	51.0
Priceite (pandermite)	$Ca_5B_{12}O_{23} \bullet 9H_2O$	49.8
Probertite (kramerite)	$NaCaB_5O_9$	49.6
Sassolite (natural boric acid)	H_3BO_3	r56.3
Szaibelyite (ascharite)	$MgBO_2(OH)$	41.4
Tincal (natural borax)	$Na_2B_4O_7 \bullet 1OH_2O$	36.5
Tincalconite (mohavite)	$Na_2B_4O \bullet 5H_2O$	47.8
Ulexite (boronatrocalcite)	$NaCaB_5O_9 \bullet 8H_2O$	43.0

rRevised.
[1]Parentheses include common names.

TABLE 3
U.S. CONSUMPTION OF BORON MINERALS AND COMPOUNDS, BY END USE

(Metric tons of boron oxide content)[1]

End use	1991	1992
Agriculture	5,712	9,186
Borosilicate glasses	29,504	29,288
Enamels, frits, glazes	5,878	8,230
Fire retardants:		
Cellulosic insulation	11,662	9,451
Other	1,769	1,394
Insulation-grade glass fibers	82,395	124,950
Metallurgy	3,518	2,624
Miscellaneous uses	16,693	23,130
Nuclear applications	546	455
Soaps and detergents	22,848	38,460
Sold to distributors, end use unknown	36,264	37,575
Textile-grade glass fibers	45,067	60,173
Total	r261,856	344,916

rRevised.
[1]Includes imports of borax, boric acid, colemanite, and ulexite.

TABLE 4
U.S. CONSUMPTION OF ORTHOBORIC ACID, BY END USE

(Metric tons of boron oxide content)[1]

End use	1991	1992
Agriculture	61	497
Borosilicate glasses	4,776	2,704
Enamels, frits, glazes	641	2,477
Fire retardants:		
Cellulosic insulation	1,516	1,506
Other	1,769	1,349
Insulation-grade glass fibers	1,935	2,758
Metallurgy	594	154
Miscellaneous uses	8,805	12,760
Nuclear applications	544	454
Soaps and detergents	127	79
Sold to distributors, end use unknown	13,753	13,133
Textile-grade glass fibers	19,473	18,625
Total	53,994	56,496

[1]Includes imports.

TABLE 5
YEAREND 1992 PRICES FOR BORON MINERALS AND COMPOUNDS PER METRIC TON[1]

Product	Price, December 31, 1992 (rounded dollars)
Borax, technical, anhydrous, 99%, bulk, carload, works[2]	690-698
Borax, technical, anhydrous, 99%, bags, carload, works[2]	760
Borax, technical, granular, decahydrate, 99%, bags, carload, works[2]	285-405
Borax, technical, granular, decahydrate, 99.5%, bulk, carload, works[2]	240
Borax, technical, granular, pentahydrate, 99.5%, bags, carload, works[2]	321-381
Borax, technical, granular, pentahydrate, 99.5%, bulk, carload, works[2]	276
Boric acid, technical, granular, 99.9%, bags, carload, works[2]	732-740
Boric acid, technical, granular, 99.9%, bulk, carload, works[2]	687
Boric acid, United States Borax & Chemical Corp., high-purity anhydrous, 99% B_2O_3, 100-pound bags, carlot	2,585
Colemanite, Turkish, 42% B_2O_3, ground to a minus 70-mesh, f.o.b. railcars, Kings Creek, SC[3]	240-285
Ulexite, Turkish, 8% B_2O_3, ground to a minus 6-mesh, f.o.b. railcars, Norfolk, VA[3]	245

[1]U.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.
[2]Chemical Marketing Reporter. V. 242, No. 26, Dec. 1992, p. 23.
[3]American Borates Co.

TABLE 6

U.S. EXPORTS OF BORIC ACID AND REFINED SODIUM BORATE COMPOUNDS, BY COUNTRY

Country	1991			1992		
	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	1,205	918	9,626	1,110	704	7,818
Belgium	1,628	965	40	1,267	427	104
Brazil	166	145	2,039	251	178	896
Canada	4,834	3,043	36,446	5,295	3,277	29,199
China	27	11	1,679	34	32	864
Colombia	140	119	1,164	170	148	565
Costa Rica	32	27	2,197	32	16	688
Dominican Republic	10	14	45	26	12	2
Ecuador	—	—	1,096	—	—	1,172
Egypt	—	—	554	—	—	54
El Salvador	—	—	5	—	—	—
Finland	—	—	18	—	—	—
France	—	—	191	2,293	906	15
Germany	16	44	124	63	63	100
Guatemala	3	3	37	—	—	2,358
Haiti	—	—	368	—	—	—
Honduras	40	46	70	—	—	10
Hong Kong	463	459	3,795	828	511	3,195
Indonesia	1,423	950	5,529	2,606	1,374	6,541
Israel	57	53	224	61	56	401
Jamaica	1	3	2	—	—	8
Japan	18,214	15,423	43,742	26,243	20,120	28,689
Korea, Republic of	5,224	3,169	18,965	8,571	4,778	13,971
Malaysia	404	238	7,357	2,837	1,396	7,319
Mexico	3,481	2,055	28,767	4,378	3,180	28,676
Netherlands	1,098	2,117	318,823	4,269	4,457	292,149
New Zealand	323	219	2,057	441	268	2,570
Pakistan	129	63	135	368	212	—
Panama	1	3	26	1	4	34
Papua New Guinea	16	10	—	—	—	16
Peru	—	—	172	—	—	—
Philippines	632	341	1,830	2,722	1,036	48
Saudi Arabia	—	—	—	9	14	1,216
Singapore	1,109	634	1,632	2,030	1,428	955
South Africa, Republic of	517	94	2,318	58	49	379
Spain	6	13	38,530	—	—	41,743
Taiwan	4,058	2,885	14,879	11,453	7,535	10,653
Thailand	784	641	4,453	1,444	974	4,005
United Kingdom	135	91	1,506	65	76	673
Uruguay	—	—	15	—	—	—
Venezuela	913	616	1,673	656	421	1,177
Zimbabwe	—	—	226	—	—	44
Other	18	45	1,475	—	—	816
Total	47,107	35,457	553,830	79,581	53,652	489,123

[1]Bureau of the Census: Harmonized Code 2440.11.0000

[2]Bureau of the Census: Harmonized Codes 2840.19.0000, 2840.30.0000, and 2840.20.0000.

TABLE 7
U.S. IMPORTS FOR CONSUMPTION OF BORIC ACID, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Belgium	—	—	1	$3
Canada	26	$16	40	25
Chile	1,298	641	2,310	1,086
France	1	1	1	1
Germany	9	6	7	7
Italy	3,066	2,641	3,587	2,762
Japan	35	150	84	193
Netherlands	21	12	12	19
Turkey	400	210	300	158
United Kingdom	95	107	72	83
Total	4,951	3,784	6,414	4,337

[1]U.S Customs declared values.

Source: Bureau of the Census.

TABLE 8
BORON MINERALS: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992[e]
Argentina	270	261	[e]260	[e]250	250
Bolivia (ulexite)	1	10	3	14	11
Chile	32	131	132	[r]97	100
China[e 2]	[r]95	[r]74	[r]75	[r]76	77
Iran (borax)[3]	[r]2	(4)	2	[r]1	1
Peru	[e]15	[r]25	[r]20	[r]26	30
Turkey[5]	1,231	[r]1,174	1,253	[r e]1,100	1,000
U.S.S.R.[e 6]	200	200	180	160	130
United States[7]	1,149	1,114	1,094	1,240	[8]1,009
Total[9]	[r]2,994	[r]2,988	[r]3,018	[r]2,965	2,608

[e]Estimated. [r]Revised.

[1]Table includes data available through May 18, 1993.

[2]B_2O_3 equivalent.

[3]Data are for years beginning Mar. 21 of that stated.

[4]Less than 1/2 unit.

[5]Concentrates from ore.

[6]Dissolved in Dec. 1991. This commodity is believed to be produced in Kazakhastan and possibly other former Soviet Republics; however, information is inadequate to formulate reliable estimates of individual country production.

[7]Minerals and compounds sold or used by producers, including both actual mine production and marketable products.

[8]Reported figure.

[9]Data may not add to totals shown because of independent rounding.

BROMINE

By Phyllis A. Lyday

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Production of bromine worldwide in 1992 was as follows: United States, 45%; Israel, 36%; the United Kingdom, 7%; and other countries, 12%. 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 171 million kilograms (Mkg). Estimated uses of bromine compounds were in flame retardants (27%), agriculture (15%), petroleum additives (15%), well-drilling fluids (10%), and other (33%).

DOMESTIC DATA COVERAGE

Domestic production data for bromine was 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, six responded, representing 100% of total elemental bromine sold or used. *(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° 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 2,591 meters (8,500 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 reports three east-west bromine-rich brine fields. Wells are drilled 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 kilograms 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 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 is 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.—Bromine containing waste from other processing is recycled into elemental bromine. The waste is reprocessed through the absorption towers to produce a high-quality elemental bromine. It was estimated that about 90 Mkg of elemental bromine was produced by recycling during 1992.

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 also are 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.

Economic Factors

Costs.—The cost of drilling and maintaining a bromine-producing well is estimated to be in excess of $1 million per well, with about 100 wells in operation. 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 1992, 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 (OSHA) regulates the working conditions of bromine plants.

When handling bromine, a person should use safety goggles, a 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.

OSHA established a phase-in schedule that gives operators until 1996 to complete process-hazard analyses (OSHA 29 CFR 1910.119) for any operator who uses, stores, manufacturers, handles, or moves highly hazardous chemicals that include bromine, bromine chloride, bromine pentafluoride, bromine trifluoride, and propargyl bromide. The fines that apply to the new standard are the same as those specified by other OSHA safety regulations. A willful violation can result in a fine up to $70,000. A serious violation can result in a fine up to $7,000 per violation. A criminal violation can result in fines up to $250,000 to any responsible individuals and up to $500,000 against the corporation. Jail terms may be imposed for criminal violations.

Employment.—During 1992 an estimated 1,600 employees were employed by the bromine industry in Arkansas. About 1,175 are employees of the companies and about 450 are contact workers.

A notice of proposed rulemaking was published by the Environmental Protection Agency (EPA) in the Federal Register of 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.

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 EPA-designated hazardous substances. The amendment required shippers and carriers to identify CERCLA hazardous substances, to comply with the hazardous materials regulations (HMR) (49 CFR, parts 173.193 and 228), and to make the required notifications if a discharge of a hazardous substance occurs.

The DOT RSPA listed a final rule for performance-oriented packaging standards that included several bromine compounds under HMR. The rule comprehensively revises the HMR with respect to hazard communication, classification, and packaging requirements. 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.

ANNUAL REVIEW

Legislation and Government Programs

EPA listed methyl bromide's ozone depletion potential (ODP) between 0.44 to 0.69. The Clean Air Act (CAA) of 1990 requires a production phaseout by the year 2000 of any substance with an ODP of 0.2 or greater. Although there are not foreseeable alternatives to methyl bromide use for quarantine treatments requiring 100% effectiveness, recovery can approach 90% of current emissions from fumigation chambers.[1]

Methyl bromide is produced naturally from marine algae and giant kelp. About 300,000 tons is produced annually from natural sources. Methyl bromide also is produced by volcanoes.[2]

Researchers say the ozone depletion problem appears to be heading toward solution before they can find any solid evidence that serious harm was or is being done. Ozone is destroyed by the absorbing ultraviolet (UV) energy, and, paradoxically, ozone is created by UV radiation. Ozone is a renewable resource. Because of its constant movement, the amount of ozone above any given spot on the planet, and hence the amount of ultraviolet light filtered out, can vary widely from hour to hour. Ozone concentrations also change more predictably on separate natural cycles. Over the tropics, where the sun's angle is high all year long, there has been no observed ozone depletion. The rising trend in skin cancer is not the result of ozone depletion or increased UV, but of lifestyle changes such as wearing skimpier clothing in summer, spending more time outdoors, and spending more time in southerly latitudes.

In January 1993, the EPA ordered a phaseout by the year 2000 of the pesticide methyl bromide. The directive complies with the provisions of the 1990 amendments to the CAA that require the EPA to update its list of ozone depleting chemicals and take steps to eliminate their use. Methyl bromide is used as a fumigant in soils to kill pests that are attracted to vegetables and fruits, to protect commodities such as grains while in storage, to fumigate fresh fruits and vegetables that are imported, and to kill insects in buildings.[3]

The EPA distributed to the chemical industry a preliminary list of chemicals and emission sources that will be covered by the CAA. The act dictates that standards must be developed for 40 source categories that emit 1 or more of the 189 hazardous air pollutants listed. EPA intended to regulate air emissions from five source categories that include process vents, wastewater treatment operations, storage facilities, transfer operations, and equipment leaks. The five source categories will be covered by technology-based National Emissions Standards for Hazardous Air Pollutants (NESHAP) standards. The Agency estimates that about 388 of the total 663 synthetic organic chemicals production subcategories meet 1 of these 2 tests.[4]

The Maximum Achievable Control Technology (MACT) changed the CAA from a health-based evaluation to a technology basis. Brominated compounds, including bromoform, methyl bromide, and vinyl bromide, will be promulgated by November 15, 1994. Existing sources have 3 years to comply.[5]

EPA announced that test data on the content of four brominated substances were received.[6] EPA granted a section 18 exemption to four States for the use of

bromoxynil to control weeds in rice.[7]

Production

Ethyl Corp. and Great Lakes Chemical Corp. 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 1992 and 100% of bromine sold or used.

Emerson Kampen, chairman, president, and chief executive officer of Great Lakes, received the chemical industry's annual Kavaler Award for Chief Executive Excellence. He was chosen by the votes of a selection committee composed of 63 leading chemical industry analysts from 49 investment firms in Canada, England, and the United States. The industry's highest recognition for executive achievement, the award is presented by the Schnell Publishing Co., publisher of the Chemical Marketing Reporter and Chemical Business.

Tetra Technologies Inc. reached a definitive agreement with Dow Chemical Co. to complete the purchase of a bromine-derivatives plant in southwestern Arkansas. The agreement dated to 1987 when Dow sold it bromine business to Ethyl. To satisfy Federal antitrust concerns Dow was required to divest its clear brine fluids to a third party, Tetra. Dow retained repurchase rights.

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 Mkg 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 2.)*

Consumption and Uses

Regulation requires that methyl bromide be used for fumigation of imported produce. About three-quarters of the 29,000 tons consumed domestically is for soil application. In colder climates, the onset of winter controls pests and diseases. But in California and Florida, where it is relatively warm year-round, farmers fumigate the soil to kill insects, weeds, fungi, nematodes, and other organisms that attach to roots of seedlings.[8]

Fire retardants were primarily tetrabromobisphenol-A (TBBA) and decabromodiphenyl oxide. Great Lakes expand TBBA production capacity at its El Dorado, AR, facility to meet growing demand as a flame retardant for acrylonitrile-butadiene-styrene polymers. The expansion increased Great Lakes' capacity by 25%. Ethyl began a $20 million expansion of its brominated flame retardants plant in Magnolia, AR, that was expected to be completed by yearend. The products are for use in polymers used in electronics and business equipment applications and contain about 67% bromine.

The U.S. International Trade Commission (USITC) publication entitled "Synthetic Organic Chemicals, 1990" (SOC) listed Ethyl and Great Lakes as the only producers 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.

There is demand for ethylene dibromide (EDB) for use as a scavenger for lead antiknock in gasoline additives. SOC listed Great Lakes and Ethyl as the only producers of EDB used in gasoline additives.

SOC 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 workover and completion fluids and other uses.

Halogenated synthetic rubber consumption has grown between 1980 and 1992. Exxon Chemical Co. is the only domestic manufacturer of bromobutly rubber. This rubber is more heat resistant than other types of rubber 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 polychoroprene.

Great Lakes announced plans to halve its 1986 production capacity for halons by the end of this year. Du Pont shut down its only halon facility last year and now has a toll manufacturing agreement with Great Lakes. Great Lakes implemented a program in 1991 through its subsidiary E/M Corp. to collect and reprocess halons from the fire industry at a plant in the Los Angeles Basin. EPA approved two halon substitutes that the firm manufactures. FM 100 can replace halon 1211 in portable handheld fire extinguishers and it has an ozone depletion potential value (ODP) of 0.5. Substitution of FM 100 for halon 1311 would require evacuation of the room. FM 200 has zero ODP and offers a direct replacement for halon 1301. Both substitutes are manufactured at the El Dorado site.[9]

Sodium bromide in bulk and drums is used in treating cooling water and wastewater. These products are specially made to ensure purity and are registered with the EPA under the Federal Insecticide, Fungicide, and Rodenticide Act. Bromine has a higher activity than chlorine and minimizes the amount of halogens released into the environment.

Prices

Prior to 1982, the price of bulk elemental bromine reported by U.S. producers, f.o.b. plant, was an average value of the quantity of bromine reported as sold. Statistical data published beginning in 1982 reported the total bromine sold and used for quantity and

value. The total has been revised for the years 1982 through 1991 to be equivalent to a weighted average of the value of bromine used by the producing company plus the value of bromine sold to other companies, as reported prior to 1982.

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 3 to serve only as a guide to yearend price levels. *(See table 3.)*

Foreign Trade

Under section 4672(a) of the Internal Revenue Code, a substance should be listed as taxable if more than 50% by weight or more than 50% of value of its constituents are taxable. EDB, a colorless liquid, is derived from the taxable chemicals ethylene and bromine. The predominant method of producing EDB is via ethylene reaction with bromine. Imports are taxed at a rate of $4.51 per ton. This is based upon a conversion factor for ethylene of 0.149 and a conversion factor for bromine of 0.851.

Israel received duty-free treatment on its bromine products in all major world markets except the United States, where duties are paid on two significant bromine products, sodium bromide and potassium bromide. The duty on all bromine products from Israel will drop to zero in 1995. *(See tables 4 and 5.)*

World Review

Methyl bromide emissions was the topic at a workshop convened at the United Nations Environmental Program's (UNEP) request. The workshop brought together participants to discuss use, alternatives, and substitutes. Methyl bromide total production and sales rose from 42,000 tons in 1984 to an estimated 63,000 tons in 1990. About one-half of the methyl bromide used is emitted into the atmosphere, or about 30,000 tons per year. Its use is considered vital for the economic viability of some agricultural products and for quarantine treatment of certain products in international trade. At the international level, opposition to a phaseout has been strong from developing countries and from Israel, which like the United States, is a major producer of methyl bromide. In the United States, Great Lakes is the biggest producer. Other producers are located in Japan and Europe where producers are Atochem, Enichem A nic, and Eurobrom B.V. Many developing countries rely heavily on fumigation of exported products to control pests.

The European Community (EC) proposed restricting the use of brominated flame retardants in EC Directive 76/769. The draft proposal restricts the use of all noncommercial brominated diphenylethers (BDPE) to less than 0.1% immediately on adoption and bans commercial BDPE, namely deca, octa, and penta BDPE.[10]

Canada.—Brine had been seeping into Potash Corp. of Saskatchewan Inc.'s Cory potash mine near Saskatoon since 1971. The brine composition is reported to contain 4,890 ppm bromine. Subsurface formation waters in Alberta range in composition from almost fresh to brines with a total dissolved solids content many times that of seawater. Brines constitute a potential commercial source of bromine.[11]

China.—Nine bromine plants are reported to have an annual production capacity of 7,000 tons per year, or more than 80% of the total bromine output. The source of the bromine is underground bitterns that are used for salt production. The location of the plants are in East China in Shandong Province near Laizhou Bay.

France.—Ethyl acquired Potasse et Produits Chimiques (PPC) from the French companies Rhone Poulenc S.A. and Entreprise Miniere et Chimique at yearend 1992. PPC is Europe's largest producer of organic and inorganic brominated compounds, used primarily as photographic, agrichemical, and pharmaceutical intermediates.

Great Lakes through Octel Associates purchased the remaining 50% interest in Octel Kuhlmann by acquiring a 25% interest each from Rhone Poulenc and Elf Atochem. Octel Kuhlmann has a plant in Paimboeuf that produces lead-base antiknock compounds for motor fuels.

Germany.—Great Lakes purchased Bayrol Chemische Fabrik GmbH, a producer of swimming pool and spa water disinfection chemicals and equipment. Bayrol was headquartered in Munich and included sales and distribution centers in France, Italy, and Spain through wholly owned subsidiaries. Bromine-base water-treatment chemicals are a fast growing market in the Mediterranean as well as expected to emerge in Central and Eastern Europe. The recreational water markets are limiting the use of chlorine because of environmental concerns.

Hungary.—Great Lakes acquired a 75% interest in Chemol RT, the former state-owned chemical trading company. Headquartered in Budapest, Chemol imports and exports chemicals through an extensive sales force coupled with a network of subsidiaries, joint ventures, and 40 warehouses. It had 200 employees. The acquisition was expected to provide effective distribution for bromine clear fluids to complement the recent expansion of manufacturing operations in Germany and the United Kingdom.

Israel.—Israeli Chemical Ltd. (ICL) planned to issue about 31% of its share onto the U.S. market by yearend as part of the privatization program that includes Dead Sea Bromine (DSB), a subsidiary of ICL. The Government began efforts in 1985 to sell a share of ICL to offset an investment program. 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 sale rather than to a foreign investor. Great Lakes was part of

the only foreign consortium that bid on ICL in 1990.

In 1991, privatization terms for ICL were approved. 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. During 1992, 21% of ICL was sold and 30% was to be offered by yearend.

During 1992, Dead Sea Works received a court order to ensure that it seeks approval from the necessary authorities before it builds any more plants in Israel. This follows revelations that during the past 30 years the company has planned and built plants without receiving official approval. The problems gained exposure because of the privatization program underway.

In September, Dead Sea Bromine Group announced a $12 million chlorine expansion at Sdom, Israel. Chlorine is the main raw material used in the production of bromine. The expansion will result in an increase in bromine production of 180,000 tons per year.

Waste brines from the bromine operation are used to produce magnesium. Plans are to build a $300 million magnesium plant using the Russian electrolysis process.

Japan.—Israel has enjoyed a margin of tariff preference for imports of bromine compounds into Japan because the Israeli Government-owned company DSB is based in a "developing country." DSB is the world's largest single producer and accounts for 60% of all international trade in bromine and bromine chemicals in a $1.3 billion market.

In 1989, Japan unilaterally eliminated its 3% tariff on elemental bromine to allow U.S. producers equal access with DSB. The U.S. industry faces tariffs on other brominated products that range from 3.8% to 4.6%.

United Kingdom.—On March 16, Great Lakes announced the purchase of Shell U.K. Ltd.'s stake in Octel Associates and the Associated Octel Co., Ltd. for $138 million. Octel Associates is the world's largest producer of certain motor fuel antiknock compounds, supplying more than 75% of the refineries outside of North America. Octel operates manufacturing facilities in France, Italy, and the United Kingdom. The purchase increases Great Lakes' share from 52% to 87.8% of Octel with Chevron, British Petroleum, Texaco, and Mobil retaining the balance of the ownership interest.

ICL Americas Inc., a producer of halon 1211, a fire extinguisher, announced plans to end production by 1993. The main fire-fighting alternatives to halon—water and carbon dioxide—are unsuitable for protection of computers, electronics, and passenger aircraft. *(See table 6.)*

Current Research

The EPA-proposed fluorescent indicator adsorption (FIA) test for monitoring the potential for ozone forming emissions in reformulated gasoline is subject to significant bias and impressions. A more accurate test is the use of a bromine number. The bromine number is the number of grams of bromine that will react with 100 grams of the olefin sample. The number obtained varies with temperature, catalysts, and method. The first test was published in 1951. With modern instrumentation, the bromine number titration is automated and can be more precise and easier to use than the FIA procedure.[12]

The Federal Register reported the results of a Health and Human Services's National Toxicology Program on June 3, 1992. There was no evidence of carcinogenic activity. Under conditions of these 2-year inhalation studies, methyl bromide caused degenerative changes in mice.[13]

Agricultural biotechnology firms are developing herbicide-resistant crops. One of the herbicides that would be affected is Bromoxynil, a brominated compound that inhibits photosynthetic electron transport. Although farmers will pay more for herbicide-tolerant plant seeds, they will pay less for the herbicides used to control the weeds. The savings result when the herbicide is used as a postemergent agent rather than a preemergent agent.[14]

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 EDB 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 Mkg. The rapid decline to 141 Mkg in 1986 was a direct result of the limits on lead in leaded gasoline. During 1991, the EC 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 affect on increases in petroleum demand. The Clean Air Act Amendments have 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

the chlorine substances that it substitutes. Sodium bromide was the fasting growing biocide intermediate with sales expected to grow 4% per year through 1995. 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 flame retardant chemicals to be used in these materials and furnishings. Chemically, the compounds are bromine and chlorine compounds, antimony and phosphorus compounds, and aluminum compounds. Alumina trihydrate is an important fire retardant that represents 32% of the market. Fire retardants are expected to grow between 2% and 4% with between 5% and 6% in the brominated fire retardant varieties as organic materials replacing metals in transportation, infrastructure, and packaging. Brominated flame retardants are about 32% of the total flame retardant market. Several State governments continue to support strong consumer laws that protect State residents from products with potential fire hazards produced in other States.

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 20% increase in activity during 1992 when compared with that of 1991. Oilfield chemicals used in drilling, completion and workover, and production operations have remained significantly more profitable internationally than in U.S. operations.

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TABLE 1

SALIENT BROMINE AND BROMINE COMPOUND STATISTICS

(Thousand kilograms unless otherwise specified)

		1988	1989	1990	1991	1992
United States:						
Bromine sold or used:[1]						
Quantity		163,000	175,000	177,000	170,000	171,000
Value	thousands	r$114,000	r$139,000	r$131,000	r$124,000	$125,000
Exports:						
Elemental bromine:						
Quantity		[2]4,328	3,557	2,932	2,563	5,320
Value	thousands	[2]$3,379	$3,165	$4,008	$7,665	$5,542
Bromine compounds:[3]						
Gross weight		13,925	35,914	17,094	17,123	19,996
Contained bromine		11,839	28,998	14,443	14,555	16,946
Value	thousands	$13,000	$24,093	$18,166	$21,280	$26,445
Imports:[2]						
Elemental bromine:						
Quantity		257	460	756	r142	851
Value	thousands	$194	$293	$508	r$91	$522
Compounds:						
Ammonium bromide:						
Gross weight		1,660	2,402	1,526	2,055	1,794
Contained bromine		1,354	1,960	1,245	1,676	1,463
Value	thousands	$2,180	$3,471	$2,399	$3,129	$2,871
Calcium bromide:						
Gross weight		4,286	7,770	11,634	r14,610	5,365
Contained bromine		3,427	6,212	9,301	r11,688	4,289
Value	thousands	$1,360	$3,231	$5,236	r$7,130	$3,212
Potassium bromate:						
Gross weight		r384	r330	r199	r386	407
Contained bromine		r184	r139	r42	r185	195
Value	thousands	r$1,095	r$918	r$615	r$1,244	$1,250
Potassium bromide:						
Gross weight		848	590	593	888	883
Contained bromine		569	395	461	595	592
Value	thousands	$1,278	$985	$1,028	$1,591	$1,663
Sodium bromate:						
Gross weight		NA	NA	NA	229	176
Contained bromine		NA	NA	NA	121	93
Value		NA	NA	NA	$391	$469
Sodium bromide:						
Gross weight		r1,870	1,369	1,630	3,036	1,097
Contained bromine		r1,459	1,063	1,266	2,358	852
Value	thousands	r$2,177	$1,922	$2,130	$3,882	$1,617
Other:						
Gross weight		32,892	28,005	11,591	11,646	11,741
Contained bromine		14,919	19,787	7,083	7,104	7,162
Value	thousands	$35,531	$42,589	$50,414	24,585	21,477
World: Production		r370,420	r401,204	r380,400	r380,023	e378,800

eEstimated. rRevised. NA Not available.

[1]Elemental bromine sold as such to nonproducers, including exports, or used in the preparation of bromine compounds by primary U.S. producers.

[2]Bureau of the Census.

[3]Bureau of the Census. Includes methyl bromine and ethylene dibromide.

TABLE 2
BROMINE-PRODUCING PLANTS IN THE UNITED STATES IN 1992

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.	45
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]256

[1]Actual production capacity is limited by brine availability.
[2]Bromine produced at this plant is reprocessed in Arkansas.
[3]Data do not add to total shown because of independent rounding.

TABLE 3
YEAREND 1992 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

[1]Delivered 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.
[2]Bureau of the Census. Average c.i.f. import value.

Source: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials. V. 243, No. 1, Jan. 4, 1993, pp. 30-37.

TABLE 4
U.S. IMPORTS OF OTHER BROMINE COMPOUNDS

Compound	Harmonized schedule code	1991		1992		Principal sources, 1992
		Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)	
Methyl bromide	2903301520	3,546	$3,724	3,532	$3,641	Israel 100%.
Chlorobromodifluormethane	2903400020	5,627	16,103	3,115	13,004	United Kingdom 100%.
Hydrobromic acid	2811195050	391	319	299	NA	Israel 100%.
Dibromoethyldibromocycloxehane	2903590500	42	209	45	244	France 100%.
Dibromomeopentyl glycol	2905505000	183	449	56	255	Israel 100%.
Tetrabromobisphenol A	2908102500	129	171	85	104	Do.
Decabromodiphenyl oxide and octabromodiphenyl oxide	2909300700	1,728	3,610	2,022	4,229	France 76%, Germany 1%, Italy 23%.
Bromoxynil	NA	NA	NA	2,096	NA	France 100%.
Brominanine	NA	NA	NA	491	NA	Republic of Korea 36%, Germany 35%, Hong Kong 14%, other 15%.

NA Not available.

Source: Bureau of the Census.

TABLE 5
WORLD BROMINE ANNUAL PLANT CAPACITIES AND SOURCES,[1] DECEMBER 31, 1992

Country and company	Location	Capacity (thousand kilograms)	Source
China:			
Laizhou Bromine Works	Shandong	11,500	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:			
Kali und Salz AG: Salzdetfurth Mine	Bleichrode	NA	Do.
Do.	Sondershausen	3,500	Do.
India:			
Hindustan Salts Ltd.	Jaipur		
Mettur Chemicals	Mettur Dam	1,500	Seawater bitterns from salt production.
Tata Chemicals	Mithapur		
Israel:			
Dead Sea Bromine Co. Ltd.	Sdom	150,000	Bitterns of potash production from surface brines.
Italy:			
Societa Azionaria Industrial Bromo Italiana	Margherita di Savoia	900	Seawater bitterns from salt production.
Japan:			
Toyo Soda Manufacturing Co. Ltd.	Tokuyama	20,000	Do.
Spain:			
Derivados del Etilo S.A.	Villaricos	900	Seawater.
U.S.S.R.:[2]			
Government	NA	24,000	Well brines.
United Kingdom:			
Associated Octel Co. Ltd.	Amlwch	30,000	Do.

NA Not available.
[1]Excludes U.S. production capacity. See table 2.
[2]Dissolved in Dec. 1991.

TABLE 6

BROMINE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand kilograms)

Country[2]	1988	1989	1990	1991	1992e
Azerbaijan[3]	—	—	—	—	5,000
France e	18,000	18,000	4 3,100	3,200	2,500
Germany: Western states e	r 2,000	r 2,000	r 1,500	r 1,500	1,500
India	1,242	1,272	e 1,300	e 1,300	1,300
Israel e	118,000	r 4 134,725	130,000	r 135,000	135,000
Italy e	450	400	400	400	300
Japan e	15,000	15,000	15,000	15,000	15,000
Spain e	300	300	300	300	200
Turkmenistan[3]	—	—	—	—	12,000
U.S.S.R. e [5]	r 25,000	r 25,000	r 25,000	r 24,000	—
Ukraine[3]	—	—	—	—	7,000
United Kingdom	27,128	29,907	26,800	r 29,323	28,000
United States[6]	163,300	174,600	177,000	170,000	4 171,000
Total	r 370,420	r 401,204	r 380,400	r 380,023	378,800

eEstimated. rRevised.

[1]Table includes data available through Apr. 26, 1993.

[2]In 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.

[3]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[4]Reported figure.

[5]Dissolved in Dec. 1991.

[6]Sold or used by producers.

CADMIUM

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 cadmium since 1987. Domestic survey data were prepared by Gloria A. Peebles, statistical assistant; and international data were prepared by Ted Spittal, international data specialist.

Cadmium has several important applications due to its unique properties. Cadmium used in secondary batteries has grown in importance during the past two decades and now represents the major use for cadmium. Cadmium coatings on aluminum, brass, iron, and steel make these metals highly resistant to corrosion in most conditions and especially in marine and alkaline environments. Cadmium pigments are stable inorganic coloring agents that have a high temperature stability, high resistance to degradation by light, and a wide range of excellent brilliant colors and opacity for applications such as ceramics, coatings, plastics, and artists' colors. Other uses for cadmium and cadmium compounds are stabilizers, alloys, solar cells, nuclear reactor controls, and several other minor uses.

Domestic production of cadmium metal decreased slightly in 1992 compared with that of 1991. Four companies operating four plants produced all of the domestic primary cadmium. The New York dealer-price range of cadmium metal, at $1.90 to $2.05 per pound at the beginning of 1992, followed a downward trend and closed the year at $0.60 to $0.70 per pound. The steady price decrease was attributed to a considerable decrease in demand owing to a global economic slowdown and the environmental concerns, together with the specific regulatory final ruling by the Occupational Safety and Health Administration (OSHA), related to the presence of cadmium in the workplace.

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 10 operations that produced cadmium compounds to which a survey request was sent, 8 responded, representing 80% of the cadmium content of production of cadmium compounds shown in table 2. Production of nonrespondents was estimated using previous years' data adjusted for general industry trends. *(See tables 1, 2, and 3.)*

BACKGROUND

Cadmium is mainly a byproduct of refining zinc metal from sulfide ore concentrates. It is also produced as a byproduct of beneficiating and refining lead ores or complex copper-zinc ores. Cadmium was discovered in Germany in 1817. Germany produced the first commercial cadmium metal later in the 19th century, and it was the only important producer of cadmium until World War I, recovering the metal as a byproduct of the smelting of cadmium-bearing zinc ores of Upper Silesia. Production in the United States began in 1907 when the Grasselli Chemical Co. of Cleveland, OH, recovered metallic cadmium as a byproduct of zinc smelting. Before cadmium production started in the United States, about 85% of the cadmium content of the zinc concentrates was lost in roasting the concentrate and fractional distillation of zinc metal.

In the early 1900's, cadmium was imported from Germany as metallic sticks and as cadmium sulfide pigment. As supplies from Germany were curtailed during World War I, domestic production, which started in 1907, increased dramatically. By 1917, the United States became the world's leading producer of cadmium and held that position for more than 50 years.

In the early part of this century, cadmium sulfide was used in this country mainly as pigment. Minor amounts of metallic cadmium were used in amalgams and other alloys. The common dental amalgam of those days consisted of 26% cadmium and 74% mercury.

During World War I cadmium was used mainly as a substitute for tin. The consumption of tin in the manufacture of food containers for U.S. and Allied troops (combat rations, popularly known as "C-rations") resulted in a scarcity of tin in the United States. To conserve tin, the quantity of tin metal in solder formulas was reduced, and cadmium was used in solders as a substitute for tin.

After World War I, prices of cadmium declined steadily, leveled off in 1925 at about $0.60 per pound, and remained stable for the next 5 years. However, there was a decline in demand for cadmium in all industrial applications during the depression in the 1930's, which resulted in a price of $0.55 per pound, the lowest ever quoted.

The U.S. Government regulated the domestic cadmium industry during World War II and the Korean conflict to provide adequate supplies for defense requirements. The price of cadmium metal has fluctuated widely in the past 40 years, and in 1988, the domestic price rose to an unprecedented value of $7.90

per pound. The price increase was attributed to tight supply of cadmium, heavy speculative trading, world labor disputes, and an increased demand by the nickel-cadmium battery industry, particularly in Japan. Cadmium prices followed a downward trend the past 4 years, and the average price for cadmium metal for 1992 was only $0.92 per pound.

The adoption of cadmium electroplating for rustproofing parts and accessories by the automobile industry was an important factor in making plating the biggest end use for cadmium for many years. Manufacturing of storage batteries using nickel-cadmium cells started in the United States during World War II. For the period 1940-45, the estimated consumption of cadmium in batteries was less than 1%, while that of plating was about 70%. However, by 1992, the consumption of cadmium in batteries reached 55% and plating had gone down to 14%.

Definitions, Grades, and Specifications

Cadmium is a soft (hardness of 2 on Mohs' scale), malleable, ductile, and bluish-white metal. The cadmium metal crystalline structure is a distorted form of hexagonal close packing. The atomic number of cadmium is 48; symbol, Cd; atomic weight, 112.40; density, 8.65 grams per cubic centimeter at 20° C; melting point, 321° C; and boiling point, 765° C.

The National Stockpile Purchase Specification P-8-R2, March 7, 1979, covered metallic cadmium in the form of balls and sticks. This specification requires a minimum cadmium content (by difference) of 99.950% with maximum impurity content of zinc, copper, tin, and antimony, 0.001% each; silver, arsenic, and thallium, 0.003% each; and lead, 0.005%.

Uses and Products for Trade and Industry

Commercial grades of cadmium metal have 99.95% to 99.96% minimum purity, but for special applications such as semiconductors, grades up to 99.9999% purity are produced by vacuum distillation. Cadmium metal is produced in a variety of shapes such as slabs, ingots, and sticks that are used in alloying, pigments, and in production of cadmium oxide. Balls and sheets are used for plating anodes.

Geology-Resources

Cadmium minerals are not found alone in commercially viable deposits, and its abundance in the Earth's crust is about 0.2 parts per million (ppm). Greenockite (CdS) is the only cadmium mineral of importance. It is not found in any isolated deposits, but is nearly always associated with sphalerite (ZnS). Cadmium is usually produced as a byproduct in the recovery of primary zinc from zinc ores and 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.

Domestic reserves of cadmium were estimated at about 70,000 metric tons, and the total world's reserves at about 535,000 tons. Cadmium reserves were estimated by applying recovery factors to zinc reserve data. A recovery factor of 0.4% was used for the United States, 0.5% for Mexico, and 0.3% for the rest of the world. The world's largest reserves of cadmium are in the United States and Canada.

The temperature of formation of zinc deposits has a partial bearing on cadmium concentration. In general, contact metamorphic and replacement deposits formed at a relatively high temperature have less cadmium content than intermediate hydrothermal ores and sedimentary-type deposits.

Technology

Mining, Beneficiation, and Refining.—Cadmium is mainly a byproduct of mining, beneficiating, and refining of zinc metal from sulfide ore concentrates. The mined zinc ores are crushed and ground to liberate the zinc sulfide particles from the waste host rock. The ground ore is usually treated by a differential flotation process to separate the zinc-bearing particles from the waste rock, yielding a high-grade zinc concentrate and a waste product called tailings. The cadmium content of the zinc concentrate is usually about 0.3% to 0.5%.[1] An estimated 90% to 98% of the cadmium present in zinc ores is recovered in the mining and beneficiating stages of the extraction process.

Refining of zinc and its cadmium content can be accomplished by treating the zinc concentrates and/or zinc-bearing secondary materials using either a hydrometallurgical or pyrometallurgical process. In both processes, the concentrate is converted from zinc sulfide to zinc oxide by roasting, and at the same time most of the sulfur is removed as sulfur dioxide (SO_2). The SO_2 offgas is stripped of all entrapped dust and other impurities and then converted to sulfuric acid in an acid plant.

In the hydrometallurgical process, cadmium, copper, and zinc are dissolved in the sulfuric acid leach of the roasted zinc ore. The copper and cadmium are among the most common interfering impurities that are removed before the purified solution is subjected to electrolysis for zinc recovery. Copper is precipitated from the solution using a determined amount of zinc dust. Most of the cadmium is precipitated in a second zinc dust addition, and any remaining dissolved cadmium is precipitated by a third stage of zinc dust addition. The purified zinc sulfate solution is sent to the cellroom, and metallic zinc is recovered from the solution by electrowinning. The cadmium precipitate is sent to the cadmium plant where it is filtered and formed into a cake containing cadmium, zinc, and minor amounts of copper and lead. Through various steps of purification the impurities are separated, and a sufficiently pure cadmium sponge is dissolved in sulfuric acid. Metallic cadmium is recovered by electrolyzing this solution where cadmium is deposited on cathodes. After deposition, the cathodes are removed from the cells and stripped and the cadmium metal is melted

and cast into desired shapes. In the pyrometallurgical process, cadmium is volatilized during the roasting and sintering of zinc concentrates, and the resultant fume and dust are collected as flue dust in baghouses or electrostatic precipitators. The initial cadmium content of the flue dust can be as high as 10%. A great deal of cadmium collects with the zinc metal and may be removed by refining the zinc by fractional distillation (the boiling point of cadmium is 767° C and that of zinc is 906° C).

The following process is usually used to obtain cadmium produced from flue dust collected at lead or copper smelters. Concentrates of copper, and especially lead, contain considerable amounts of cadmium. In copper smelters, the cadmium reports in flue dusts, which are collected and recycled through the smelter system to upgrade the cadmium content. At the lead smelters the cadmium is fumed off and collected in the blast furnace baghouses. The baghouse dust is recycled to upgrade the cadmium content and is later used as feed material for the cadmium refinery plant.

The cadmium-upgraded dusts are charged into a tank and dissolved with sulfuric acid. The resulting solution is filtered to remove impurities and to obtain a purified cadmium sulfate solution. Next, metallic cadmium, called sponge because of its appearance, is precipitated from the solution using zinc dust. The sponge is usually briquetted, remelted, and cast into ingots. Some plants produce cadmium oxide and/or metallic cadmium powder. Cadmium oxide is produced by melting the ingots and keeping a controlled oxidizing atmosphere in the retort. To produce metal powder, the melted ingots in the retort are kept under an inert atmosphere while cadmium is distilled into a condenser as metallic powder.

The availability of cadmium is in most cases dependent on the amount of zinc production. However, smelter residues from which cadmium is recovered may be stockpiled in times of low demand, low prices, or both and can be used to recover metal at a later date.

Recycling.—Cadmium recycling has been practical only for nickel-cadmium batteries, some alloys, and dust generated during the operation of electric arc furnaces used by steelmaking industries. The amount recycled is not known.

Almost all of the cadmium used in coating and plating, plastic stabilizers, and pigments occur at low concentrations of metal and involves a large number of products that are difficult to identify. Collection and recycling of such products is almost impossible to achieve.

Cadmium from spent nickel-cadmium batteries and cadmium alloys can be recovered using pyrometallurgical or hydrometallurgical processes. Generally, the recycling plants employ pyrometallurgical processes for the recovery of cadmium from spent nickel-cadmium batteries. Large cadmium batteries, normally heavier than 2 kilograms, are emptied of their electrolyte and dismantled mechanically. The separators are then removed together with the plastic casings, and the cadmium is recovered by distillation from the plates. The plastic casings and separators of the small sealed batteries are burned off at a lower temperature prior to a higher temperature treatment required for volatilization and condensation of cadmium content.

In this country, a collection and sorting infrastructure is not in place to generate a supply of spent household Ni-Cd batteries for feed material capable of sustaining a commercial recycling operation.

INMETCO, an American company located 56 kilometers northwest of Pittsburgh in Ellwood City, PA, started commercial recovery of metal values from stainless steel wastes in 1978; since 1990, cadmium from industrial Ni-Cd batteries has also been recovered as cadmium dust, which is then sent to Horsehead Resource Development Co. (HRD), Palmerto, PA, for further purification treatment.[2]

Saft Nife Inc., at its Greenville, NC, facilities, collects Ni-Cd industrial batteries. The electrolyte of the batteries is emptied and purified for later use, while the dry batteries are packaged and shipped to the Saft Nife recycling plant in Sweden.

In Sweden, the batteries are dismantled, and the positive electrodes, composed of some graphite, iron, and nickel, are sold to the stainless steel manufacturing industry. The cadmium from the negative electrodes is recovered by distillation using furnaces.[3]

Cadmium is present as a trace element in the raw materials used in the manufacture of iron and steel products. These materials included iron ore, coal, limestone, scrap steel, and the lead and zinc metals used to coat or treat specialty steel products. In the steel industry, cadmium is generated as a fugitive emission from electric arc furnaces (EAF) and open-hearth furnaces.

At current production levels, the total EAF dust generated per year, which is collected in baghouses, is estimated at more than 0.5 million tons containing approximately 250 tons of cadmium.

HRD, together with its sister company, Zinc Corp. of America (ZCA), are currently recovering cadmium, iron, lead, and zinc from EAF dust. The separation of the contained metals in EAF dust is made by a two-stage-kiln volatilization process. In the first stage all nonferrous metals are volatilized to produce a marketable iron metal. In the second stage cadmium, chloride, fluoride, and lead are selectively volatilized to separate them from the zinc oxide. The fume product, known as lead-cadmium concentrate, is used to produced cadmium metal and a lead-silver-rich intermediate product that is sold to lead smelters.[4]

Substitutes

Among the possible substitutes for nickel-cadmium batteries are lithium, nickel-hydrogen, nickel-zinc, and silver-zinc batteries. However, nickel-cadmium batteries are less expensive, have a greater service lifetime, and are less sensitive to abuse due to overcharging.

Coatings of zinc and/or vapor-deposited aluminum substitutes for cadmium-plating applications. Barium-zinc and calcium-zinc stabilizers are replacing barium-cadmium stabilizers

used in flexible polyvinyl chloride (PVC). Organotin stabilizers have been found suitable for flexible PVC applications. Indium, silver, and/or zinc can be used in brazing alloys to get lower melting temperatures without cadmium.

Economic Factors

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 $0.33 per kilogram was imposed on these materials for non-MFN.

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, was rescheduled to end on December 31, 1995.

Cadmium producers are granted a depletion allowance of 22% on domestic production and 14% on foreign production.

Operating Factors

Cadmium has long been recognized as a toxic metal that must be handled with care to avoid prolonged exposure to cadmium fumes and/or dust. Cadmium poisoning can result from inhalation of cadmium dust and fumes or the ingestion of contaminated food and water. Chronic exposure to cadmium can lead to kidney dysfunction.

Concerns over human exposure to cadmium have generated a greater interest on the subject by Government agencies and the general public. The U.S. Bureau of Mines published an open file report on cadmium that presents a concise review on sources, processes, supply, and historical use patterns of domestic cadmium. It also covers a preliminary estimated cadmium material balance for 1989. The data in this report were obtained from both known published and/or unpublished sources of information.[5]

Based on a 1976 report, the energy requirement for the production of cadmium metal from zinc plant fume and dust using a pyrometallurgical process is 166 million British thermal units (Btu) per net ton of cadmium metal. The energy requirement for the production of cadmium from cadmium filter cake using an electrolytic process is 154 million Btu per net ton of cadmium metal.[6]

ANNUAL REVIEW

Legislation and Government Programs

On August 3, 1992, the Department of Commerce (DOC) notified the public of its intention to revoke the antidumping duties on cadmium metal from Japan, which were established on August 4, 1972. Because DOC received objections to the revocation and following the Department's regulations, on December 29, 1992, DOC notified the public that it no longer intended to revoke the antidumping duties on cadmium metal from Japan.[7]

On August 31, 1992, OSHA, meeting a court-imposed deadline, issued its final decision on permissible 8-hour exposure limit (PEL) to airborne cadmium in the workplace. OSHA's final ruling requires that cadmium fumes or dust levels be lowered to an average of 5 micrograms per cubic meter of air over an 8-hour period. The previous allowable average PEL levels for an 8-hour period were 100 micrograms per cubic meter for cadmium fumes and 200 micrograms per cubic meter for cadmium dust.

OSHA has determined that some processes in six industries would be unable to achieve the PEL of 5 micrograms per cubic meter through engineering controls and work practice alone. Therefore, OSHA established separate engineering control air of either 15 or 50 micrograms for those processes. The six industries were nickel-cadmium battery manufacturing, zinc and cadmium refinery, pigments manufacturing, plastic stabilizers, lead smelting, and plating. These final standards took effect 90 days from their publication in the Federal Register dated September 14, 1992.[8]

On October 23, 1992, the President signed the Defense Authorization Act for Fiscal Year 1992 (Public Law 102-484). This law, under Title XXXIII—National Defense Stockpile, authorized the disposal of obsolete and excess materials currently contained in the National Defense Stockpile (NDS) in order to modernize the stockpile. Disposal of the entire inventory of cadmium was authorized. However, the legislation does not establish a set timetable to accomplish the disposal of all the cadmium.

On December, 18, 1992, the Defense Logistics Agency (DLA) issued a draft sale invitation for bids for 45 tons of cadmium metal and planned to hold an industry forum on January 6, 1993, to hear industry's views on the terms and provisions of the draft sale solicitation. DLA expected to have the final invitation for bids by mid-February, and the initial bid opening was scheduled for March 22, 1993.

The U.S. Environmental Protection Agency (EPA) sponsored a technical forum in Providence, RI, on December 2-3, 1992, to promote discussion on the potential source reduction of cadmium, lead, and mercury in municipal solid waste (MSW). These three metals were selected following a set of criteria developed to identify those products which, according to EPA, are significant contributors to the total heavy-metal content in MSW. In reference to cadmium, EPA target products selected were nickel-cadmium batteries and cadmium-base stabilizers. Most participants in the nickel-cadmium batteries workshop recognized that an effective recycling program of spent batteries would considerably lower the amount of batteries entering the MSW stream. As for cadmium-base stabilizers, substitution has already taken place, and more barium-zinc and calcium-zinc stabilizers are replacing barium-cadmium stabilizers used in PVC. Furthermore, the industry began manufacturing

cadmium-free stabilizers in the mid-1980's, and it expects most stabilizers to be cadmium-free in 5 years. EPA expects to distribute the final forum report in the second quarter of 1993.

Strategic Considerations

Cadmium is included in the 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. The 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 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 tons.

Under the 1992 Annual Material Plan, Public Law 102-484 of October 23, 1992, the Department of Defense was authorized to sell the entire cadmium inventory. No inventory acquisitions or sales were made during the year, and, as of December 31, 1992, the stockpile inventory was 2,871 tons of cadmium metal.

Domestic 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 1991. Although the U.S. Bureau of Mines does not collect actual consumption data, apparent consumption by use categories in 1992 was estimated as follows: batteries, 55%; coating and plating, 14%; pigments, 16%; plastics and synthetic products, 10%; and alloys and other, 5%. *(See table 3.)*

On January 24, 1992, Ferro Corp.'s Color Div. announced its decision to withdraw from the cadmium pigment market for paints and plastics in the United States. A shrinking market, more stringent environmental regulations, increased availability of alternative pigments, and potential liability for pigments suppliers and consumers under the hazardous waste regulations were given as reasons for discontinuing the sale of cadmium pigments effective February 1, 1992.

Stocks

Inventories of cadmium metal held by metal producers decreased during the year, although metal held by cadmium compound manufacturers increased during 1992. *(See table 4.)*

Markets and Prices

The New York dealer price for cadmium metal at the beginning of 1992 ranged from $1.90 to $2.05 per pound. The price range for cadmium metal followed a steady downward trend during the first 6 months of the year and reached a low range of $0.60 to $0.70 cents per pound by June 25, 1992. July showed some signs of recovery in the cadmium market, and the price range for the next 3 months remained stable at $0.80 to $1.00 per pound. However, during the last quarter of 1992, once more prices followed a downward trend and closed the year at a range of $0.60 to $0.70 per pound. The steady price decrease was attributed to a considerable decrease in demand due to a global economic slowdown and the environmental concerns, together with the specific regulatory final ruling by OSHA, related to the presence of cadmium in the workplace.

Foreign Trade

Exports of cadmium products increased about 13% in 1992 compared with those of 1991. Cadmium metal imports for consumption decreased about 4% in 1992 compared to those of 1991. The principal supplying countries, in descending order of receipts, were Canada, Belgium, Mexico, and France. *(See tables 5 and 6.)*

World Review

Industry Structure.—World refinery production of cadmium was estimated at 18,750 metric tons in 1992. Japan was the largest producer of refined cadmium in 1992, followed by the United States, Canada, Belgium, China, Australia, Kazakhstan, and Russia. These eight countries accounted for approximately 62% of the world's refined cadmium production in 1992. 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. *(See table 7.)*

Capacity.—Rated annual production capacity for cadmium refineries 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 total world cadmium refinery production capacity for 1992 was estimated at 25,000 tons.

Belgium.—Vielle Montagne, a subsidiary of Belgian-owned Acec-Union Miniere SA, closed its overpelt zinc smelter and cadmium refinery in February 1992. The closure represented a loss of about 500 tons of cadmium refinery capacity per year.[9]

United Kingdom.—Sir Clive Sinclair, a known British inventor, has produced an electric bicycle power by 20 high-capacity, D-size rechargeable nickel-cadmium batteries. The specially designed and manufactured batteries are recharged in 1 hour, and in return they provide about 1 hour of continuous service.[10]

Current Research

The Cadmium Association, London, England; The Cadmium Council Inc., Reston, VA, and the International Lead Zinc Research Organization, Research Triangle Park, NC, held the Seventh International Cadmium Conference in New Orleans, LA, April 5-8, 1992. Major topics of discussion covered all aspects of production and uses of cadmium, methods of controlling cadmium losses to the environment, and the current regulatory scene around the world. Sponsoring organizations expected to have the conference proceedings published by the first quarter of 1993.

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

Despite an application decline of cadmium in pigments, stabilizers, and coating, the cadmium industry remains optimistic about the metal and its compounds future applications in other areas. Nickel-cadmium batteries will continue to capture a greater share of the cadmium consumption market, and other high-technological developments in the use of cadmium, such as cadmium-telluride-base solar cells, appear to have a great potential for both terrestrial and extraterrestrial (ET) power sources. As an ET important application of cadmium, National Aeronautics and Space Administration's (NASA) missions have relied almost exclusively on nickel-cadmium batteries as a secondary power source, and this Agency will probably continue using such batteries in its future spacecrafts.

On the supply side, there is an increased interest on cadmium recycling from all secondary sources, besides spent batteries, EAF dust, and alloys. Electroplating sludges, process wastes, and possible cadmium pigments contained in plastics are being considered as a source of secondary cadmium production. However, if cadmium prices keep deteriorating, there would be no economical incentive to recover cadmium metal from these secondary sources.

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[3]Nilsson, A. O. Recycling of NiCd Consumer Industrial and EV Batteries. Fourth International Seminar on Battery Waste Management. Boca Raton, FL, Nov. 9-11, 1992.

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[5]Llewellyn, T. O. Cadmium (Materials Balance). BuMines OFR 90-92, 1992, 37 pp.; NTIS PB 92-233907.

[6]Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 6-Energy Data and Flowsheets, Low-Priority Commodities). BuMines OFR 117(1)-76, 1976, pp. 32-38; NTIS PB 261150.

[7]Federal Register. Cadmium From Japan; Determination Not To Revoke Antidumping Finding. V. 57, No. 250, Dec. 29, 1992, pp. 61873-61874.

[8]———. Occupational Exposure to Cadmium; Final Rules. V. 57, No. 178, Sept. 14, 1992, pp. 42102-42463.

[9]Jones, H. Minor Metals Prove a Major Challenge to MHO. Met. Bull. Monthly, v. 256, Apr. 1992, pp. 8-13.

[10]Advanced Battery Technology, v. 28, No. 5, May 1992, p. 14.

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Cadmium. Ch. in Mineral Facts and Problems, 1985 ed.

Other Sources

American Metal Market.
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Metal Bulletin (London).
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TABLE 1
SALIENT CADMIUM STATISTICS

		1988	1989	1990	1991	1992
United States:						
Production[1]	metric tons	1,885	1,550	1,678	1,676	1,620
Shipments by producers[2]	do.	2,074	2,015	1,855	1,736	2,075
Value	thousands	$5,389	$2,282	$3,567	$3,234	$1,931
Exports	metric tons	613	369	385	158	178
Imports for consumption, metal	do.	2,482	2,787	1,741	2,039	1,958
Apparent consumption	do.	3,620	4,096	3,107	r3,105	3,515
Price, average per pound, in 1 to 5 short ton lots:						
New York dealer		$6.91	$6.28	$3.38	$2.01	$0.92
World: Refinery production	metric tons	r21,869	r21,427	r19,842	r20,221	e18,750

eEstimated. rRevised.
[1]Primary and secondary cadmium metal. Includes equivalent metal content of cadmium sponge used directly in production of compounds.
[2]Includes 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]
1988	345	1,497
1989	267	1,451
1990	228	1,144
1991	r263	1,089
1992	270	1,073

rRevised.
[1]Includes cadmium lithopone and cadmium sulfoselenide.
[2]Includes plating salts and oxide.

TABLE 3
SUPPLY AND APPARENT CONSUMPTION OF CADMIUM

(Metric tons)

	1990	1991	1992
Stocks, January 1	726	653	1,105
Production	1,678	1,676	1,620
Imports for consumption, metal	1,741	2,039	1,958
Total supply	4,145	4,368	4,683
Exports	385	158	178
Stocks, December 31	653	r1,105	990
Consumption, apparent[1]	3,107	r3,105	3,515

rRevised.
[1]Total supply minus exports and yearend stocks.

TABLE 4
INDUSTRY STOCKS, DECEMBER 31

(Metric tons)

	1991		1992	
	Cadmium metal[r]	Cadmium in compounds	Cadmium metal	Cadmium in compounds
Metal producers	624	W	422	W
Compound manufacturers	91	r379	203	350
Distributors	10	1	15	—
Total	725	r380	640	350

rRevised. 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)
1990	385	$1,174
1991	158	218
1992	178	244

Source: Bureau of the Census.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION[1] OF CADMIUM METAL, BY COUNTRY

Country	1990		1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	—	—	27	$105	—	—
Australia	199	$1,272	221	1,015	151	$262
Belgium	37	288	20	65	338	687
Brazil	—	—	47	136	—	—
Bulgaria	—	—	—	—	127	229
Canada	743	5,402	750	3,130	558	1,230
China	17	171	4	8	[2]	1
Finland	2	21	—	—	22	67
France	29	249	72	288	177	276
Germany	71	615	201	676	162	314
Greece	—	—	38	116	—	—
Italy	—	—	40	123	24	42
Japan	[2]	31	[2]	22	[2]	42
Korea, Republic of	—	—	1	2	—	—
Mexico	345	1,926	352	1,178	224	300
Netherlands	59	448	40	145	57	165
Norway	85	589	113	464	48	116
Peru	27	95	41	152	—	—
Spain	22	195	47	210	69	111
Taiwan	22	185	—	—	—	—
United Kingdom	83	417	10	53	—	—
Venezuela	—	—	5	12	—	—
Zaire	—	—	10	28	—	—
Total	1,741	11,904	2,039	7,928	[3]1,958	3,842

[1]General imports and imports for consumption were the same in 1990, 1991, and 1992.

[2]Less than 1/2 unit.

[3]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 7

CADMIUM: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1988	1989	1990	1991	1992e
Algeria	55	46	65	r78	75
Argentina	r54	r60	r55	r49	50
Australia	855	696	638	r1,076	2 1,003
Austria	26	49	44	22	—
Belgium	1,836	r1,764	1,956	r1,807	1,520
Brazil	r283	r283	e200	e200	200
Bulgaria e	300	350	r309	300	290
Canada	1,694	1,620	1,437	r1,787	3 1,529
China e	750	800	1,000	1,200	1,200
Finland	703	612	r569	593	570
France	558	790	r187	r271	200
Germany:					
Eastern states	30	26	17	—	—
Western states	r1,156	1,208	973	—	—
Total	r1,186	1,234	990	r1,060	900
India	237	275	277	r207	250
Italy	r686	r776	r691	r658	600
Japan	2,614	2,694	2,451	2,889	2,950
Kazakhstan[4]	—	—	—	—	1,000
Korea, North e	100	100	100	100	100
Korea, Republic of e	2 490	500	500	450	450
Macedonia[5]	—	—	—	—	250
Mexico	1,117	976	882	r686	630
Namibia	106	88	r69	r67	29
Netherlands	563	505	590	549	500
Norway	169	r207	286	r227	230
Peru	303	352	265	r e180	250
Poland	642	485	373	e350	350
Romania e	75	70	62	60	55
Russia[4]	—	—	—	—	800
Serbia and Montenegro[5]	—	—	—	—	80
South Africa, Republic of e	2 37	40	40	40	40
Spain	438	361	355	r300	300
Turkey	22	54	46	r45	45
U.S.S.R. e 6	3,000	3,000	2,800	2,500	—
United Kingdom	399	395	438	449	400
United States[7]	1,885	1,550	1,678	1,676	1,620

See footnotes at end of table.

TABLE 7—Continued

CADMIUM: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1988	1989	1990	1991	1992[e]
Ukraine[4]	—	—	—	—	200
Yugoslavia[5]	405	471	362	[e]280	—
Zaire	281	224	[r]127	[r]65	[2]84
Total	[r]21,869	[r]21,427	[r]19,842	[r]20,221	18,750

[e]Estimated. [r]Revised.

[1]This 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, 1993.

[2]Reported figure.

[3]Reported preliminary estimate.

[4]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[5]Formerly part of Yugoslavia; data were not reported separately until 1992.

[6]Dissolved in Dec. 1991.

[7]Includes secondary.

[8]Dissolved in Apr. 1992.

CEMENT

By Cheryl Solomon

Ms. Solomon, a physical scientist with 7 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 97% of the total domestic production. The remainder comes from masonry, hydraulic, and aluminous cements.

In 1992, U.S. demand for cement increased by approximately 3%. Domestic production of portland cement increased by 5%. Cement imported for consumption declined for the fifth year to 6.8 million short tons. Portland cement prices stayed approximately the same.

The U.S. International Trade Administration suspended its antidumping investigation involving imports of gray portland cement and cement clinker from Venezuela. The basis for the suspension was an agreement by producers or exporters of cement from Venezuela to make all necessary price revisions to eliminate completely any amount by which the foreign market value of their merchandise exceeded the U.S. price of the subject merchandise.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for cement are developed by means of the portland and masonry cement voluntary survey. Of the 120 cement manufacturing plants to which an annual survey collection request was made, 108 responded, representing 93% 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. *(See table 1.)*

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 Designation: 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-1157 first developed in 1992 covers blended hydraulic cements for both general and special applications.[2] This is a specification giving performance requirements. There are no restrictions on the composition of the cement or its constituents. The specification classifies cements by type based on specific requirements for general use, high early strength, resistance to attack by sulfates, and heat of hydration. As a performance

standard and not a rigid formula of ingredients, it does not replace ASTM's existing standards (C-595 for blended cement described below) but is an additional way to specify blended cements.) 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.[3] 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, or high-alumina cement, 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 4.02 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:[4]

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, for example, can be used for pumping applications. Superplasticizers also can 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 act as reservoirs for the water when it freezes, allowing it to expand without harming the structure of the concrete. They also can 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 used mainly 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 97% of total domestic output; the remainder is mostly masonry cement with white, expansive, portland slag and pozzolan, waterproof, and a variety of miscellaneous cements accounting for a small percentage of the remainder.

Industry Structure

The industry is composed of 120 cement-producing plants in 38 States. Multiplant operations were being run by 18 companies. Seventeen independent importers have constructed terminals to receive foreign cement for markets near coastal areas.

The cement industry has been very active in vertically integrating the cement companies since 1985, when the Federal Trade Commission removed the ruling that prevented vertical integration in the construction materials industries. Vertical integration would include owning ready-mix concrete, concrete products, aggregate, and construction businesses that buy the cement. In addition, the cement companies own crushed stone, sand and gravel, hot-mix asphalt, and precast and prestressed concrete companies. Other companies may own fly ash, slag, chemical admixtures, colored cement, waste material including fuel, and cement distribution companies. Therefore, cement companies have moved beyond simply acquiring the cement consumers, but also are owning the fuel and cement distribution companies.

In 1992, one of the activities in the U.S. cement industry with respect to vertical integration was the acquisition by Sunbelt Enterprises, the U.S. subsidiary of Cementos Mexicanos (Cemex), S.A., of C.L. Pharris Sand & Gravel, Inc. and a substantial portion of the assets of the Pharris Group based in southern California. Pharris had significant sand and gravel reserves in California.[5] Lone Star Industries Inc. sold the assets of the San Vel ready-mixed concrete and aggregate operation to Aggregate Materials Corp. for $5.5 billion.[6]

Most of the cement companies in the United States that were vertically integrated were foreign owned.[7] Such companies included Beazer U.S.A., owned by Hanson Industries; Blue Circle Cement Inc.; Calaveras Cement of Cimenteries CBR, S.A.; Dragon Products Co., owned by Cementos del Norte; Essroc Corp., owned by Ciments Francais; CSR; Lafarge Corp.; National Cement Co., owned by Ciments Vicats; Mitsubishi Cement Corp.; California Portland Cement, owned by Onoda Cement; and Tarmac. Southdown Inc., a wholly owned U.S. cement company, was integrated in California.

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 short tons of raw materials is required to make 1 short 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 wetmilling, water is added with the mill feed to produce a slurry containing about 65% solids. The raw material then is 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.—The cement industry has cut energy consumption and costs considerably over the past 30 years by modernizing the kilns, utilizing secondary fuel burning, and improving efficiency. Energy costs account for about 35% of the total production costs for cement. Plant operating costs may make up 70% of the value of cement.

Tariffs.—For countries with most-favored-nation status, duties are imposed only on white cement in the amount of $0.22 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 white cement and for all other types of cement and clinker, respectively.

Operating Factors

Environmental Requirements.—The U.S. Environmental Protection Agency (EPA) was involved in a number of studies involving cement kilns. One study, due in 1993, was of cement kiln dusts, the last of the Bevill Amendment wastes that were excluded from regulation as hazardous wastes until studies had been completed. Another study was of the process of using wastes in making cement. The study was to serve as a basis for a regulation targeted for late 1994 that would "reduce unnecessary regulatory barriers to the appropriate use of hazardous waste in the production of cement and other building materials."[8]

The EPA also was to conduct a major overhaul of Federal regulations for waste combustion, requiring full risk assessments and new permits, to include "an appropriate dioxin standard."[9]

Energy Requirements.—The U.S. cement industry consumed an average of 4.8 million British thermal units per short ton (Btu/short ton) in 1992.[10] Types of fuel consumed in the cement kiln were natural gas, bituminous and anthracite coal, and petroleum coke. High sulfur petroleum coke may be blended with coal and used as fuel in the cement kiln.

The cement industry also has been using wastes derived from other industries as fuel for cement kilns since the 1980's. The waste fuel market is divided into two broad areas: hazardous waste and nonhazardous waste.[11] The hazardous-waste area contains wastes such as printing inks and dyes, paints, solvents, chemicals, plastics, and any other materials that have come into contact with these industrial wastes. Nonhazardous wastes include scrap tires, medical waste, used oil, nonhazardous plastics and chemicals, and municipal wastes.

Over the past 6 years, there has been a steady increase in the use of hazardous waste derived fuels. Cement kilns are said to be ideal waste disposal units because the clinkermaking process requires high temperatures, long burning times, and a high level of turbulence. Liquid wastes, solvents, used motor oil, and scrap tires can be burned effectively, cutting down on fuel costs.[12]

Currently, liquids are used more commonly as hazardous waste derived fuels.[13] Solids and sludges can be introduced into the kiln in a variety of ways. Solids can be suspended in liquids and pumped into the kiln or injected directly into the calcining zone. Preprocessed solids and sludges are dried, ground into powder, and air-conveyed into the hot end of the kiln.

With any of these three processes, as fuel is consumed, the organic compounds are destroyed. The inorganic compounds recombine with the raw materials and are incorporated into the matrix of cement.

Cement kilns may need to be modified to burn some of these wastes. Some kilns already have been retrofitted to use waste oil. Using scrap tires as fuel for preheater kilns is well known, but had not been an option for long kilns. New technology will allow whole tires to be inserted into the calcining zone. One automated bulk tire feeder can run unattended with a programmable controller.[14] The costs involved in converting to using wastes as fuel depend upon the type of waste, with hazardous waste the most expensive and tires the least expensive. However, the cement kilns are paid approximately $50 per short ton for using hazardous liquids and $250 to $400 per ton for solids.

Other waste fuels that cement kilns may be recycling in the future could be municipal wastes or waste timber.[15]

ANNUAL REVIEW

Legislation and Government Programs

The EPA has a mandate under the Bevill Amendment of the Resource Conservation and Recovery Act (RCRA) to study cement kiln dusts and to present a Report to Congress by yearend 1993.[16]

Issues

One of the main issues facing the cement industry seemed to be whether the cement industry could increase profitability by retiring old plants, cutting costs, improving its efficiency, and raising prices. Another crucial issue for the cement industry was the environment and the use of alternate fuels to make cement. (See sections on Environment Requirements and Energy Requirements of this report.) Other issues were that the cement industry continued to pursue vertical integration, or acquisition not only of downstream customers, but also of competitors or companies that would source fuel. (See Industry section of this report.)

These issues were interconnected. For example, the use of alternate fuels aided the cement industry with respect to cutting costs and increasing profitability. In addition, cement companies pursued vertical integration with respect to the buying of waste companies to ensure a fuel supply. Vertical integration in the cement industry has been undertaken to attempt to improve efficiency in supply of materials, fuel, and customers.

Production

One State agency and 49 companies operated 120 plants in 38 States. In addition, two companies operated two plants in Puerto Rico, manufacturing hydraulic cement. The production data obtained are listed 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 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, 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.—Clinker production in the United States, excluding Puerto Rico, stayed approximately the same as that in 1991. California continued to lead all States in clinker production, followed by Texas, Pennsylvania, Missouri, and Michigan.

By yearend, multiplant operations were being run by 19 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 60%. 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.; Lehigh Portland Cement Co.; Ash Grove Cement Co.; Essroc Materials Inc.; California Portland Cement Co.; and Medusa Cement Co.

Portland Cement.—Portland cement production increased by 5% to 74.3 million short tons. The reason was attributed to increased demand for cement, primarily in the Mountain, East/West North Central, and East/West South Central States.

The industry operated 120 plants, including 8 grinding facilities, to produce various types of finished hydraulic cement.

The size of individual companies, as a percentage of total U.S. finished cement production capacity, ranged from less than 0.01% 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.; Blue Circle Inc.; Ash Grove Cement Co.; Essroc Materials Inc.; Medusa Cement Co.; and California Portland Cement Co.

Masonry Cement.—Production of masonry cement increased by 8% to 3.1 million short tons. At yearend, 82 plants were manufacturing masonry cement in the United States. One plant producing masonry cement exclusively was Riverton Corp., Riverton, VA.

Aluminous Cement.—Aluminous cement continued to be produced by Lehigh, Buffington, IN; 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 69.5% of the energy consumed.[17] The consumption of electrical energy represented 9.9% of the fuel used. Fuel used in wet-process plants was 5.9 million Btu per short tons, or 34% higher than the dry process of 4.4 million Btu per short tons. Kilns without preheaters averaged 5.4 million Btu per short tons, those with preheaters averaged 4.3 million Btu per short tons, and those with precalciners averaged 3.9 million Btu per short ton.

Corporate Changes.—Arawak Cement Co., a 1,000-metric ton-per-day, dry-process plant in Barbados, was advertised for sale. The plant, brought on line in 1984, was owned by the Governments of Barbados and Trinidad and Tobago.[18]

Ash Grove Cement West was merged into the Ash Grove Cement Co., the U.S. cement and lime manufacturer.[19] Boxcrow Cement Co., Midlothian, TX, filed for chapter 11 bankruptcy in December. Holderbank, which had been managing the operation, let its contract expire in September. CBR, owner of the Calaveras Tehachapi plant in northern California, modernized the plant, which came on-stream during the year.

Italcementi, Italy's largest cement manufacturer, purchased 54.6% of Societe des Ciments Francais' capital to increase its international presence.[20] Italcementi produced 16.5 million metric tons, or approximately 35% of the Italian cement market. In North America, Ciments Francais operated under the name Essroc and had cement plants in Indiana, Maryland, Michigan, Ohio, Pennsylvania, and Ontario, Canada. Italcementi already had holdings in the United States: River Cement, Hercules, and Signal Mountain.[21]

Cemex acquired two Spanish cement companies, Compania Valenciana de Cementos Portland and Auxiliar de la Construccion (Sanson). In the United States, Valenciana had a joint venture with Scancem in Norval, an import terminal in Brooklyn, NY.[22]

Heracles General Cement Co. was acquired by Calcestruzzi, subsidiary of Ferruzzi Finanziaria, a large Italian industrial group. The acquisition was to be a joint venture between Calcestruzzi and the National Bank of Greece. Heracles, which was controlled by the Greek Government, was Greece's largest cement company.[23]

Hanson PLC asked the Federal Trade Commission to approve the sale of its 50% interest in Cencal Cement Co. to Cencal's other co-owner, SsangYong Cement.[24]

Holnam Inc. closed its cement production plant in Okay, AR.[25] The two-kiln operation was closed because of its age (it was built in 1929) and the cost of operating the facility, as well as overcapacity in its market area.[26]

Lone Star Industries Inc., which filed for bankruptcy in 1990, planned to sell its cement plant in Nazareth, PA, as part of its proposed reorganization plan. It also planned to reorganize its board of directors.[27] Lone Star Industries also sold all of the capital stock of Compania Argentina de Cemento Portland to Loma Negra Compania Industrial Argentina for $38 million.

Medusa Corp. signed a letter of intent to purchase the Demopolis cement plant from the Lafarge Corp.[28] The $45 million transaction included nine cement distribution terminals in Alabama, Florida, Georgia, and Tennessee. The decision by Lafarge to sell the 15-year-old plant was made to rationalize the company's existing cement asset base in the southeastern U.S. and Mississippi River markets.[29]

Red Rock of Minnesota opened a new terminal south of Cincinnati-Grey Stone of Kentucky. Grey Stone was to receive its cement from Spain, which would ship the cement up the Mississippi and Ohio Rivers.[30]

Tarmac America Inc. and Titan Cement Co. of Athens, Greece, completed their joint-venture agreement to operate Roanoke Cement Co. Titan was to be the majority partner.[31] Twenty-five million dollars was to be invested in modernizing the plant.

Consumption and Uses

Consumer demand for cement in the United States, excluding Puerto Rico, increased by 5%. According to U.S. Department of Commerce (DOC) data, housing starts declined 14% to 860,000 units. The value of new construction put in place increased 6.5% to $427 billion. The value of residential construction put in place increased 17% to $184 billion, primarily in single-unit structures. The value of nonresidential construction put in place declined 13% to $85.5 billion owing primarily to decreases in industrial, office, and other commercial building construction. Public construction increased by 5% to $52.9 billion, caused in part by spending for highways and streets, hospitals and schools, and conservation and development.[32]

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, Pennsylvania, and Ohio. Together, these States consumed 39% of total U.S. tonnage.

On a regional basis, all of the census regions but the Pacific experienced increases in consumption. The largest increases were experienced by the Mountain, West North Central, East South Central, New England, and East North Central, with 18.9%, 14.8%, 9.2%, 8.5%, and 7.7%, respectively. The West South Central, South Atlantic, and Middle Atlantic experienced increases of only 5.2%, 3.6%, and 2.3%, respectively. The Pacific Region experienced a 3% decrease in consumption.

Shipments of domestically produced portland cement from U.S. mills increased by 7% as shown in table 9, while masonry cement shipments increased by 8%. *(See table 9.)* Ready-mix concrete producers were the primary consumers of cement, accounting for about 69.4% of the total, followed by concrete product manufacturers with 12.9%, highway contractors with 4.9%, building material dealers with 4.4%, and other contractors with 3.1%. 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 per ton stayed approximately the same at $49.54 per short ton, and the value of masonry cement showed a decrease of 2% to $67.78 per short ton. The average value of cement by yearend reported by Engineering News-Record (ENR) was $61.81 per short ton. The ENR prices are based on an average per short ton value of cement delivered to 20 cities. The prices ranged from a low of $61.81 in August and October through December to a high of $63.45 in January. The average price change for portland cement for December 1992 decreased by 1% compared with December 1991.[33]

Foreign Trade

On February 27, 1992, the DOC suspended its antidumping investigation involving gray portland cement and cement clinker from Venezuela.[34] The basis for the suspension was an agreement by Venezolana de Cementos, S.A.C.A. and Cementos Caribe, C.A., which accounted for substantially all imports of these products from Venezuela, to make any necessary price revisions to eliminate completely any amount by which the foreign market value of their merchandise exceeded the U.S. price of the subject merchandise. The investigation began in 1991 when three Florida-based producers filed antidumping petitions with the United States International Trade Commission (ITC). The three producers were Florida Crushed Stone Co., Southdown Inc., and Tarmac America Inc. Venezuelan cement exports to the United States in 1992 were 60,000 metric tons compared with 0.9 million metric tons in 1991 and 1.5 million tons in 1990.

In 1992, the DOC increased the dumping margin on Cemex, S.A. cement from 58.38% to 59.91% and "all others" from 58.05% to 59.91%.[35] Mexico exported only 909,000 short tons of cement to the United States in 1992. The United States traditionally received the bulk of Mexico's cement exports, which peaked in 1988 at 5 million short tons. In 1989, the United States received 4.4 million short tons of cement from Mexico. This amount, however, was halved in 1990, when the ITC and DOC determined that Mexico was dumping cement and dumping duties were collected.

That year 2.3 million short tons of cement was exported to the United States; and only 1 million short tons was exported to the United States in 1991.

A panel of the General Agreement on Tariffs and Trade (GATT) ruled that the DOC had improperly applied the stiff antidumping duties to imports of Mexican cement and recommended that the United States return the $30 million in duties it had collected.[36] Because GATT does not have the authorization to enforce that recommendation, it was unlikely that the United States would return any antidumping tariffs.

According to trade data reported by the DOC, Bureau of the Census, cement imported for consumption in the United States and its possessions and territories was 6.8 million short tons or 22% below the level of 1991. This was the fifth year of decline following 4 consecutive years of record-high imports from 1984 to 1987. The decline corresponded to the marginal decrease in total demand resulting from reduced construction activity. Canada, Mexico, and Colombia were the principal import sources, respectively accounting for 49%, 13%, and 8% of the total. Clinker accounted for 1.73 million short tons or 25% of total imports, which represented an increase of 8% over that of 1991. Clinker imports as a percentage of total imports reached 32% in the peak year of 1985. This percentage then gradually declined from 24% in 1986 to 17% in 1991. The value of foreign cement and clinker, including cost, insurance, and freight, delivered to U.S. ports averaged $43.72, down 6% from that of 1991.

The passing of the North American Free Trade Act (NAFTA) was debated in 1992. NAFTA had among its objectives the elimination of barriers to trade in and to facilitate the cross border movement of goods and services between the territories of Canada, Mexico, and the United States and to promote conditions of fair competition in the free trade area.[37] It was unclear whether NAFTA would have a significant effect on the cement industry.

Exports of hydraulic cement and clinker, as reported by the Bureau of the Census, increased 26% to 698,000 short tons. Canada received 74% of the total.

New York led all States in the amount of imports received, with 17% of total U.S. imports. Sixty-four percent or 732,345 short tons of New York imports was shipped through the Buffalo Customs District. Eighteen percent or 208,349 short tons was shipped through the New York City Customs District and 18% or 203,332 short tons was shipped through the Ogdensburg Customs District. These imports comprised 17% of New York's portland cement consumption compared with 8% of apparent consumption nationally. Eighty-two percent of imports into New York came from Canada, 12% came from Greece, 2% came from Spain, and 4% came from the United Kingdom. Michigan was the second largest recipient of imported cement, receiving 1.09 million short tons or 16% of the total. All of the Michigan imports were shipped through the Detroit Customs District, and all came from Canada.

In 1992, China exported 21,000 short tons of cement to the United States for the first time. The shipment arrived at the Lone Star Northwest Seattle, WA, and Portland, OR, terminals in December. The cement was manufactured by a plant built by Onoda Cement of Japan and jointly owned by Onoda and the Chinese Government. The new plant was brought on-line in July.[38]

World Review

World cement production increased by 5% to 1.4 billion short tons. China continued to lead all nations with 24% of production, followed by Japan with 7%, and the United States with 6%. Countries with excess capacity continued to export cement to the United States. Twenty-three countries exported cement to the United States in 1992, one more

than in 1991. The amount of cement imports declined by 22% because of increased demand within exporting countries and because of a continued decline in demand in certain U.S. markets.

During the year cement industries were privitized in such diverse countries as China, the Czech Republic, Egypt, Estonia, Greece, and the Slovak Republic. In other countries, foreign investment in cement companies continued.

Capacity.—In the United States, 44% of the clinker production capacity was concentrated in five States: California, Michigan, Missouri, Pennsylvania, and Texas. At yearend, 210 kilns at 112 plants were being operated, excluding Puerto Rico. The average annual kiln capacity increased to 394,000 short tons, compared with 388,000 short tons in 1991.[39]

Australia.—Australia produced less than 6 million metric tons of cement in 1992, which was more than 8% lower than the more than 6.5 million metric tons sold in 1991.[40] There was reduced demand for cement, with oversupply of the market, lower prices, and decreased foreign imports. There also was increased vertical integration of cement companies, with cement companies linked up with the raw material suppliers and end-product users. Falling demand and lower prices made it uneconomical to export cement to Australia. More than 60% of cement was used in the production of premixed concrete. Most of the cement production was located on the eastern coast with most of the population in this area. There were five major cement companies: Adelaide Brighton (ABCL), Australian Cement Co. (ACL), Cockburn Cement, Blue Circle Southern Cement Co., and Queensland Cement Co. Late in the year, ABCL acquired the Geelong Cement works of Australian Cement Holdings, and at yearend, ABCL had the largest clinker capacity in Australia. During the year ABCL completed the upgrade of its Birkenhead plant, and ACL upgraded the Goliath Cement plant at Railton in Tasmania.[41] Queensland Cement had spent $38 million on a cement milling and storage plant at Gladstone and $22 million on a cement port terminal at Townsville to improve its international competitiveness and cost efficiency. Cement would be shipped from Gladstone to Townsville, which would have Australia's largest cement storage silo of 30,000 metric tons.[42] A major expansion of Goliath Portland Cement Co. in Tasmania, Australia, took place in 1992.[43] A joint venture by Holderbank (QCL) and EC Levy, known as Australian Steel Mill Services or ASMS, was to process 2.65 million metric tons of slag per year, which could serve as a cement substitute.[44]

Bahamas.—Cementos Mexicanos acquired a 50% share in Concem Ltd. and Contrade Ltd., which market and distribute cement in the Caribbean region.[45] Concem Ltd. had a shipping terminal in Freeport and Contrade, with its headquarters in the Bahamas.

Bangladesh.—The Bangladesh cement industry was expected to expand from a 1991 total production base of 275,000 metric tons per year to double its production capacity by 1993.[46] Part of the production expansion was to come from new plants such as the Modern Structural Services' cement mill, which began producing 60 metric tons per day in April. Clinker grinding projects of Confidence Cement and Sena Kalyan Sangstha were to begin operating in 1993, while the Chittagong Cement Clinker Grinding Co. was to be privatized.

Barbados.—The Arawak Cement Co., jointly owned by the Government of Barbados and the Republic of Trinidad and Tobago, requested offers for its dry-process cement manufacturing plant.[47]

Belgium.—Cement production was approximately 8 million metric tons, up slightly from 7.9 million metric tons in 1991. Exports of cement and clinker in 1992 were estimated to be 3.3 million metric tons compared with 2.5 million metric tons in 1991. The building and construction industries were not affected by the economic downturn as were other industrial sectors.[48] No cement plants or plant expansions were built; however, significant investments were made in the modernization of storage, handling, and dispatching plants. Cimenteries CBR integrated the main Czech producer, CVM Mokra, into the CBR group.[49] This represented CBR's first foothold in central Europe. Improvements made at the Tehachapi and Tilbury cement plants were operational. Several acquisitions in the ready-mix concrete and aggregate sectors strengthened the group's presence in Belgium, the Netherlands, North Rhine-Westphalia, Alberta, Canada, and the States of California and Washington in the United States.[50]

Bosnia and Herzegovina.—In 1991, cement production was given as 765,000 metric tons.[51] The war in the former Yugoslavian Republic severely impacted the cement industry. The 276,000-metric ton-per-year plant, Tvornica, at Lukavac, about 100 kilometers north of Sarajevo, was damaged by shelling. This plant and another plant at Kakanj, about 20 kilometers west of Sarajevo, stopped cement production. The road and railway communications would have to be restored before production could begin again.[52]

Brazil.—Production of 30.98 million metric tons of cement was slightly higher than the 30.3 metric million tons that had been produced in 1991. This represented the highest production figure ever.

Brazil experienced political problems in 1992. The Government had a restrictive monetary policy with high interest rates and was reluctant to invest. The cement market was reportedly overpriced.[53] Exports, however, increased from 1991's approximate 54,000 metric tons to 66,000 metric tons. The main problem facing the cement industry was the utilization of installed capacity, with 50% of capacity being

used as a whole and 35% in some regions. One plant came on-line, the Camargo Correa Industrial Apiai plant.[54]

Cimento Caue S.A, the largest company in the Caue group, was expected to invest $20 million in its plants at Pedro Leopoldo and Mesquita in 1993 and 1994. The Pedro Leopoldpo plant was to invest $19 million for the automation of its industrial processes, a slag-drying and milling unit, and environmental projects.[55] Cimento Bahia SA was to invest $20.8 million in its Brumado plant to increase the plant's capacity to produce 476,000 metric tons of cement per year.[56] Construction companies in Brazil formed consortia to import cement from such countries as Turkey, or countries in Eastern Europe, due to the high price of cement offered by the small group of Brazilian cement manufacturers.[57] Approximately 70% of the national cement market was supplied by two companies.

Canada.—Canada produced 9.4 metric million tons of cement in 1992. This was a decrease of approximately 10% from that of 1991. However, consumption of cement was 7.2 million metric tons compared with 6.8 million metric tons in 1991. The Canadian economy had not recovered yet from the recession, which was strongest in 1990 and 1991. Canada was the largest exporter of cement to the United States, having exported 3.3 million metric tons of hydraulic cement and clinker. The Canadian cement industry was highly integrated, both vertically and horizontally, compared to that in the United States. There were eight Canadian cement companies. The three largest companies, Lafarge Canada, a subsidiary of France's Lafarge Coppee; St. Lawrence Cement; and St. Marys Cement; together accounted for 75% of capacity. Foreign ownership of Canadian cement amounted to 77% of capacity. Lafarge, Holderbank, CBR, and Ciments Francais were the major foreign owners.[58]

Chile.—The production of portland cement in Chile increased to approximately 3 million metric tons compared with 2.5 million metric tons in 1991. Although exports dropped by 54% to 35,500 metric tons, imports rose by 60% to 8,000 metric tons.[59]

Chile had four cement plants, three of which did not have suitable limestone deposits nearby, making it necessary to use unconventional methods to obtain this resource.[60] Industria Nacional de Cemento SA (INACESA) had a plant near Antofagasta, which was fortunate to extract limestone from a traditional opencast quarry. Cementos Bio operated the plant Talcahuano, a slag-cement plant in Concepcion. INACESA and Bio were affiliated. Cemento Melon operated La Calera, about 120 kilometers north of Santiago. Cemento Melon, the largest and oldest company, put the Super Center terminal of Cemento Melon, a sales and distribution center, in operation in 1992. Cemento Polpaico operated Cerro Blanco, approximately 50 kilometers north of central Santiago.[61] Downstream integration into aggregates and ready-mix continued at a rapid rate. For example, Petreos, the concrete division of Cemento Polpaico, opened 23 batching plants in 1992.[62]

China.—China, with abundant raw materials, continued to be the largest cement producer in the world. China produced approximately 270 million short tons in 1991. Eighty-five percent was made by local plants and 15% by state key plants.[63] The quality of the cement was varied. High-grade 525 cement was produced, as well as 425- and 325-grade cement. More than 60 varieties of cement could be produced in China. In 1991, China exported 11.8 million metric tons of cement, valued at $443 million, to 60 Asian, 24 European, and 16 African countries. More than 99% of the exports went to Asia. According to 1989 statistics of the State Bureau of Building-Material Industry (SBBMI), with headquarters in Beijing, China was to open more construction projects to foreign participation as part of its drive to build up national infrastructure. Companies would be allowed to invest solely, or jointly, with Chinese partners in the construction of motorways, bridges, and tunnels, and solely in building docks and private waterways. Foreign cooperation also was to be encouraged in managing loading, unloading, and packaging at docks.[64]

Japan was planning to enter the Chinese cement market with three Japanese cement firms in various stages of planning joint ventures with Chinese concerns. Mitsubishi Materials Corp. announced that it would sign a contract to establish a joint-venture cement company in China. The agreement covered the construction of a 1-million-metric-ton-per-year plant in Yantai, Shadong Province, by the end of 1994 at a cost of 15 billion yen or $120 million. Japanese companies, including Mitsubishi, were to provide 70% of the capital, and Chinese concerns were to supply the remainder.[65] Onoda Cement formed a joint venture for the new Dalian plant and had plans for another at Nanjing City.[66] Nihon Cement announced that it was planning to launch a joint venture with the Chinese trading house Marubeni Corp. to develop a 1.4-million-metric ton cement works in Qinhaungdao, east of Beijing.[67]

The Republic of Korea also was planning that nation's largest to date investment in China, a US$300 million cement factory in Shangdong Province. The factory was to be in Jilan City with an annual production capacity of approximately 2.8 million metric tons. The plan was to be approved by the South Korean Government, with the project to be completed by 1995. Large amounts of cement were to be sold for export.[68]

Croatia.—Production and consumption has continued to decline since 1982.[69] During the first 6 months of the year, cement production was reduced to approximately 934,000 metric tons.[70] Cement consumption was expected to increase in the next few years as the country rebuilt its war-ravaged areas. Foreign investment also was expected to increase. Exports of cement from Dalmatian cement plants of St. Caius and St. George near Split were approximately 72,000 metric tons and 597,000 metric

tons, respectively, to Mediterranean countries, such as Italy and Spain. The Bosnian market for 331,000 metric tons of Croatian cement and the continental Croatian market of 276,000 metric tons of cement were disrupted owing to the fighting in the former Yugoslavian Republics.[71]

Cuba.—According to the International Cement Review, cement production reached about 1.4 million metric tons with a production capacity at approximately 5.5 million metric tons. Exports jumped by 80%, from 154,000 metric tons in 1991 to 276,000 metric tons in 1992.[72] The Bahamas, Dominican Republic, and the Windward Islands were among the countries to which Cuba had exported cement. Brazil was seen as an important new market. Most sales were of bagged cement; however, investments in bulk handling facilities could make sales of bulk cement equal to those of bagged cement. Prices were approximately $43 per bag and $36 for bulk.

Cyprus.—Sante Trading Co. and Yazd White signed an agreement to construct a 551-metric ton-per-day-capacity white cement plant at a cost of $38 million. Sante was to be the lead contractor and would finance the project via the Middle East Trading Co., based on the Isle of Man. Machinery and technology for the plant were to come from Europe, but 30% of the equipment would be bought from Iran. Construction was scheduled to take 3 years. Sante would export at least one-half of the output, most likely to the Persian Gulf States.[73]

Czech Republic.—The Czech Republic signed bilateral trade agreements with the Baltic States of Estonia, Latvia, and Lithuania. Trade with the three republics was expected to total approximately $36 million, with the Baltic States said to be interested in buying Czechoslovakian cement, machine tools, and other products.[74] SA Cimenteries CBR finalized a partnership agreement with the Czech National Assets Fund and the cement and lime manufacturing company Cementarny a Vapenka Mokra, near Brno in Moravia. CBR was to acquire 35% of the capital of Mokra, which was to increase to 72% by 1995.[75] With 2.4 million metric tons of cement capacity per year, CVM Mokra was the leading Czech cement producer and operated two cement plants Mokra and Malomerice.[76]

In addition, Heidelberger Zement of Germany bought 40% of the Czech Republic cement factory, Kraluv Dvur, with the remaining 60% staying in the hands of CEVA-Holding of Prague.

Holderbank had signed an agreement with the Czech Republic for a 30.4% stake in the cement company CEVA Prachovice. The Prachovice plant is 100 kilometers east of Prague and had the capacity for 1.2 million metric tons of cement per year. The facilities were the most efficient of their kind in the Czech Republic.[77]

Denmark.—The domestic market for cement was weak and was expected to remain unchanged in 1993. Aalborg Portland in Aalborg, Denmark, invested money to burn process residues from the paper recycling industry in its cement kilns. A cooperative venture with Blue Circle of the United Kingdom led to increased exports in 1992 of both grey and special cements.[78]

Egypt.—Egyptian cement production decreased slightly to about 18 million metric tons. The main production centers were south of Cairo in Helwan and Tourah, west of Alexandria in Assiut, and in Suez. No cement imports were reported, but there were exports of about 194,000 metric tons.[79]

The Government of Egypt publicly invited private firms with experience in operations and management of cement factories to undertake the implementation of the major restructuring of three large Egyptian cement companies, Tourah Portland Cement Co., Helwan Portland Cement Co., and the National Cement Co. National Cement Co. was one of Egypt's largest cement producers with a 2.65-million-metric-ton-per-year plant at El Tabbin. A 1.1-million-metric-ton-per-year plant was designed by Kobe Steel and Kawasaki Industries of Japan and was scheduled to go on-stream in 1993. The exact role of foreign ownership in the privatization process continued to be discussed.[80] The Suez Cement Co., which had completed a preliminary study for expansion at its Suez plant, also was designated to be returned to the private sector. Amerijah Cement Co., Assiut Cement Co., and Alexandria Cement Co. were other Egyptian cement companies that were owned by the Government that could be owned by private investors in the future.[81]

Estonia.—An agreement establishing Kunda Nordic Cement Corp. marked the largest privatization and foreign investment project in Estonia since its independence from the former U.S.S.R. in 1991. The Kunda Cement Works, the oldest cement factory in the region and one of Estonia's largest industries, was to be transferred from state ownership to the new company, in which a consortium of European and U.S. cement companies would take 35% equity participation in the Estonian plant.[82] The new company, Kunda Nordic, was to modernize the plant to meet western cement and environmental standards. A feasibility study also was designed to study the construction of a major new cement production and port facility, which would make Kunda a major producer and exporter in the Baltic region. The foreign partners in the project were Atlas Cement LP (United States); Holderbank (Switzerland), Euroc (Sweden), and Lohja and Partek (Finland).[83]

Greece.—Privatization of the cement industry was a major goal of the Greek Government. 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 had been 70% owned by Greece's state-owned industrial holding company. Heracles was acquired by a large industrial group and the

National Bank of Greece.[84]

The sale of Halkis Cement Co. to the Italian company Calcestruzzi was to have occurred by November 1992. By yearend, the sale had not occurred; however, the sale was expected to occur when a financial agreement was reached between Calcestruzzi and Halkis.[85]

Hong Kong.—Total cement demand within Hong Kong was expected to drop to 4.3 million metric tons. The Hong Kong cement industry included one fully integrated cementworks, owned by Green Island Cement Holdings Ltd. One other grinding facility was closed in 1992. Bulk and bagged import terminals, such as the Far East Cement, Nihon, and Kowloon Cement terminals, were in operation. It was estimated that Green Island produced 1.9 million metric tons of cement. Hong Kong imported almost 4 million metric tons of cement and clinker and exported 330,000 metric tons of cement.[86]

Japan.—Japan was the second largest country in world cement production. Cement was also Japan's largest market by volume for industrial minerals. Leading consuming sectors were portland cement, ready-mix concrete, and various cement products.[87] Exports of cement, 12.57 million metric tons, increased substantially, by 57%, compared to those of 1991. The exports went primarily to Hong Kong, the Republic of Korea, Taiwan, and Thailand. Imports amounted to only about 1.2 million meritc tons, down 41% from 2.02 million metric tons, and came mainly from the Republic of Korea and Taiwan.[88]

China and Japan signed a $16 million contract to form Yantai-Mitsubishi Cement Co. The jointly run company was to be managed by the Yantai City building materials company, the State Energy Investment Corp., the Mitsubishi Business Corp., and other Japanese companies and associations. Japanese investment amounted to 70% of the total funds in the project, and advanced technology developed by Mitsubishi would be used to produce high-grade cement.[89]

The Japanese cement industry made capital investments of 160 billion yen or $1.3 billion. No cement plants were built, nor were plans announced for new plants in 1993 or 1994. However, Nihon Cement Co. Ltd., Japan's leading cement producer, announced its intention to build a 1.32-million-metric-ton-per-year plant through China's State Administration of Building Materials Industry.

The cement industry was using recycled materials and industrial waste as raw materials, fuel substitutes, and admixtures to cement. The cement industry estimated that it consumed 60% of the blast furnace slag produced in Japan, 27% of the fly ash, and 18% of the waste tires.[90]

After the discovery of illegal cement cartels in 1991, Japanese cementmakers took steps to ensure that their activities were firmly within the country's Anti-Monopoly Law. Top companies such as Nihon Cement and Mitsubishi set up executive watchdog committees and groups to monitor any potential violations of the law.[91]

A marketing agreement between Chichubu Cement Co. and its subsidiary, Tsugura Cement Co., was to provide a greater concentration in the Japanese cement market. Under the agreement, the parent company was to take direct control of Tsugura's distribution and sales division. Tsugura sold about 1.4 million metric tons of cement annually. The parent company was to reach 8.8 million metric tons annually.[92]

In response to a request by Onoda Cement, the DOC conducted an administrative review of the antidumping order on gray portland cement and clinker from Japan, which took place in 1991. As a result of the review, the DOC preliminarily determined to assess dumping duties equal to the calculated differences between the U.S. price and the foreign market value.[93]

Korea, Republic of.—Cement demand was expected to fall in part owing to the Government's policy to put a hold on new construction permits. Cement production was estimated to be 47 million metric tons, with imports of 6.1 million metric tons. Domestic demand was 51.4 metric million tons, and exports were 1.90 million metric metric tons. Significant capacity growth was being made in slag-cement facilities, with POSCO, the world's second largest steelmaker, providing a source of slag. The cement producers were expected to concentrate on exporting cement to make up for export market share lost when domestic demand boomed in the 1980's and early 1990's. Thus, cement exports were expected to increase by about 24% in 1993.[94]

Mexico.—The Mexican cement industry produced 29.6 million metric tons of cement, 7.1% more than in 1991. Mexico concentrated on improving its infrastructure, which had not been adequately maintained or modernized in the 1980's. Projects included the construction and rehabilitation of the highway and road systems, improvements in ports and airports, and building houses and mass transit systems among others. Mexico also continued to experience a housing shortage, which in 1992 was approximately 6 million units. Therefore, while a large part of the Mexican cement produced had gone to exports in prior years, in 1992, Mexico was using more of the cement produced internally. Eighty-seven percent of the cement produced was for the domestic market and 13% was exported.[95] Cemex, the largest Mexican cement producer, exported 1.43 million metric tons of cement, 12.7% less than in 1991. Mexican exports to the United States were 0.9 million metric tons, 4 million metric tons less than the peak in 1988. (See Foreign Trade Section.)

There were 30 cement plants, including Cemex, with 16 plants, and the second largest producer, Apasco, with two plants. Partially owned by Holderbank of Switzerland, Cementos Cruz Azul was a workers' cooperative with two plants. Most Mexican cement plants had switched to fuel oil from natural gas because the first priority for natural gas was Mexico's petrochemical industry, followed by industries with environmental problems.

Cementos Mexicanos, the world's fourth largest cement company, saw its net profits increase to $548 million in 1992, an increase of 13% over that of 1991.[96] Cemex held 63% of the market share. Cemex subsidiaries operated 16 cement plants and 28 strategically located distribution terminals in Mexico. This infrastructure served more than 5,000 Mexican distributors throughout the country. Cemex continued to increase its production capacity, mainly in central Mexico, where growth in the demand for cement was high. The Cemex expansion of the 0.5-million-metric-ton Atotonilco plant was completed at a cost of $27 million. Work continued on the Huichapan plant, which was to increase the plant's annual production capacity by 2 million metric tons. Operations were expected to commence during 1993. Construction of a new $400 million plant at Tepeaca, in the State of Puebla, was well advanced.[97] It was to be the largest and most modern on the North American continent and was to produce 3.3 million metric tons of cement annually. During 1992, only 12% of all the cement produced by Cemex reached the consumer as concrete. Therefore, this sector had great potential for growth as the Mexican economy recovered further.

The concrete division began operating 19 new plants during the year. Cemex's concrete production capacity, measured in distribution units, increased by 24% during the year. Three hundred seventy-one million dollars was invested in the cement and concrete divisions. This was part of the $1 billion that Cemex planned to invest from 1992 to 1994 in an expansion program. This expansion was expected to increase the group's annual cement production capacity in Mexico by 8.8 million metric tons. When the expansion program was completed, Cemex expected to invest an average of $400 million per year to maintain its share of the Mexican cement market and to increase its penetration of the concrete market. Cemex was actively promoting the use of concrete in areas that had not traditionally used concrete in Mexico, such as in the use of slip form concrete for road surfaces and roller-compacted concrete for the construction of highways, which was a new concept in Mexico. Cemex also planned to invest $100 million from 1992 to 1994 in equipment and measures to protect the environment. In the second half of the year, Cemex began negotiations to integrate a cement-producing plant in northeast Mexico into the group. The plant has an annual production capacity of 500,000 metric tons.

During 1992, Cemex continued to consolidate its position as the world's fourth largest cement producer. The group purchased the two main Spanish cement producers, Compania Valenciana de Cementos Portland, S.A. and La Auxiliar de la Construccion, S.A. (Sanson). Cemex already held 24.9% of Compania Valenciana and bid $1.25 billion for this company. Valenciana operated four cement plants in Spain and held a joint venture in the United States with Scancem in Norval, a Brooklyn-based import terminal. Valenciana was the second largest cement producer in Europe and held 15% of the Spanish market.[98] Cemex purchased Sanson for a reported $600 million. With both acquisitions, Cemex controlled five cement plants and a clinker grinding operation in Spain.[99] These strategic acquisitions increased annual cement production by 11.5 million metric tons, making Cemex the largest cement producer in Spain with a 29% market share. It also made the group one of Spain's main producers of ready-mixed concrete, with an annual production capacity of 14 million cubic meters. The investment of $1.84 billion in Spain was part of the group's policy of globalization. The Spanish acquisitions were to give Cemex access to the cement markets in Europe.

Cemex assimilated the Tolteca and Anahuac Groups, facilitating the integration of the Spanish operations into the entire Cemex Group. Cemex acquired C.L. Pharris, based in southern California. With this acquisition, Cemex had 40 concrete mixing plants in the United States. C.L. Pharris was a company with considerable strategic importance because of its aggregate reserves, which were among the 10 largest in the United States. These reserves would allow Cemex to offer an integrated supply of cement, concrete, and aggregates to the construction industry of the region. During 1992, Southern Materials, a company based in Austin, TX, also was integrated into the group. This company operates six concrete mixing facilities and one aggregates plant, and its acquisition allows Cemex to increase its sales in the Houston and Austin areas.

Cemex agreed to supply 800,000 metric tons of cement over 2 years for the construction of the Huites Dam in Mexico. The dam was to be built on the River Fuerte in the northeast Sinaloa region by the construction consortium Consorcio Mexicano Constructor de Huites. The cement was to be supplied by the Cemex subsidiary Cementos del Yaqui, which has a production capacity of 1.65 million metric tons. The retaining wall of the dam was to be one of the highest in Mexico, holding 4 million cubic meters of water. It would be capable of generating 875 million kilowatts per year. The dam would provide irrigation water for the States of Sinaloa and Sonora.[100]

Cemex began the operation of a new company, Pro-Ambiente, S.A., to develop the disposal, treatment, and use of waste fuels. In a $20 million joint venture with Mobley Environmental Services in Texas, the company was to recycle industrial waste into kiln fuel for Cemex plants.[101] One of the first steps of Pro-Ambiente was building two fuel-blending plants. In addition, Mexico has recycled more than 100,000 used tires annually. Alternative fuels provided 15% of the energy of one of the kilns in Ensenada, Baja California.[102] Cementos Apasco was planning to build a new cement plant, the production line of which was scheduled for commissioning in early 1994.[103]

In April, the U.S. Court of International Trade upheld the ITC's 1990 decision that U.S. cement producers were injured by Mexican cement. The result of the ruling was that the antidumping order was to remain in effect and that

importers of cement from Mexico were to be required to pay estimated duties of up to 60% on all imports of Mexican cement. The DOC reconsidered its ruling with respect to the dumping margin on Cemex, the largest Mexican producer and exporter of cement, and increased the margin from 58.38% to 60%.[104]

In November, in the Ad Hoc Committee of the Arizona, New Mexico, Texas, and Florida producers of Gray Portland Cement vs. United States, a lawsuit challenging the DOC's final determination of sales at less than fair value of gray portland cement and clinker from Mexico, the Court of International Trade affirmed the DOC's redetermination on remand. As a result, the final dumping margin for one of the respondents, Cemex, S.A., increased from 58.38% to 60.33%; all other margins increased from 58.05% to 59.91%.[105]

The GATT ruled that the United States improperly applied stiff antidumping duties on Mexican cement imported into because of the United States and urged the United States to return the more than $30 million in duties that it had collected. However, the recommendation would have had to be approved by the full GATT Trade Association. Therefore, it was not likely that the duties would be removed.[106]

Saudi Arabia.—High demand for cement was likely to continue in 1993. Construction had boomed since the end of the Gulf War in 1991.[107] Most of the publicly traded companies announced expansion plans, totaling about $1.1 billion, that were to raise production by 4 million metric tons to about 20 million metric tons. Yammama Saudi Cement reported tripled profits at nearly $68 million. Saudi Kuwaiti Cement revealed a 145% rise in net profit to nearly $45 million. Two hundred twenty thousand metric tons of cement was imported to make up for the increased demand.

Slovak Republic.—The Swiss cement group Holderbank was expected to sign an agreement with the Slovak Republic for a 34% stake in ZCV Rohoznik, a cementworks near Bratislava. The cementworks was Slovakia's largest and most modern plant. Holderbank's stake would be raised to a majority holding by the end of 1996 through a series of capital increases.[108] ZCV Rohoznik was renamed Hirocem A.S. and ran a cementworks and limeworks with an annual capacity of 1.7 million metric tons of cement and 100,000 metric tons of lime. The plant was 30 kilometers northwest of Bratislava and linked to the rail network. It had shipment facilities on the Danube and was close to the Bratislava-Prague motorway.

Spain.—Following the 1992 Olympic games and International Expo in Seville, the demand for cement fell, sparking a price war. Production of cement in Spain was estimated at 29 million metric tons. Spanish cement producers alleged that cement imports into Spain were "dumped" at unfairly low prices. There was to be a European investigation of imports of Tunisian, Turkish, and Romanian cement into Spain.[109]

Compania Valenciana de Cementos Portland, the second largest cement producer in Europe, and Auxiliar de la Construccion (Sanson), Spain's second largest cement company, were purchased by Cemex. Portland Valderrivas and Cementos Portland merged to form the largest Spanish-owned cement company. Further mergers were expected in the future.[110] Cemex thus controlled five cement plants and 28% of the Spanish market.

Taiwan.—In 1992, 20.5 million metric tons of clinker was produced. Exports of 1.28 million tons of cement were 22% higher than in 1991.[111] Two new plants came on-line: Asia Cement Corp. with a 1.6-million-ton Hualien plant and Taiwan Cement Corp. with a 1.6-million-metric ton Suao plant.

Venezuela.—According to the Associacion Venezolana de Productores de Cementos, 6.2 million metric tons of cement was produced, similar to that in 1991.[112] Cement and clinker imports were approximately 69,000 metric tons compared with 22,000 metric tons in 1991. Exports of cement and clinker totaled 1.41 million metric tons compared with 2 million metric tons in 1991, a decline of 30%.

No new plants were built, but Consolidada de Cementos installed a 800,000-ton-per-year production line in its San Sebastian plant. It was expected to begin production about mid-1993.[113]

The antidumping investigation involving gray portland cement and clinker from Venezuela was suspended following an agreement to not sell Venezuelan produced cement and exports in the United States for less than the price it was sold in Venezuela. (See Foreign Trade section of this report.)

Cement exports from Venezuela to the United States, 60,300 metric tons, fell by 93% in 1992. Much of this decrease was due to increased domestic demand. However, in 1990, imports of Venezuelan cement were 1.5 million metric tons compared with 923,000 metric tons and in 1991. Although the dumping investigation had been resolved by early 1992, because of long lead times in contracts, exports to the United States were still very low in 1992. Exports to the United States were expected to increase in 1993.[114]

Current Research

The main chemical aspects of portland cement hydration were highlighted at BP Research in Middlesex, United Kingdom. Reactions of the major cement phases, differences in the hydration behavior of different types of portland cement, and descriptions of blended cements were given. Understanding the basis of hydration was an essential prerequisite for appreciating the chemical effects admixtures that have been incorporated into cementing systems. Such understanding can help to address any problems of long-term durability of cement pastes, mortars, and concretes that use chemical admixtures.

Concrete Hitech, a specialist cement technology group with headquarters in

France, announced that it had a new product, formulated to provide a ceramic-type concrete.[115] The product was a ceramic white cement capable of withstanding normal weathering effects and carbonation, among other things. One of the major factors affecting concrete durability is its permeability and porosity. The challenge has been to stop water from infiltrating the concrete. The solution was to eliminate the pores throughout the concrete and not allow the water to pass. Samples of the white concrete comprising a crushed granite coarse aggregate set in a matrix of natural sand and cement paste containing an additive showed zero porosity during tests.

Concrete structures may be subjected to sulfate salts, usually of sodium, magnesium, or possibly calcium, that exist naturally at varying concentrations in many soils, ground waters, and the sea. Sulfate salts do not attack concrete unless they are present in solution. Attack of hydrated cement can take place by the reaction of sulfate with calcium hydroxide and calcium aluminate hydrate to form ettringite and often gypsum. The formation of ettringite was mainly responsible for large-volume expansion, which often led to cracking and disintegration of the concrete matrix. Factors influencing the rate of attack on inland structures were the concentration and type of sulfate solution and the pH in soil or ground water, the watertable, and the mobility of ground water. Concrete exposed to seawater also is vulnerable to sulfate attack, which could be aggressive particularly in the warmer oceans. The constituents of the concrete mix and the curing regime employed, as well as the form of construction, had a strong influence on sulfate attack.

At the Department of Engineering, University of Aberdeen, United Kingdom, the influence of initial curing on the sulfate resistance of blended cement concrete made with ordinary portland cement and using pulverized fuel ash (pfa), silica fume, and ground granulated blast furnace slag for partial replacement of cement was investigated.[116] It was found that the sulfate resistance of concrete increased with replacement of cement with 22% fly ash, 9% silica fume, and 80% ground granulated blast furnace slag. The possible common factor that led to improved sulfate resistance was the reduced $Ca(OH)_2$ content, which led to a smaller volume of the expansive reaction products with sulfate ions. The effect of initial curing at high temperature (45° C) was significantly harmful to the sulfate resistance of plain concrete but much less so to the blended cement concretes.

As a result of their significantly better performance in durability, both microsilica- and slag-blended cements have been projected as cementitious materials with potential for use in harsh environments. Damage caused by alkali silica reaction has received considerable attention in the Middle East. Tests were carried out on plain, microsilica, and blast furnace slag cements at the King Fahd University of Petroleum and Minerals in Saudi Arabia.[117] Some of the conclusions were that 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. Blast furnace slag was shown to be an active remover of alkalis and was especially effective in medium-alkali cements, where, for equal alkali contents, the performance of 60%-slag cement was comparable with that of 10% microsilica cement.

High strength concrete in high-rise buildings could provide many advantages over medium strength concrete, such as improvements in stiffness and durability and reduction in construction cost. Development of compressive strength and pulse velocity for high-strength concrete were studied in relation to cementitious material types and curing conditions at the University of Technology in Sydney, Australia.[118] Nondestructive test methods for the evaluation of concrete strength have been the most popular tests because of minimum cost, rapid testing, and minimal damage to concrete structures. In the ultrasonic pulse velocity method, an ultrasonic wave is sent through concrete and the time taken by the pulse to travel through a known path length is measured. Through the relationships between pulse velocity and modulus of elasticity and between compressive strength and the modulus of elasticity, strength can be correlated to the pulse velocity of concrete. Normal portland cement, blast furnace slag cement, and silica fume were used individually or in combination. Among other findings, the presence of silica fume in concrete increased the pulse velocity at all ages and curing conditions.

Characteristically, a mortar or concrete element developed strength primarily as a result of hydration and hardening of the cement paste and the resultant bond at the paste-aggregate interface. The phenomenon of hydration is both time and temperature dependent. The latter condition has been of particular importance in those regions of the world that experienced hot weather conditions during most of the year. This phenomenon was studied in the Department of Civil Engineering at King Abdul Aziz University in Jeddah, Saudi Arabia.[119] Adverse effects of long-term exposure of plain cement mortars and concrete to hot weather conditions had been emphasized in previous publications of the authors. With the current trend in concrete technology and practice of using admixtures and/or replacing cement partially by pozzolanic materials, it has been important to understand the behavior of these modified or blended materials that still retain their conventional form and nature at higher than normal exposure temperatures. The beneficial influence of certain pozzolans resulted from their particle size, surface texture, and pozzolanic reactions. The slow hydration characteristics of most pozzolans, when compared with ordinary portland cement (OPC), made them suitable for an environment where the ambient conditions were hot.

In the present study, OPC was blended with powdered tuff, powdered slag, and silica fume, and compressive strengths of mortar and concrete specimens were determined at regular intervals after exposing them continuously to 25° C, 35° C, or 50° C. A superplasticizing

admixture also was used in one set of experiments. Plain OPC paste specimens were tested to compare the strength development characteristics of identical specimens under various curing temperatures. According to the study, mortar and concrete specimens that contained OPC underwent a deterioration in terms of compressive strength when exposed to air temperatures higher than 25° C for a long period. The detrimental effect of temperature was related to either the weaker formation of cement paste hydrates or the differential thermal expansion of matrix components. Blending of OPC with pozzolanic materials, such as powdered tuff, slag, and silica fume, helped to improve the performance of mortars and concrete on exposure to higher-than-normal temperatures, particularly in the range of 35° C to 50° C. Reduction of water content in the mix by a suitable admixture also was beneficial in hot weather conditions.

In September 1991, an international conference was held in Sheffield, United Kingdom, on blended and composite cements. Approximately 50 papers from nearly 30 countries were presented, and some of them were published in 1992. The papers presented included the following: Freeze-Thaw Durability of Air-Entrained Condensed Silica Fume Concrete, Influence of the Method of Fly Ash Incorporation on the Sulfate Resistance of Fly Ash Concrete, Effect of Microsilica and Blast Furnace Slag on Pore Solution and Alkali-Silica Reaction, A Review of Limestone Additions to Portland Cement and Concrete, Use of Ash Derived From Refuse Incineration as a Partial Replacement of Cement, Pulverized Fuel Ash Concrete Mix Design for the 1990's, and Measurement of the Heat of Hydration of Cement, among many others.

The need for more durable concrete and in particular, improved resistance to freeze-thaw exposure in the presence of salts, motivated investigations on condensed silica fume concrete. The investigations included studies of air pore system characteristics, ice formation and pore structure, freeze-thaw tests with and without deicing salts, and chemical resistance. A study on the freeze and thaw durability of concrete incorporating various amounts of condensed silica fume (csf) was conducted at the Polytechnic Institute of Wales in the United Kingdom.[120] The incorporation of the condensed silica fume in concrete improved the compressive and flexural strength. The air entrainment decreased appreciably with increasing csf content.

Other studies dealt with problems arising from grinding of multicomponent cements containing clinker, pozzolans, slag, and fly ash. At the National Technical University of Athens, Greece, a review of the intergrinding phenomenon of the great number of additives used in cements was undertaken.[121] A special procedure, based on the separation of the cement components, was applied to determine the specific surface that each component developed during the final grinding. The relation between the cement composition, the cement specific surface, and the component fineness were obtained. With the proposed relationship and a computer program, the appropriate mixing ratio of clinker with one or more of the additives used was extracted. The mixing was based on the specifications for the cement composition and the minimum specific surface that each component must develop during the intergrinding. Then, the behavior of cement components during their intergrinding was studied, resulting in the easier treatment of a multicomponent cement grinding.

Controlled low-strength material (CLSM), a flowable, cementitious material used as backfill in lieu of compacted fill, has been used extensively to backfill trenches and open excavations near structural foundations. Other terms used to define this material are flowable fill, unshrinkable fill, plastic soil-cement, and soil-cement slurry, among others. A bibliography was available for a potential or current user of CLSM to investigate the properties, applications, and characteristics of the material.[122] CLSM has been defined by American Concrete International as a material having a compressive strength of 1,200 pounds per square inch or less. The materials and flow characteristics for CLSM vary depending upon local conditions. Sand, cement, fly ash, and water are the predominant materials for CLSM, although others such as coarse aggregate may be used.

In another study on soil cement slurry, various materials were experimented with to serve as slurry walls to build around hazardous waste sites to prevent contamination of soils and ground water by waste chemicals and leachate.[123] The most widely used technique for such construction has been the slurry wall method. The two common types of cutoff walls were the cement bentonite (CB) and soil bentonite walls. In a CB wall, the slurry was composed of bentonite and cement, which was left in place to act as an "impervious barrier." Soil bentonite walls utilized backfill materials consisting of sodium bentonite and soils, displacing bentonite slurry, and formed the impervious barrier. The investigation was on mixtures consisting of calcium bentonites from cement, slag, and fly ash using flexible wall permeameter. The majority of the data indicated that the hydraulic conductivity of soil-sodium bentonite mixtures increased severalfold, with many of the chemicals found at waste disposal sites. The investigation was funded by the Industry/University Cooperative Center for Research in New Jersey.

In the management of low- and medium-level, short-lived (approximately 30 years) radioactive wastes, stored in shallow-ground disposal facilities, storage safety has demanded the isolation of the wastes from the biosphere during the time necessary for the virtual disappearance of the radioactivity; in other words, for about 300 years. The alternative selected for the containment of radioisotopes in a stable engineered environment consisted of a series of barriers designed to stop radiation and to protect them against the action of external agents such as water and human intrusion, which could disperse them in the natural environment. A portland and a blended cement (containing slag and fly ash) were stored at constant pH's of 13, 11.5, and 4.6 in

solutions without aggressive salts.[124] The structural and textural variations of the pastes were investigated over 3 years.

Reprocessing of nuclear fuel from Magnox reactors has been carried out at the Sellafield, Seascale Cumbria, the United Kingdom, plant for more than 30 years.[125] A number of radioactive wastes were generated by these operations, which required storage on-site pending a disposal route being identified. One intermediate level waste, Magnox Swarf, arises after mechanical decanning of fuel from Magnox reactors and had been stored at Sellafield in water-filled silos since the early 1960's. A number of different cement systems were evaluated to encapsulate the Magnox swarf, including blends of sand, blast furnace slag (BFS), and pulverised fuel ash with OPC. For all three cement systems, a high OPC replacement was required, typically 75% to control the product hydration exotherm. Based on initial studies BFS/OPC was selected as the reference cement system for developing the Magnox encapsulation process. Extensive development work then showed that the Magnox swarf could successfully be encapsulated in BFS/OPC systems. It was necessary to control the physical and chemical composition of the BFS and OPC powders to satisfy process and product requirements for the encapsulation of Magnox swarf.

OUTLOOK

The cement industry was expected to continue to focus on increasing the profitability of the industry by not substantially increasing capacity and by trimming plant operating and personnel costs. The cement industry was expected to propose price increases following a decade of flat or decreased prices.

The cement industry would continue to invest in downstream industries, such as ready-mix concrete, and other construction industries. In addition, the cement industry would continue to acquire interests in industries dealing with admixtures into cement, such as fly ash and slag, as well as companies supplying wastes as fuel to cement kilns. (See Industry section of this report.)

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TABLE 1
SALIENT CEMENT STATISTICS

(Thousand short tons unless otherwise specified)

		1988	1989	1990	1991	1992
United States:[1]						
Production[2]		76,867	77,189	77,111	73,585	77,354
Shipments from mills[2 3]		89,460	86,238	86,200	74,481	77,073
Value[2 3 4]	thousands	$4,370,463	$4,242,931	$4,280,105	$3,704,996	$3,823,699
Average value per ton[2 3 4]		$48.85	$49.20	$49.65	$49.74	$49.61
Stocks at mills,[2] Dec. 31		5,997	6,300	6,214	6,382	6,057
Exports		101	512	554	698	823
Imports for consumption		r17,488	r15,741	r13,273	8,701	6,797
Consumption, apparent[5 6]		93,256	90,676	89,623	79,484	82,075
World: Production		r1,232,686	r1,266,064	r1,265,514	1,311,590	e1,382,107

eEstimated. rRevised.
[1]Excludes Puerto Rico and the U.S. Virgin Islands.
[2]Portland and masonry cement only.
[3]Includes imported cement shipped by domestic producers.
[4]Value received, f.o.b. mill, excluding cost of containers.
[5]Quantity shipped plus imports minus exports.
[6]Adjusted to eliminate duplication of imported clinker and cement shipped by domestic cement manufacturers.

TABLE 2

PORTLAND CEMENT PRODUCTION, CAPACITY, AND STOCKS IN THE UNITED STATES, BY DISTRICT[1]

District	1991					1992				
	Plants active during year	Production[4] (thousand short tons)	Capacity[2]		Stocks[3] at mills, Dec. 31 (thousand short tons)	Plants active during year	Production[4] (thousand short tons)	Capacity[2]		Stocks[3] 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	r2,859	4,315	66.2	289	5	3,176	4,405	72.0	269
Pennsylvania, eastern	8	3,818	r5,271	r72.4	359	8	4,215	5,271	79.9	390
Pennsylvania, western	4	r1,567	2,395	r65.4	147	4	1,649	2,195	75.1	168
Maryland	3	r1,610	1,980	r81.3	r197	3	1,664	2,030	81.9	207
Ohio	4	r1,401	r2,200	r63.6	r83	4	1,456	2,200	66.1	83
Michigan	5	r5,016	r6,071	r82.6	r383	5	5,402	6,305	85.6	392
Indiana	4	2,296	3,090	74.2	312	4	2,432	3,090	78.7	195
Illinois	4	r2,694	r3,150	r85.5	r241	4	2,792	3,160	88.3	191
Georgia and Tennessee	4	r1,944	r2,615	r74.3	r231	4	1,942	2,615	74.2	220
South Carolina	3	r2,149	3,340	r64.3	r106	3	2,281	3,330	68.4	92
Kentucky, Virginia, West Virginia	3	2,019	r3,080	r65.5	213	3	2,099	3,080	68.1	205
Florida	6	2,806	5,125	54.7	r249	6	2,937	5,225	56.2	263
Alabama	5	r3,739	r5,404	r69.1	r218	5	3,337	4,130	80.7	69
Arkansas and Mississippi	3	r1,175	r2,235	r52.5	r64	3	1,371	2,025	67.7	238
South Dakota	1	W	W	W	W	1	W	W	W	W
Iowa	4	r2,415	r3,350	r72.0	r324	4	2,618	3,350	78.1	248
Missouri	5	r4,276	r5,250	r81.4	r376	5	4,512	5,013	90.0	394
Kansas	4	r1,763	r2,550	r69.1	r172	4	1,512	1,950	77.6	151
Oklahoma	3	r1,366	r2,095	r65.2	r166	3	1,389	1,925	72.1	139
Texas, northern	6	3,203	4,968	64.4	214	6	3,401	4,968	68.4	251
Texas, southern	6	r4,034	r4,793	r84.1	r183	6	4,434	5,913	74.9	162
Idaho, Montana, Utah	5	r1,807	r2,080	r86.9	r79	5	1,838	1,929	95.3	67
Colorado, Nebraska, Wyoming	5	2,201	r3,920	r56.1	r244	5	2,627	3,744	70.2	145
Alaska, Oregon, Washington	4	W	W	W	W	4	W	W	W	W
Arizona, Nevada, New Mexico	4	1,810	r3,282	r56.9	116	4	2,004	3,282	61.0	138
California, northern	3	r2,668	3,175	r84.0	r205	3	2,673	3,175	84.1	168
California, southern	8	r6,439	r8,094	r79.5	r319	8	6,331	8,155	77.6	288
Hawaii	1	555	600	r92.5	27	1	571	600	95.1	35
Total or average	120	r70,729	r97,697	r72.2	r5,936	120	74,261	96,495	78.4	5,604
Puerto Rico	2	1,402	2,156	65.0	r44	2	1,432	1,880	76.2	26

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Total or average."

[1]Includes 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 1991-92) as follows: Alaska (1), Florida (2), Iowa (1), Michigan (1), Pennsylvania (1), and Texas (2).

[2]Grinding capacity based on fineness necessary to grind Types I and II cement, making allowance for downtime required for maintenance.

[3]Includes imported cement. Source of imports withheld to avoid disclosing company proprietary data.

[4]Includes cement produced from imported clinker (1991—1,759,197 tons, 1992—2,056,394) tons.

TABLE 3

CLINKER CAPACITY AND PRODUCTION IN THE UNITED STATES,[1] BY DISTRICT

District	Active plants: Process used: Wet	Dry	Both	Total	Number of kilns	Daily capacity (thousand short tons)	Average number of days maintenance	Apparent annual capacity[2] (thousand short tons)	Production[3] (thousand short tons)	Percent utilized
1991:										
New York and Maine	4	1	—	5	6	10	90	3,341	2,825	84.6
Pennsylvania, eastern	2	5	—	7	16	16	75	4,651	3,737	80.3
Pennsylvania, western	3	1	—	4	8	6	64	1,808	1,608	88.9
Maryland	1	2	—	3	7	6	36	1,976	1,754	88.8
Ohio	2	1	—	3	5	4	38	2,103	1,360	64.7
Michigan	2	2	—	4	9	10	49	5,142	4,371	85.0
Indiana	2	2	—	4	8	9	62	2,732	2,448	89.6
Illinois	—	4	—	4	8	8	53	2,496	2,541	101.8
Georgia and Tennessee	1	2	1	4	7	7	29	2,355	1,851	78.6
South Carolina	2	1	—	3	7	8	66	2,395	2,276	95.0
Kentucky, Virginia, West Virginia	1	2	—	3	9	19	78	5,468	1,973	36.1
Florida	2	2	—	4	8	11	26	3,758	2,536	67.5
Alabama	—	5	—	5	6	13	53	4,068	3,671	90.2
Arkansas and Mississippi	3	—	—	3	6	5	41	1,620	1,244	76.8
Iowa	—	4	—	4	4	9	119	2,458	2,314	94.1
Missouri	2	3	—	5	7	11	50	4,573	4,359	95.3
Kansas	2	2	—	4	11	6	71	1,764	1,538	87.2
Oklahoma	1	2	—	3	7	6	57	1,852	1,381	74.6
Texas, northern	3	3	—	6	14	14	47	4,462	3,317	74.3
Texas, southern	1	4	1	6	6	14	47	4,456	3,944	88.5
Idaho, Montana, Utah	4	1	—	5	7	6	150	2,085	1,955	93.8
Colorado, Nebraska, Wyoming, South Dakota	1	4	1	6	11	12	80	3,532	2,855	80.8
Alaska, Oregon, Washington	1	1	—	2	2	3	195	950	886	93.3
Arizona, Nevada, New Mexico	—	4	—	4	11	9	34	3,153	1,930	61.2
California, northern	—	3	—	3	3	10	15	2,699	2,659	98.5
California, southern	—	8	—	8	17	23	96	7,434	6,356	85.5
Hawaii	—	1	—	1	1	1	57	234	222	94.9
Total or average[4]	40	70	3	113	211	256	58	83,565	67,911	81.3
Puerto Rico	—	1	1	2	9	9	38	2,951	1,444	48.9
1992:										
New York and Maine	4	1	—	5	6	12	93	3,268	3,058	93.6
Pennsylvania, eastern	2	5	—	7	16	16	71	4,712	4,186	88.8
Pennsylvania, western	3	1	—	4	8	5	47	1,975	1,687	85.4
Maryland	1	2	—	3	7	6	37	1,968	1,557	79.1
Ohio	2	1	—	3	5	5	37	1,821	1,304	71.6
Michigan	2	2	—	4	9	14	41	4,537	4,241	93.5
Indiana	2	2	—	4	8	9	58	2,765	2,408	87.1
Illinois	—	4	—	4	8	8	48	2,543	2,661	104.6
Georgia and Tennessee	1	2	1	4	7	7	22	2,405	1,894	78.8
South Carolina	2	1	—	3	7	8	62	2,429	2,210	91.0
Kentucky, Virginia, West Virginia	1	2	—	3	9	8	25	2,726	2,061	75.6
Florida	2	2	—	4	8	11	58	3,385	2,743	81.0
Alabama	—	5	—	5	6	3	82	3,359	3,272	97.4

See footnotes at end of table.

TABLE 3—Continued

CLINKER CAPACITY AND PRODUCTION IN THE UNITED STATES,[1] BY DISTRICT

District	Active plants			Total	Number of kilns	Daily capacity (thousand short tons)	Average number of days maintenance	Apparent annual capacity[2] (thousand short tons)	Production[3] (thousand short tons)	Percent utilized
	Process used									
	Wet	Dry	Both							
1992—Continued:										
Arkansas and Mississippi	2	—	—	2	4	5	61	1,522	1,309	86.0
Iowa	—	3	—	3	4	8	57	2,464	2,348	95.3
Missouri	2	3	—	5	7	15	62	4,610	4,449	96.5
Kansas	2	2	—	4	11	6	75	1,744	1,552	89.0
Oklahoma	1	2	—	3	7	6	61	1,828	1,386	75.8
Texas, northern	3	3	—	6	14	14	42	4,525	3,573	79.0
Texas, southern	1	4	1	6	6	14	46	4,477	4,127	92.2
Idaho, Montana, Utah	4	1	—	5	7	3	88	1,741	1,721	98.9
Colorado, Nebraska, Wyoming, South Dakota	1	4	1	6	11	9	30	3,848	3,062	79.6
Alaska, Oregon, Washington	1	2	—	3	3	3	98	1,495	1,103	73.8
Arizona, Nevada, New Mexico	—	4	—	4	11	9	34	2,981	1,800	60.4
California, northern	—	3	—	3	3	10	86	2,795	2,640	94.5
California, southern	—	8	—	8	17	24	78	6,911	5,979	86.5
Hawaii	—	1	—	1	1	1	153	212	215	101.4
Total or average[4]	39	70	3	112	210	239	63	79,046	68,546	86.7
Puerto Rico	—	1	1	2	7	8	73	2,603	1,353	52.0

[1]Includes Puerto Rico and white cement-producing facilities.
[2]Calculated on individual company data; 365 days minus average days for maintenance times the reported 24-hour capacity.
[3]Includes production reported for plants that added or shut down kilns during the year.
[4]Data may not add to totals shown because of independent rounding.

TABLE 4

RAW MATERIALS USED IN PRODUCING PORTLAND CEMENT IN THE UNITED STATES[1]

(Thousand short tons)

Raw materials	1990	1991	1992
Calcareous:			
Limestone (includes aragonite, marble, chalk)	86,098	76,726	78,422
Cement rock (includes marl)	20,239	21,971	26,457
Coral	1,128	1,738	2,712
Other	17	10	34
Argillaceous:			
Clay	4,661	5,066	4,673
Shale	4,447	4,565	4,465
Other (includes staurolite, bauxite, aluminum dross, alumina, volcanic material, other)	565	389	347
Siliceous:			
Sand and calcium silicate	1,839	1,952	2,138
Sandstone, quartzite, other	770	582	613
Ferrous: Iron ore, pyrites, millscale, other iron-bearing material	1,031	1,004	987
Other:			
Gypsum and anhydrite	3,858	3,676	3,919
Blast furnace slag	168	101	96
Fly ash	696	763	1,064
Other, n.e.c.	317	435	539
Total	[2]125,835	118,978	126,466

[1]Includes Puerto Rico.

[2]Data do not add to total shown because of independent rounding.

TABLE 5

MASONRY CEMENT PRODUCTION AND STOCKS IN THE UNITED STATES, BY DISTRICT

District	1991			1992		
	Plants active during year	Production (thousand short tons)	Stocks[1] at mills, Dec. 31 (thousand short tons)	Plants active during year	Production (thousand short tons)	Stocks[1] at mills, Dec. 31 (thousand short tons)
New York and Maine	4	97	16	4	97	21
Pennsylvania, eastern	6	197	47	6	224	47
Pennsylvania, western	4	91	14	4	104	14
Maryland	2	W	W	2	W	W
Ohio	3	110	13	3	122	25
Michigan	5	223	43	5	235	44
Indiana	4	323	63	4	366	52
Illinois	1	W	W	1	W	W
Georgia and Tennessee	4	154	24	4	163	28
South Carolina	2	W	W	2	W	W
Kentucky, Virginia, West Virginia	4	219	27	4	225	26
Florida	4	332	32	4	337	29
Alabama	4	211	32	4	262	31
Arkansas and Mississippi	2	W	W	2	W	W
South Dakota	1	W	W	1	W	W
Iowa	2	W	W	2	W	W
Missouri	3	100	11	3	103	10
Kansas	4	37	20	4	22	15
Oklahoma	2	W	W	2	W	W
Texas, northern	4	83	9	4	105	9
Texas, southern	4	70	8	4	83	8
Idaho, Montana, Utah	4	11	W	4	10	47
Colorado, Nebraska, Wyoming	3	W	W	3	27	4
Arizona, Nevada, New Mexico	3	53	8	3	45	5
California, southern	2	W	W	2	W	W
Hawaii	1	10	2	1	7	4
Total or average[2]	82	2,856	446	82	3,093	453

W Withheld to avoid disclosing company proprietary data; included in "Total or average."

[1]Includes imported cement.

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

TABLE 6

SHIPMENTS OF PORTLAND CEMENT FROM MILLS IN THE UNITED STATES,[1] IN BULK AND IN CONTAINERS, BY TYPE OF CARRIER

(Thousand short tons)

Type of carrier	Shipments from plant to terminal		Shipments to ultimate consumer				
			From terminal to consumer		From plant to consumer		Total shipments[2]
	In bulk	In containers	In bulk	In containers	In bulk	In containers	
1991:							
Railroad	10,635	44	1,157	3	3,973	78	5,211
Truck	3,143	464	18,794	494	42,006	2,883	64,177
Barge and boat	8,791	25	418	—	461	—	879
Unspecified[3]	2,338	9	2,175	1	579	24	2,779
Total[2]	24,907	542	22,544	498	47,019	2,985	[4]73,046
1992:							
Railroad	10,576	70	1,453	—	2,689	406	4,548
Truck	3,622	138	18,913	398	43,060	1,966	64,337
Barge and boat	9,075	9	2,043	—	582	—	2,624
Unspecified[3]	2,371	9	2,060	15	1,862	66	4,003
Total[2]	25,644	226	24,469	413	48,193	2,438	[5]75,513

[1]Includes Puerto Rico.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes cement used at plant.
[4]Bulk shipments were 95.2% and container (bag) shipments were 4.8%.
[5]Bulk shipments were 96.2% and container (bag) shipments were 3.8%.

TABLE 7

PORTLAND CEMENT SHIPPED BY PRODUCERS IN THE UNITED STATES, BY DISTRICT[1]

District	1991			1992		
	Quantity (thousand short tons)	Value (thousands)	Average per ton	Quantity (thousand short tons)	Value (thousands)	Average per ton
New York and Maine	2,650	$147,183	$55.54	3,123	$145,977	$46.74
Pennsylvania, eastern	3,674	181,597	r49.42	3,948	180,307	45.67
Pennsylvania, western	r1,551	r75,972	r48.98	1,581	78,580	49.70
Maryland	r1,643	r79,882	r48.61	1,669	84,191	50.44
Ohio	r1,363	r74,074	r54.34	1,455	77,053	52.96
Michigan	r5,019	r238,675	r47.55	5,509	262,063	47.57
Indiana	2,092	97,558	46.63	2,466	110,737	44.91
Illinois	r2,668	r104,498	r39.16	2,860	118,982	41.60
Georgia and Tennessee	2,109	r97,393	r46.17	2,134	97,092	45.50
South Carolina	r2,157	r94,682	r43.89	2,296	93,726	40.82
Kentucky, Virginia, West Virginia	2,007	102,455	51.05	2,057	136,621	66.42
Florida	3,169	166,874	52.65	3,195	161,969	50.69
Alabama	r3,806	r166,202	r43.67	4,103	180,763	44.06
Arkansas and Mississippi	r1,257	r52,112	r41.45	1,450	60,313	41.60
Iowa	r2,477	r104,287	r42.10	2,824	116,477	41.25
Missouri	r4,100	r168,322	r41.06	4,725	196,073	41.50
Kansas	r1,756	r80,732	r45.97	1,710	79,464	46.47
Oklahoma	r999	r38,570	r38.60	1,026	39,280	38.28
Texas, northern	3,060	147,655	48.25	3,096	142,874	46.15
Texas, southern	r4,148	r146,339	r35.28	4,444	220,564	49.63
Idaho, Montana, Utah	r1,599	r97,834	r61.18	1,783	110,525	61.99
Colorado, Nebraska, South Dakota, Wyoming	r2,690	r133,378	r49.59	3,452	184,243	53.37
Alaska, Oregon, Washington	1,407	98,091	69.69	1,407	97,738	69.47
Arizona, Nevada, New Mexico	1,907	r109,200	57.26	1,949	102,589	52.64
California, northern	r2,519	r149,937	r59.53	2,181	134,337	61.59
California, southern	r6,224	r349,654	r56.18	5,854	293,679	50.17
Hawaii	556	53,300	r95.86	573	53,936	94.13
Total[2 3] or average	r68,607	r3,356,456	r48.92	72,870	3,560,153	48.86
Foreign imports[4]	r3,044	r152,850	r50.21	1,213	60,869	50.18
Puerto Rico	1,395	r114,099	81.77	1,431	119,643	83.61
Grand total[3 5] or average	r73,046	r3,623,406	49.60	75,513	3,740,665	49.54
Grand total thousand metric tons	r66,266	XX	XX	68,504	XX	XX

rRevised. XX Not applicable.

[1]Includes 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 1991-92) as follows: Alaska (1), California (1), Florida (2), Iowa (1), Michigan (1), Ohio (1), and Texas (1).

[2]Includes cement produced from imported clinker.

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

[4]Cement imported and distributed by domestic producers only.

[5]Does not include cement consumed at plant.

TABLE 8

MASONRY CEMENT SHIPPED BY PRODUCERS IN THE UNITED STATES,[1] BY DISTRICT

District	1991			1992		
	Quantity (thousand short tons)	Value (thousands)	Average per ton[2]	Quantity (thousand short tons)	Value (thousands)	Average per ton[2]
New York and Maine	103	r$5,239	r$50.86	95	$6,300	$65.98
Pennsylvania, eastern	197	13,629	69.23	229	15,665	68.51
Pennsylvania, western	88	7,243	81.90	97	7,976	64.52
Maryland	W	W	W	W	W	W
Ohio	r116	r10,862	r93.63	113	10,260	90.41
Michigan	r225	r19,829	r88.28	234	20,381	86.97
Indiana	310	22,263	71.86	371	24,822	66.94
Illinois	W	W	W	W	W	W
Georgia and Tennessee	161	r10,395	r64.54	164	10,628	64.78
South Carolina	W	W	W	W	W	W
Kentucky, Virginia, West Virginia	189	13,203	69.83	196	12,390	63.09
Florida	333	21,218	63.77	342	22,424	65.56
Alabama	r235	r14,105	r59.97	213	13,069	61.49
Arkansas and Mississippi	W	W	W	W	W	W
Iowa	6	533	88.83	50	W	W
Missouri	r92	4,550	r49.43	99	4,726	47.86
Kansas	r37	r1,723	r47.14	34	1,914	57.06
Oklahoma	W	W	W	W	W	W
Texas, northern	53	4,566	86.04	71	6,052	85.84
Texas, southern	71	4,250	59.54	83	5,065	60.98
Idaho, Montana, Utah	5	271	r54.20	5	270	54.00
Colorado, Nebraska, Wyoming, South Dakota	r30	r1,712	r57.07	32	1,782	55.70
Alaska, Oregon, Washington	W	W	W	W	W	W
Arizona, Nevada, New Mexico	51	r2,828	r55.93	47	2,633	55.54
California, southern	W	W	W	W	W	W
Hawaii	9	1,770	190.67	8	1,421	186.86
Total[3] or average	r2,802	r193,465	r69.05	2,932	197,727	67.44
Foreign imports[4]	28	2,224	78.12	58	4,950	85.34
Grand total[3] or average	r2,830	r195,689	r69.15	2,990	202,677	67.78
Grand total[3] thousand metric tons	2,567	XX	XX	2,712	XX	XX

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Total or average." XX Not applicable.

[1]Does not include quantities produced on the job by masons.

[2]Calculated on unrounded data.

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

[4]Cement imported and distributed by domestic producers only. Source of imports withheld to avoid disclosing company proprietary data.

TABLE 9
CEMENT SHIPMENTS, BY DESTINATION AND ORIGIN[1]

(Thousand short tons)

Destination and origin	Portland cement			Masonry cement		
	1990	1991	1992	1990	1991	1992
Destination:						
Alabama	1,500	1,317	1,430	125	104	117
Alaska	144	98	112	W	W	W
Arizona	1,971	1,744	1,843	W	W	W
Arkansas	803	742	872	43	43	50
California, northern	3,961	3,270	3,060	W	W	W
California, southern	7,702	5,966	5,732	W	W	W
Colorado	1,114	1,297	1,946	13	14	17
Connecticut[2]	707	659	656	17	13	14
Delaware[2]	258	193	257	14	9	9
District of Columbia[2]	247	191	100	(3)	(3)	(3)
Florida	6,210	5,173	5,429	491	372	390
Georgia	2,730	2,332	2,450	189	159	174
Hawaii	533	547	566	12	9	8
Idaho	354	341	412	1	(3)	(3)
Illinois	1,354	1,363	1,466	27	23	25
Chicago, metropolitan[2]	2,287	1,987	2,205	65	52	57
Indiana	1,867	1,766	1,960	100	88	100
Iowa	1,362	1,309	1,540	15	12	14
Kansas	1,156	1,166	1,211	16	15	15
Kentucky	1,139	1,074	1,263	88	77	92
Louisiana[2]	1,867	1,787	1,716	38	37	46
Maine	272	243	274	7	5	7
Maryland	1,540	1,169	1,114	137	91	83
Massachusetts[2]	1,008	831	971	29	24	26
Michigan	2,702	2,285	2,415	135	111	129
Minnesota[2]	1,630	1,448	1,574	45	34	39
Mississippi	766	702	802	43	40	48
Missouri	1,949	1,760	2,164	43	40	39
Montana	188	185	254	1	(3)	(3)
Nebraska	868	853	891	11	10	11
Nevada	1,225	987	1,086	1	(3)	(3)
New Hampshire[2]	254	219	237	8	7	7
New Jersey[2]	1,635	1,267	1,471	62	49	55
New Mexico	540	551	625	5	5	6
New York, eastern	593	528	592	32	27	27
New York, western	1,024	895	873	50	41	42
New York, metropolitan[2]	1,496	1,194	957	48	48	39
North Carolina[2]	2,065	1,865	1,994	245	217	232
North Dakota[2]	201	173	294	2	3	4
Ohio	3,455	3,113	3,191	190	162	173
Oklahoma	999	1,178	1,099	30	30	34
Oregon	868	893	852	(3)	(3)	(3)
Pennsylvania, eastern	2,061	1,823	1,914	82	64	62
Pennsylvania, western	1,276	1,252	1,308	79	71	81

See footnotes at end of table.

TABLE 9—Continued

CEMENT SHIPMENTS, BY DESTINATION AND ORIGIN[1]

(Thousand short tons)

Destination and origin	Portland cement			Masonry cement		
	1990	1991	1992	1990	1991	1992
Destination—Continued:						
Rhode Island[2]	164	142	139	6	4	4
South Carolina	1,163	1,001	1,013	128	109	108
South Dakota	299	273	344	7	5	5
Tennessee	1,649	1,525	1,545	158	134	157
Texas, northern	3,316	3,308	3,671	80	75	114
Texas, southern	4,152	3,757	3,973	2	82	75
Utah	763	788	903	4	3	3
Vermont[2]	119	107	112	205	4	4
Virginia	2,132	1,634	1,653	9	145	144
Washington	1,814	1,752	1,787	34	8	8
West Virginia	444	414	462	46	28	33
Wisconsin	1,793	1,747	1,971	1	39	44
Wyoming	258	249	234	1	3	1
U.S. total[4]	85,948	76,433	80,987	3,300	2,753	2,975
Foreign countries[5]	240	243	333	83	57	54
Puerto Rico	1,487	1,382	1,426	—	—	—
Total shipments[4]	87,675	78,058	82,746	3,383	2,810	3,029
Total shipments thousand metric tons	79,537	70,813	75,066	3,069	2,549	2,748
Origin:						
United States[6]	75,106	70,293	75,403	3,142	2,629	2,840
Puerto Rico	1,276	1,382	1,426	—	—	—
Foreign:[7]						
Domestic producers	7,288	5,000	5,917	225	181	189
Others	4,005	1,383	—	16	—	—
Total shipments[4]	87,675	78,058	82,746	3,383	2,810	3,029
Total shipments thousand metric tons	79,537	70,813	75,066	3,069	2,549	2,748

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

[1]Includes cement produced from imported clinker and imported cement shipped by domestic producers, Canadian cement manufacturers, and other importers. Includes Puerto Rico.

[2]Has no cement-producing plants.

[3]Less than 1/2 unit.

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

[5]Direct shipments by producers to foreign countries and U.S. possessions and territories; includes States indicated by the symbol W.

[6]Includes cement produced from imported clinker by domestic producers.

[7]Imported cement distributed by domestic producers, Canadian cement manufacturers, and other importers. Origin of imports withheld to avoid disclosing company proprietary data.

TABLE 10

CEMENT SHIPMENTS,[1] BY DESTINATION (REGION AND SUBREGION)

Region and subregion[2]	Portland cement				Masonry cement			
	Quantity (thousand short tons)		Percent of grand total		Quantity (thousand short tons)		Percent of grand total	
	1991	1992	1991	1992	1991	1992	1991	1992
Northeast:								
New England	2,201	2,389	3	3	58	62	2	2
Middle Atlantic	6,959	7,116	9	9	302	306	11	10
Total[3]	9,160	9,505	12	12	360	368	13	12
South:								
Atlantic	13,972	14,473	18	18	1,131	1,173	41	39
East Central	4,618	5,041	6	6	356	414	13	14
West Central	10,772	11,331	14	14	267	319	10	11
Total[3]	29,362	30,845	38	38	1,754	1,906	64	64
Midwest:								
East	12,261	13,208	16	16	476	528	17	18
West	6,982	8,018	9	10	119	126	4	4
Total	19,243	21,226	25	26	596	654	21	22
West:								
Mountain	6,142	7,303	8	9	26	28	1	1
Pacific	12,526	12,109	16	15	17	16	1	1
Total[4]	18,668	19,412	24	24	43	44	2	2
Grand total[3]	76,433	80,987	100	100	2,753	2,975	100	100

[1]Includes imported cement shipped by importers.
[2]Geographic regions as designated by the U.S. Department of Commerce, Bureau of the Census.
[3]Data may not add to totals shown because of independent rounding.
[4]Does not include proprietary data from table 9.

TABLE 11

PORTLAND CEMENT SHIPMENTS, BY DISTRICT OF ORIGIN AND TYPE OF CUSTOMER[1]

District of origin	Building material dealers		Concrete product manufacturers		Ready-mixed concrete		Highway contractors		Other contractors		Federal, State and other government agencies		Miscellaneous including own use		Total[2] (thousand short tons)
	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	
1991:															
New York and Maine	132	5.0	351	13.2	1,975	74.5	66	2.5	87	3.3	14	0.5	24	0.9	2,650
Pennsylvania, eastern	256	7.0	772	21.0	2,407	65.5	84	2.3	66	1.8	25	.6	64	1.7	3,674
Pennsylvania, western	130	8.4	192	12.4	1,006	64.9	176	11.3	19	1.2	—	—	28	1.8	1,551
Maryland	83	5.1	284	17.3	1,197	72.9	22	1.3	22	1.3	23	1.3	11	.7	1,643
Ohio	65	4.8	101	7.4	1,084	79.5	101	7.4	6	.4	—	—	6	.4	1,363
Michigan	216	4.3	609	12.1	3,707	73.9	323	6.4	74	1.5	7	.1	83	1.7	5,019
Indiana	74	3.5	218	10.4	1,656	79.2	100	4.8	29	1.4	—	—	16	.8	2,092
Illinois	113	4.2	258	9.7	1,674	62.7	140	5.2	11	.4	11	.4	461	17.3	2,668
Georgia and Tennessee	79	3.7	338	16.0	1,574	74.6	80	3.8	34	1.6	—	—	4	.2	2,109
South Carolina	63	2.9	358	16.6	1,591	73.8	89	4.1	19	.9	—	—	37	1.7	2,157
Kentucky, Virginia, West Virginia	82	4.1	271	13.5	1,488	74.1	90	4.5	25	1.2	—	—	50	2.5	2,007
Florida	272	8.6	552	17.4	2,020	63.7	111	3.5	70	2.2	1	—	144	4.5	3,169
Alabama	280	7.4	457	12.0	2,260	59.4	178	4.7	92	2.4	166	4.3	373	9.8	3,806
Arkansas and Mississippi	53	4.2	137	10.9	794	63.2	159	12.6	66	5.3	9	.7	39	3.1	1,257
Iowa	68	2.7	550	22.2	1,623	65.5	167	6.7	36	1.5	3	.1	30	1.2	2,477
Missouri	46	1.1	250	6.1	3,231	78.8	447	10.9	126	3.1	—	—	—	—	4,100
Kansas	87	5.0	100	5.7	1,227	69.9	118	6.7	78	4.4	4	.2	142	8.1	1,756
Oklahoma	48	4.8	80	8.0	606	60.7	33	3.3	179	17.9	48	4.8	5	.5	999
Texas, northern	121	4.0	270	8.8	1,484	48.5	235	7.7	258	8.4	64	2.0	628	20.5	3,060
Texas, southern	183	4.4	312	7.5	2,872	69.2	240	5.8	99	2.4	21	.5	421	10.1	4,148
Idaho, Montana, Utah	39	2.4	144	9.0	1,106	69.2	98	6.1	109	6.8	6	.1	97	6.1	1,599
Colorado, Nebraska, Wyoming, South Dakota	64	2.4	313	11.6	1,961	72.9	221	8.2	52	1.9	12	.7	67	2.5	2,690
Alaska, Oregon, Washington	71	5.0	505	35.9	600	42.6	76	5.4	126	9.0	8	.1	21	1.5	1,407
Arizona, Nevada, New Mexico	43	2.3	294	15.4	1,217	63.8	116	6.1	201	10.5	—	—	36	1.9	1,907
California, northern	123	4.9	251	10.0	1,962	77.9	20	.8	35	1.4	1	—	127	5.0	2,519
California, southern	320	5.1	979	15.7	4,493	72.2	22	.4	317	5.1	9	.1	84	1.3	6,224
Hawaii	29	5.2	51	9.2	465	83.6	1	.2	11	2.0	—	—	—	—	556
Foreign imports[3]	—	—	261	8.6	2,426	79.7	—	—	—	—	—	—	357	11.7	3,044
Total[2] or average	3,140	4.4	9,258	12.9	49,706	69.4	3,513	4.9	2,247	3.1	432	.6	3,355	4.7	71,651
Puerto Rico	563	40.4	112	8.0	645	46.2	—	—	42	3.0	33	2.3	—	—	1,395
1992:															
New York and Maine	158	5.1	247	7.9	2,556	81.8	106	3.4	31	1.0	—	—	25	.8	3,123
Pennsylvania, eastern	298	7.5	822	20.8	2,568	65.0	99	2.5	71	1.8	30	.7	61	1.5	3,948
Pennsylvania, western	138	8.7	188	11.9	1,010	63.9	202	12.8	7	.4	15	.9	21	1.3	1,581
Maryland	89	5.3	320	19.2	1,196	71.7	19	1.1	33	2.0	—	—	12	.7	1,669
Ohio	84	5.8	127	8.7	1,049	72.1	126	8.7	48	3.3	—	—	21	1.4	1,455

See footnotes at end of table.

TABLE 11—Continued

PORTLAND CEMENT SHIPMENTS BY DISTRICT OF ORIGIN AND TYPE OF CUSTOMER[1]

District of origin	Building material dealers		Concrete product manufacturers		Ready-mixed concrete		Highway contractors		Other contractors		Federal, State and other government agencies		Miscellaneous including own use		Total[2] (thousand short tons)
	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	
1992—Continued:															
Michigan	370	6.7	464	8.4	3,869	70.2	506	9.2	201	3.6	—	—	98	1.8	5,509
Indiana	84	3.4	263	10.7	1,929	78.2	138	5.6	35	1.4	—	—	16	.6	2,466
Illinois	116	4.1	286	10.0	1,870	65.4	89	3.1	12	.4	12	0.4	476	16.6	2,860
Georgia and Tennessee	150	7.0	260	12.2	1,570	73.6	89	4.2	49	2.3	1	—	14	.7	2,134
South Carolina	57	2.5	434	18.9	1,625	70.8	78	3.4	61	2.7	1	—	41	1.8	2,296
Kentucky, Virginia, West Virginia	77	3.7	267	13.0	1,535	74.6	96	4.7	35	1.7	—	—	48	2.3	2,057
Florida	274	8.6	490	15.3	2,132	66.7	85	2.7	81	2.5	6	.1	126	3.9	3,195
Alabama	168	4.1	401	9.8	3,015	73.5	197	4.8	71	1.7	193	5.8	57	1.4	4,103
Arkansas and Mississippi	58	4.0	146	10.1	904	62.3	222	15.3	73	5.0	10	.6	36	2.5	1,450
Iowa	135	4.8	517	18.3	1,760	62.3	256	9.1	86	3.0	—	—	70	2.5	2,824
Missouri	34	.7	447	9.5	3,561	75.4	468	9.9	179	3.8	35	.7	—	—	4,725
Kansas	83	4.9	97	5.7	1,189	69.5	121	7.1	50	2.9	4	.2	167	9.8	1,710
Oklahoma	52	5.1	85	8.3	592	57.7	36	3.5	201	19.6	54	5.2	5	.5	1,026
Texas, northern	120	3.9	252	8.1	1,791	57.8	326	10.5	235	7.6	16	.5	356	11.5	3,096
Texas, southern	256	5.8	350	7.9	3,183	71.6	152	3.4	89	2.0	25	.5	391	8.8	4,444
Idaho, Montana, Utah	36	2.0	160	9.0	1,278	71.7	112	6.3	92	5.2	—	—	104	5.8	1,783
Colorado, Nebraska, Wyoming, South Dakota	78	2.3	428	12.4	2,260	65.5	447	12.9	100	2.9	15	.1	123	3.6	3,452
Alaska, Oregon, Washington	43	3.1	91	6.5	1,015	72.1	104	7.4	88	6.3	—	—	65	4.6	1,407
Arizona, Nevada, New Mexico	64	3.3	340	17.4	1,220	62.6	50	2.6	246	12.6	—	—	29	1.5	1,949
California, northern	117	5.4	213	9.8	1,704	78.1	16	.7	23	1.1	—	—	108	5.0	2,181
California, southern	353	6.0	784	13.4	4,354	74.4	44	.8	253	4.3	41	.7	25	.4	5,854
Hawaii	29	5.1	53	9.2	479	83.6	1	.2	11	1.9	—	—	—	—	573
Foreign imports[3]	73	6.0	102	8.4	631	52.0	36	3.0	15	1.2	—	—	356	29.3	1,213
Total[2] or average	3,594	4.9	8,634	11.7	51,845	70.0	4,221	5.7	2,476	3.3	458	.6	2,851	3.8	74,083
Puerto Rico	319	38.2	93	11.1	397	47.6	—	—	21	2.5	3	.3	—	—	1,431

[1]Includes Puerto Rico.

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

[3]Cement imported and distributed by domestic producers only. Source of imports withheld to avoid disclosing company proprietary data.

TABLE 12

PORTLAND CEMENT SHIPPED FROM PLANTS IN THE UNITED STATES,[1] BY TYPE

Type	1991			1992		
	Quantity (thousand short tons)	Value[2] (thousands)	Average per ton	Quantity (thousand short tons)	Value[2] (thousands)	Average per ton
General use and moderate heat (Types I and II)	66,725	$3,253,593	$48.76	68,874	$3,339,854	$48.49
High-early-strength (Type III)	2,558	130,417	50.98	2,812	147,846	52.58
Sulfate-resisting (Type V)	836	45,885	54.89	1,296	68,450	52.82
Oil well	889	42,457	47.76	921	45,506	49.41
White	367	61,766	168.30	418	70,169	167.87
Portland slag and portland pozzolan	326	16,355	50.17	315	17,109	54.31
Expansive	43	3,465	80.58	50	5,685	113.70
Miscellaneous[3]	1,302	69,470	53.36	827	46,046	55.68
Total[4 5] or average	73,046	3,623,406	49.60	75,513	3,740,665	49.54
Total thousand metric tons	66,266	XX	XX	68,504	XX	XX

XX Not applicable.
[1]Includes Puerto Rico.
[2]Mill value is the actual value of sales to customers, f.o.b. plant, less all discounts and allowances, less all freight charges to customer, less all freight charges from producing plant to distribution terminal if any, less total cost of operating terminal, if any, less cost of paper bags and pallets.
[3]Includes waterproof, low-heat (Type IV), and regulated fast-setting cement.
[4]Data may not add to totals shown because of independent rounding.
[5]Does not include cement consumed at plant.

TABLE 13

AVERAGE MILL VALUE, IN BULK, OF CEMENT IN THE UNITED STATES[1]

(Per short ton)

Year	Portland cement	Prepared masonry cement[2]	All classes of cement
1988	48.55	68.48	49.36
1989	48.93	69.08	49.71
1990	49.47	68.88	50.20
1991	49.60	69.15	50.33
1992	49.54	66.92	50.23

[1]Includes Puerto Rico. Mill value is the actual value of sales to customers, f.o.b. plant, less all discounts and allowances, less all freight charges from producing plant to distribution terminal if any, less total cost of operating terminal, if any, less cost of paper bags and pallets.
[2]Masonry cement made at cement plants only.

TABLE 14

U.S. EXPORTS OF HYDRAULIC CEMENT AND CLINKER, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1990		1991		1992	
	Quantity	Value[1]	Quantity	Value	Quantity	Value
Bahamas	12	963	82	3,020	144	5,418
Canada	449	30,569	531	33,720	591	34,712
Ghana	10	712	13	950	14	1,006
Mexico	31	2,509	25	3,286	21	3,328
Netherlands	3	274	2	417	2	336
Other[2]	49	3,279	45	4,381	51	3,920
Total	554	38,306	698	45,774	823	48,720
Total thousand metric tons	503	XX	633	XX	747	XX

XX Not applicable.

[1]F.a.s. value is the value of exports at the U.S. seaport, or border port of export, based on the transaction price, including inland freight, insurance, and other charges incurred in placing the merchandise alongside the carrier at the U.S. port of exportation. The value excludes the cost of loading.

[2]Includes 58 countries in 1990; 47 in 1991; and 59 in 1992.

Source: Bureau of the Census.

TABLE 15

U.S. IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1990			1991			1992		
	Quantity	Value		Quantity	Value		Quantity	Value	
		Customs[1]	C.i.f.[2]		Customs[1]	C.i.f.[2]		Customs[1]	C.i.f.[2]
Canada	3,216	132,138	144,317	3,127	117,757	131,992	3,304	121,992	132,003
Colombia	1,088	30,219	41,021	1,201	39,133	49,900	559	16,744	22,174
France	443	24,860	35,922	471	28,902	35,293	464	23,678	29,037
Greece	808	25,242	32,711	697	21,305	29,071	259	8,143	9,995
Japan	2,101	59,368	75,859	331	9,664	13,248	306	10,129	13,547
Korea, Republic of	87	2,150	2,949	—	—	—	—	—	—
Mexico	2,307	56,144	85,906	1,044	35,291	42,817	909	32,098	38,023
Spain	1,309	44,071	53,826	699	22,654	29,667	492	17,193	24,377
Venezuela	1,503	44,718	58,462	923	47,743	55,310	60	2,383	2,857
Other	411	20,707	22,074	208	10,837	15,279	441	17,349	25,160
Total	13,273	439,617	553,047	8,701	333,286	402,577	6,797	249,708	297,174
Total thousand metric tons	12,041	XX	XX	7,893	XX	XX	6,166	XX	XX

XX Not applicable.

[1]Customs value price actually paid or payable for merchandise when sold for exportation to the United States, excluding U.S. import duties, freight, insurance, and other charges incurred in bringing the merchandise to the United States.

[2]Cost, insurance, and freight import value represents the landed value of the merchandise at the first port of arrival in the United States. It is computed by adding "import charges" to the "customs value."

Source: Bureau of the Census.

TABLE 16

U.S. IMPORTS FOR CONSUMPTION OF CLINKER, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1990			1991			1992		
	Quantity	Value		Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Canada	524	14,698	15,091	601	15,192	16,011	1,106	28,029	28,589
Colombia	419	11,084	16,189	562	13,947	20,043	218	5,553	7,471
France	163	10,580	12,126	93	8,195	9,430	64	7,921	8,844
Greece	—	—	—	—	—	—	50	2,022	2,522
Japan	163	4,289	5,969	—	—	—	—	—	—
Mexico	87	2,455	3,175	—	—	—	[2]	2	2
Spain	57	5,112	7,008	—	—	—	—	—	—
Other	441	8,692	12,764	207	5,538	7,924	288	8,064	12,880
Total	1,854	56,910	72,322	[3]1,462	42,872	53,408	1,726	51,591	60,308
Total thousand metric tons	1,682	XX	XX	1,326	XX	XX	1,566	XX	XX

XX Not applicable.

[1]Cost, insurance, and freight.

[2]Less than 1/2 unit.

[3]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 17

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	1991			1992		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Anchorage:						
Canada	6	604	778	8	643	1,013
Colombia	—	—	—	16	492	864
Japan	61	1,954	2,775	17	1,046	1,461
Total[2]	67	2,558	3,553	40	2,181	3,338
Baltimore:						
Japan	(3)	47	61	(3)	10	13
Netherlands	(3)	52	56	(3)	131	139
United Kingdom	(3)	6	8	—	—	—
Total[2]	(3)	106	126	(3)	141	152
Boston:						
Greece	70	2,057	2,645	36	1,008	1,068
United Kingdom	(3)	1	2	—	—	—
Total[2]	70	2,059	2,647	36	1,008	1,068
Buffalo:						
Canada	708	32,465	36,436	732	36,239	39,146
Germany	—	—	—	(3)	6	6
United Kingdom	—	—	—	(3)	15	16
Total	708	32,465	36,436	732	36,260	39,168
Charleston:						
Netherlands	(3)	13	15	—	—	—
Venezuela	—	—	—	13	412	549
Total	(3)	13	15	13	412	549
Chicago:						
Japan	(3)	37	48	(3)	20	25
United Kingdom	—	—	—	(3)	11	12
Total[2]	(3)	37	48	(3)	32	38
Cleveland: Canada	224	7,057	8,982	119	3,338	4,305
Columbia-Snake: Japan	246	6,808	9,268	203	6,164	8,243
Detroit:						
Canada	527	18,097	18,908	1,091	32,400	33,124
France	(3)	7	7	—	—	—
Germany	—	—	—	(3)	1	1
United Kingdom	—	—	—	(3)	9	10
Total[2]	527	18,104	18,914	1,091	32,411	33,135
Duluth: Canada	94	2,741	3,221	100	3,224	3,795
El Paso: Mexico	123	3,833	5,160	89	3,027	4,000
Great Falls:						
Canada	121	2,604	2,805	161	3,223	3,518
Germany	(3)	4	5	(3)	9	20
United Kingdom	(3)	31	37	(3)	45	51
Total[2]	122	2,639	2,848	161	3,277	3,589

See footnotes at end of table.

TABLE 17—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	1991			1992		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Honolulu:						
Australia	—	—	—	90	2,864	4,925
Colombia	170	4,346	7,230	81	1,985	2,910
New Zealand	93	2,539	4,153	148	3,849	6,072
Total	263	6,885	11,383	319	8,698	13,907
Houston-Galveston:						
Germany	—	—	—	(3)	11	12
Japan	(3)	103	134	(3)	70	88
Total	(3)	103	134	(3)	81	100
Laredo:						
China	1	100	128	—	—	—
Hong Kong	—	—	—	1	93	117
Mexico	39	2,978	3,447	37	2,867	3,284
Total	40	3,078	3,575	38	2,960	3,401
Los Angeles:						
Australia	(3)	20	22	—	—	—
Austria	(3)	2	3	—	—	—
Colombia	103	3,478	4,320	28	826	1,058
France	189	6,333	7,877	—	—	—
Greece	148	4,515	6,946	—	—	—
Japan	(3)	58	69	(3)	43	54
Mexico	562	19,392	22,739	531	18,564	21,480
Spain	36	792	1,083	—	—	—
United Kingdom	(3)	1	2	—	—	—
Yugoslavia	(3)	11	33	—	—	—
Total[2]	1,039	34,602	43,094	560	19,434	22,592
Miami:						
Belgium	2	198	288	8	464	576
Colombia	79	2,569	3,381	168	5,615	7,197
Denmark	17	1,037	1,325	18	1,110	1,419
Honduras	—	—	—	2	55	61
Spain	115	4,973	6,707	137	5,851	7,359
United Kingdom	(3)	5	6	(3)	2	2
Venezuela	359	11,780	14,883	3	101	127
Total[2]	572	20,562	26,590	335	13,197	16,739
Minneapolis: Germany	(3)	19	20	(3)	19	23
New Orleans:						
Belgium	(3)	52	59	(3)	26	28
France	156	6,841	8,793	87	5,907	7,168
Spain	151	4,470	5,694	156	4,618	8,392
Total[2]	306	11,363	14,545	243	10,551	15,588
New York City:						
Canada	149	4,577	5,664	—	—	—
Greece	231	6,869	8,776	140	4,493	5,659

See footnotes at end of table.

TABLE 17—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	1991			1992		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]
New York City—Continued:						
Netherlands	—	—	—	(3)	57	80
Spain	135	4,952	5,948	18	1,478	1,770
United Kingdom	(3)	30	32	51	1,368	1,900
Total[2]	515	r16,428	20,420	208	7,396	9,409
Nogales: Mexico	207	6,059	7,338	250	7,479	9,059
Norfolk:						
France	63	13,892	16,273	53	7,619	8,477
Greece	151	4,810	6,054	83	2,642	3,269
Netherlands	(3)	69	78	(3)	95	107
United Kingdom	1	555	629	—	—	—
Total[2]	216	19,326	23,034	136	10,357	11,853
Ogdensburg:						
Canada	226	7,743	7,988	203	6,470	6,783
Morocco	—	—	—	1	19	20
Total	226	7,743	7,988	204	6,489	6,803
Pembina: Canada	181	4,319	5,384	80	2,348	2,813
Philadelphia:						
India	(3)	2	2	—	—	—
United Kingdom	—	—	—	(3)	38	45
Venezuela	(3)	15	18	—	—	—
Total	(3)	17	20	(3)	38	45
Portland: Canada	(3)	16	18	1	91	105
St. Albans: Canada	179	5,868	6,705	—	—	—
San Diego:						
Colombia	154	6,161	7,615	—	—	—
Mexico	113	3,030	4,132	2	161	200
Total[2]	267	9,192	11,747	2	161	200
San Francisco:						
Canada	(3)	2	2	—	—	—
Colombia	176	9,127	9,670	—	—	—
Croatia	—	—	—	(3)	4	6
France	(3)	2	2	—	—	—
Greece	96	3,054	4,650	—	—	—
Japan	—	—	—	(3)	97	115
Total[2]	273	12,185	14,324	(3)	101	121
San Juan:						
Belgium	4	310	530	5	415	680
Colombia	331	8,100	10,916	37	840	1,137
Denmark	16	1,298	2,130	15	1,146	1,911
Spain	—	—	—	(3)	4	4
Venezuela	25	571	776	—	—	—
Total[2]	377	10,279	14,352	57	2,405	3,732

See footnotes at end of table.

TABLE 17—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	1991			1992		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Savannah:						
Denmark	2	209	246	—	—	—
France	(3)	3	4	—	—	—
Italy	—	—	—	(3)	6	12
Total[2]	3	213	249	(3)	6	12
Seattle:						
Canada	712	31,844	35,104	714	31,318	34,160
China	—	—	—	21	697	941
Colombia	—	—	—	38	1,175	1,843
Japan	24	656	893	86	2,674	3,545
Total[2]	736	32,500	35,998	859	35,863	40,489
Tampa:						
Colombia	153	4,325	5,527	150	4,539	5,662
Denmark	65	4,076	5,210	70	4,365	5,463
France	63	1,823	2,335	324	10,151	13,391
Spain	262	7,465	10,234	181	5,243	6,853
Venezuela	496	16,034	19,901	3	136	177
Total[2]	1,039	33,724	43,208	729	24,435	31,546
Virgin Islands of the United States:						
Colombia	35	1,027	1,240	42	1,272	1,504
Denmark	(3)	1	1	—	—	—
Italy	2	60	83	1	38	48
Japan	—	—	—	(3)	3	4
Panama	1	41	76	2	65	75
Trinidad and Tobago	3	76	84	9	304	369
Venezuela	44	19,358	19,750	42	1,735	2,005
Total[2]	85	20,563	21,234	95	3,417	4,004
Grand total[2]	8,701	333,286	402,577	6,797	249,708	297,174
Grand total thousand metric tons	7,893	XX	XX	6,166	XX	XX

[r]Revised. XX Not applicable.
[1]Cost, insurance, and freight.
[2]Data may not add to totals shown because of independent rounding.
[3]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 18

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[1]	
	Quantity	Value (customs)	Quantity	Value (customs)	Quantity	Value (customs)	Quantity	Value (customs)
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	8,701	333,286
1992	4,722	171,584	1,726	51,591	349	26,534	6,797	249,708

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

Source: Bureau of the Census.

TABLE 19

HYDRAULIC CEMENT: WORLD PRODUCTION BY COUNTRY[1]

(Thousand short tons)

Country	1988	1989	1990	1991	1992e
Afghanistan e	110	110	r125	r125	130
Albania e	2822	2831	830	770	440
Algeria	7,931	7,517	6,985	r6,965	6,600
Angola e	1,100	1,100	1,100	1,100	1,100
Argentina	6,667	4,927	4,000	r e4,830	5,620
Armenia[3]	—	—	—	—	550
Australia	7,055	r7,605	r7,790	r6,183	25,479
Austria	5,250	5,235	5,404	r5,529	5,620
Azerbaijan[3]	—	—	—	—	660
Bahrain	174	174	163	165	165
Bangladesh[4]	343	345	360	r303	320
Barbados e	2203	237	r195	r220	195
Belgium	7,111	7,408	7,638	r7,919	8,300
Belarus[3]	—	—	—	—	1,800
Benin	e220	e275	r331	r353	2408
Bolivia	499	557	618	r652	605
Bosnia and Herzegovina[5]	—	—	—	—	440
Brazil	r27,922	r28,578	r28,493	r30,303	230,975
Bulgaria	6,101	5,476	5,159	r e5,200	5,000
Burma	385	434	r463	r442	440
Cameroon	644	677	688	686	680
Canada	13,267	r13,879	r12,947	r10,357	29,352
Chile	r2,078	r2,216	r2,331	r2,481	22,921
China e	231,000	228,000	224,000	273,000	335,000
Colombia	7,456	7,323	r6,253	r6,837	27,503
Congo	r85	134	100	113	110
Costa Rica	613	r672	r683	r772	770
Côte d'Ivoire e	770	550	550	550	550
Croatia[5]	—	—	—	—	21,951
Cuba	3,931	r3,459	r e3,300	r e2,200	2,200
Cyprus	956	1,149	1,249	1,250	1,250
Czechoslovakia	12,097	12,002	11,260	9,148	8,800
Denmark	1,853	2,209	1,825	r2,222	2,500
Dominican Republic	1,647	1,764	1,168	r1,357	1,400
Ecuador	2,425	2,480	e2,500	r2,535	2,440
Egypt	10,789	r13,757	r15,555	r18,108	17,700
El Salvador	687	697	707	r749	750
Estonia[3]	—	—	—	—	660
Ethiopia	447	r e410	375	e320	360
Fiji	49	64	79	r93	100
Finland	1,658	1,760	1,836	r1,459	1,430
France	27,888	29,580	29,088	r29,219	23,810
Gabon	146	127	e127	r e130	127
Georgia[3]	—	—	—	—	1,100

See footnotes at end of table.

TABLE 19—Continued

HYDRAULIC CEMENT: WORLD PRODUCTION BY COUNTRY[1]

(Thousand short tons)

Country	1988	1989	1990	1991	1992e
Germany:					
Eastern states	r13,797	13,519	r7,967	—	—
Western states	28,897	31,415	33,572	—	—
Total	r42,694	44,934	r41,539	r37,915	41,340
Ghana	526	623	744	r827	2 1,129
Greece	14,388	13,817	r14,948	r14,969	14,400
Guadeloupe e	r265	r240	r250	r265	260
Guatemala	r884	r962	r980	r e990	990
Haiti	276	e240	r220	r276	220
Honduras	617	715	719	r764	720
Hong Kong	2,413	2,360	1,993	r1,849	1,900
Hungary	4,269	4,252	4,335	r2,788	2 2,465
Iceland	146	130	r126	r117	105
India	r44,864	50,706	54,013	r56,218	55,115
Indonesia	13,495	15,541	15,170	17,806	2 19,048
Iran e	2 13,450	13,800	14,330	r16,500	20,000
Iraq e	2 11,600	13,800	r11,000	r5,500	11,000
Ireland	1,857	1,791	1,791	e1,765	1,800
Israel	2,564	2,523	3,161	r e3,750	4,400
Italy	41,760	43,414	r44,692	r44,883	2 45,577
Jamaica	409	r481	r487	r435	430
Japan	85,489	87,873	93,085	r98,723	2 99,980
Jordan	2,015	2,127	2,006	r1,933	1,900
Kazakhastan 3	—	—	—	—	6,600
Kenya	1,366	1,341	1,666	e1,650	2 1,676
Korea, North e	13,000	18,000	18,000	18,000	19,000
Korea, Republic of	31,961	33,592	37,038	r42,257	47,000
Kuwait	979	1,224	r992	e330	550
Kyrgyzstan 3	—	—	—	—	1,100
Latvia 3	—	—	—	—	440
Lebanon e	1,000	1,000	1,000	1,000	1,000
Liberia	117	94	r54	r3	2 9
Libya e	3,000	3,000	3,000	r 2 2,611	2,500
Lithuania 3	—	—	—	—	2,200
Luxembourg	621	r651	r701	r e660	660
Macedonia 5	—	—	—	—	550
Madagascar e	r55	r65	r65	r65	65
Malawi	72	85	r110	r e130	130
Malaysia	4,161	5,284	6,483	r8,213	10,500
Mali e	28	22	22	22	22
Martinique e	220	220	220	220	220
Mauritania	99	99	e99	e99	99
Mexico	24,816	25,095	r26,261	r27,668	29,600
Moldova 3	—	—	—	—	1,870
Mongolia e	550	570	485	r330	90
Morocco e	2 4,652	4,630	4,630	r6,360	7,000

See footnotes at end of table.

TABLE 19—Continued

HYDRAULIC CEMENT: WORLD PRODUCTION BY COUNTRY[1]

(Thousand short tons)

Country	1988	1989	1990	1991	1992e
Mozambique	76	r83	r87	r e33	33
Nepal	237	240	118	r150	300
Netherlands	3,768	3,903	4,111	r3,909	3,700
New Caledonia[e]	66	2r74	70	r 2r99	70
New Zealand	895	804	e830	r635	2r638
Nicaragua	e110	144	r242	r264	270
Niger	29	30	r21	r22	22
Nigeria[e]	r3,860	3,860	3,860	3,860	3,860
Norway	1,574	1,516	1,390	e1,265	2r1,396
Oman	953	1,044	1,102	e1,100	1,100
Pakistan	7,761	r7,646	r8,254	r8,556	2r8,590
Panama	r243	186	e330	r e300	300
Paraguay[e]	2r354	360	360	360	360
Peru	2,771	2,320	2,409	r e2,400	2,400
Philippines	r4,511	r3,995	r7,011	r e7,600	2r7,165
Poland	18,722	18,877	13,889	e13,260	13,200
Portugal[e]	2r6,500	6,600	6,600	r8,270	8,270
Qatar	e330	331	294	r580	600
Romania	r15,925	r14,622	r11,445	r e11,000	10,000
Russia[3]	—	—	—	—	75,000
Rwanda	64	75	e67	e66	66
Saudi Arabia	12,071	12,613	e13,230	r14,330	17,000
Senegal	431	419	518	r555	2r663
Serbia and Montenegro[5]	—	—	—	—	3,300
Singapore	1,759	1,881	2,041	r e2,200	2,100
Slovenia[5]	—	—	—	—	900
Somalia[e]	55	55	44	10	30
South Africa, Republic of	9,354	8,852	r8,610	r8,187	2r7,992
Spain (including Canary Islands)	r e28,000	30,175	30,966	r30,403	29,000
Sri Lanka[e]	440	440	440	440	440
Sudan[e]	155	165	2r184	185	275
Suriname[e]	55	55	55	55	55
Sweden	r2,478	r2,680	r2,728	r e2,800	2,800
Switzerland	5,473	6,020	5,739	r5,181	2r5,093
Syria	3,671	3,859	e3,860	e3,860	3,860
Taiwan	19,049	19,889	20,348	21,373	22,800
Tajikistan[3]	—	—	—	—	330
Tanzania	r209	r595	r e600	r e600	600
Thailand	12,692	16,561	19,901	e19,900	20,000
Togo	416	429	r439	r e430	430
Trinidad and Tobago	397	419	483	r535	500
Tunisia[e]	r 2r3,558	r3,600	r3,600	r3,600	3,600
Turkmenistan[3]	—	—	—	—	770
Turkey	24,995	r26,231	r26,914	r28,689	2r31,534
Uganda	r16	r15	r30	r e55	55
Ukraine[3]	—	—	—	—	22,000

See footnotes at end of table.

TABLE 19—Continued

HYDRAULIC CEMENT: WORLD PRODUCTION BY COUNTRY[1]

(Thousand short tons)

Country	1988	1989	1990	1991	1992e
U.S.S.R.[6]	153,771	154,804	151,371	e140,000	—
United Arab Emirates	r3,621	r3,734	r3,598	r3,828	3,900
United Kingdom	18,195	18,573	15,432	r e12,855	11,820
United States (including Puerto Rico)	78,252	78,559	r78,713	r73,583	2r78,734
Uruguay	r478	617	r551	e550	550
Uzbekistan[3]	—	—	—	—	6,600
Venezuela	6,833	4,971	5,765	6,985	7,200
Vietnam[e]	2r2,154	2,200	2,800	r3,300	3,300
Yemen	712	e770	r913	r937	940
Yugoslavia[7]	9,744	9,436	8,768	e8,270	—
Zaire	546	e500	508	r e275	220
Zambia	446	425	e415	r404	415
Zimbabwe	855	793	r e770	r e950	990
Total thousand short tons	r1,232,686	r1,266,064	r1,265,514	r1,311,590	1,382,107
Total thousand metric tons	1,118,274	1,148,554	1,148,055	1,189,855	1,253,826

eEstimated. rRevised.

[1]Table includes data available through June 9, 1993.

[2]Reported figure.

[3]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[4]Data are for the year ending June 30 of that stated.

[5]Formerly part of Yugoslavia; data were not reported separately until 1992.

[6]Dissolved in Dec. 1991.

[7]Dissolved in Apr. 1992.

CHROMIUM

By John F. Papp

Dr. Papp, a physical scientist with 21 years of U.S. Bureau of Mines experience, has been the commodity specialist for chromium since 1983. Domestic survey data were prepared by John Macke, statistical assistant; and chromite world production data, by country, were prepared by Audrey D. Wilkes, international data coordinator. Cost of production data were 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 also is 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 10 by industry accounted for 100% of the chromite consumption data by industry in the current year of table 12. All of the metallurgical, refractory, and chemical companies that consumed chromite in 1992 reported to the Bureau.

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 10 represented 100% of the domestic production shown in the current year of table 11.

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 in 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 also is 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 Department of the Treasury, 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.

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 phosphorus 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 also is 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 also is called charge chrome. Producers of chromium ferroalloys typically specify chromium, carbon, silicon, phosphorus, 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 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 also are 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 silicious 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, ore that is not sold directly 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 then is 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. Using water, the chromium is leached out of the kiln roast product in the form of sodium chromate. The sodium chromate is processed further to make chromic acid, sodium bichromate, 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 1 and 2.)*

Geology-Resources

The geology of many chromium deposits has been characterized.[1] The data in table 21 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 prereduced 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 prereduction process has been 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 such as 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. Increased supply of ferrochromium, resulting from producer expansions and new plant construction, resulted in declining ferrochromium prices in 1990. The dissolution of the U.S.S.R. in 1991, along with political and economic reforms and reduced demand for materials in the Commonwealth of Independent States (C.I.S.), permitted C.I.S. chromite ore and ferrochromium producers to enter western markets, further exacerbating excess supply and low prices.

The historical values of chromite ore by grade, ferrochromium by grade, and chromium metal imported to the United States are shown in tables 3 and 4. 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 and 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 3 and 4.)*

Costs.[4]—Operation 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 5 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 5 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 also could 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 5.)*

The low-carbon ferrochromium availability curve is shown in figure 3; 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 percent 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 percent discounted cash-flow rate of return. *(See figures 3 and 4.)*

Consumer cost and producer competitiveness can be significantly impacted by currency exchange rates. Ferrochromium is usually sold on a U.S. dollar basis. Production costs are mostly based in local currency. In the short term, a ferrochromium producer whose local currency declines in value relative to the U.S. dollar, without a change in its local production cost structure, achieves a competitive advantage. It can earn the same amount of local currency while selling its product for fewer U.S. dollars because of the change in exchange rates. In the long term, the producer may become less competitive if it must buy new equipment, replacement parts, or get capital in U.S. dollars.

An economic analysis of the South African ferroalloy industry[5] identified those business factors that were perceived as most important to determining new plant feasibility. In descending order of importance, the study found those factors to be: market opportunities for the salable product, local metal-ore deposits, energy

costs and availability, and exchange-rate projections. Factors of less importance, again in descending order of importance, were as follows: capital costs and availability, escalation in other production and transport costs, State export incentives, skilled work force availability, domestic consumption of the final product, and other (including taxation and labor relations). The study found that domestic processing of South African ore increased from 6.8% in 1960 to 61% in 1988 and estimated that domestic processing could reach 80%. The cost distribution of charge-grade ferrochromium production in the Republic of South Africa was found to be, in dollars per ton of product: electricity (at 4,390 kilowatt-hours per ton), $135; transport (from plant to market), $122; ore, $75; carbon materials, $58; labor, $36; fluxes, electrodes, etc., $16; working capital, $10; and other direct costs, $97. In this study, exchange rate stability was found to be important because lack of exchange rate stability makes projected income indeterminate in cost analysis studies.

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 Issues.—Chromium is an essential trace element for human health. However, some chromium compounds are acutely toxic, chronically toxic, and/or carcinogenic. Chromium releases into the environment are regulated by the Environmental Protection Agency (EPA). Workplace exposure is regulated by the Occupational Safety and Health Administration.

Health.—Chromium is a trace mineral required by the human body for good health.[6] 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.

Toxicity.—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.[7]

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.[8] Because experimentation on human subjects is morally unacceptable, most toxicity data result 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.

Environmental Releases and Transfers.[9]—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. 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 (SIC) Division E 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 onsite; 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.

Energy Requirements.—Electric arc furnace ferrochromium production is an electrical energy intensive process (requiring about 4,000 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 provide 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. Western World power consumption per ton of ferrochromium product was estimated to range from 2,000 kilowatt-hours to 5,000 kilowatt-hours and averaged 3,950 kilowatt-hours from 1988 to 1991.[10]

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 typically are barged or hauled by truck and/or rail to end users who have no loading and unloading facilities for ships.

ANNUAL REVIEW

In 1992, chromium apparent consumption was about 414,000 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 ore increased. Reported consumption of chromium ferroalloys increased while imports increased. *(See table 6.)*

U.S. supply consisted of recycled and imported chromium materials. The United States recycled about 568,000 tons, gross weight, of stainless steel scrap and imported about 662,000 tons of chromite ore, ferroalloys, chemicals, and pigments valued at about $330 million. The United States exported about 41,000 tons of chromium materials valued at about $42 million. In 1992, both quantity and value of imports of chromium materials increased, while both quantity and value of exports decreased compared with those of 1991.

Legislation and Government Programs

The International Trade Commission of the U.S. Department of Commerce included ferrochromium among those commodities covered that are duty free under the Generalized System of Preferences (GSP). GSP status was changed effective July 1992. Countries that are expected to benefit from this change in ferrochromium status include Brazil, the Philippines, Turkey, Yugoslavia, and Zimbabwe.[11] Countervailing duties on South African ferrochromium were applied at the rate of 3.47% ad valorem. South African producers petitioned to have the duty reduced.[12] The Department of Commerce started a study of the duty. The Bureau of Export Administration of the Department of Commerce requested public comment on the market impact of disposal of chemical-grade chromite ore, metallurgical-grade chromite ore, refractory-grade chromite ore, and high-carbon ferrochromium currently held in excess in the NDS.[13] Public comment was being sought for inclusion in the 1994 Annual Materials Plan, a plan for stockpile acquisition and disposal created by the DLA (Department of Defense) in consultation with other Federal Government agencies.

Dissolution of the U.S.S.R. into the C.I.S. and other independent states at the transition from 1991 to 1992 resulted in the reevaluation of the NDS. The absence of a single large adversary encouraged many to advocate getting rid of the NDS or substantial parts of it. Others argued that history has demonstrated the need for a stockpile because periods of relative peace have been interlaced with conflict and that there is no reason to expect this pattern to change. Based on new international political conditions, the DLA submitted a revised annual materials plan to Congress for 1992.

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 contract year 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. DLA contracted with Macalloy to have chromite ore converted to about 73,000 tons of ferrochromium between September 1992 and October 1993. DLA has the option of extending its contract to have about 7,000 additional tons produced to satisfy the public law mandating the program. *(See table 7.)*

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, 1990, and 1991. In 1992, DLA contracted with Elkem to convert low-carbon ferrochromium to about 1,600 tons of chromium metal. *(See table 8.)*

The EPA, as required under section 112(c) of the Clean Air Act, identified major sources and areas of sources of hazardous air pollutants. To identify these sources of hazardous air pollutants, EPA must find a threat of adverse effects from the area sources. EPA identified chromium electroplaters and anodizers as an area source of hazardous air pollutants that warrant regulation under section 112 of the Clean Air Act and described that source's adverse impact. The chromium electroplating industry includes hard chromium platers (usually a thick chromium coating on steel for wear resistance of hydraulic cylinders, zinc diecastings, plastic molds, and marine hardware), decorative chromium platers (usually over a nickel layer on aluminum, brass, plastic, or steel for wear and tarnish resistance of auto trim, tools, bicycles, and plumbing fixtures), and surface-treatment electroplaters or anodizers (usually a chromic acid process to produce a corrosion-resistant oxide surface on aluminum used for aircraft parts and architectural structures subject to high stress and corrosive conditions). EPA estimated that 1,540 hard chromium electroplaters, 2,800 decorative electroplaters, and 680 chromic acid anodizers nationwide are affected. EPA estimated that electroplaters collectively emit 175 tons of chromium per year, most of which is hexavalent and carcinogenic in humans. EPA estimated that the resulting U.S. nationwide population risk is an additional 110 cases of cancer per year resulting from that emission. EPA estimated the resulting individual risk in the proximity of particular facilities ranged from less than 2 chances per 100,000 for small chromic acid anodizing operations to 5 chances per 1,000 for large hard plating operations. Worker exposure at chromium electroplater and chromic acid anodizer operations is currently controlled by the Occupational Safety and Health Administration.[14]

The Forest Service, U.S. Department of Agriculture, announced that it is preparing an environmental impact statement in cooperation with the State of Montana, Department of State Lands, to disclose environmental effects of a proposed chromite ore production rate increase from 1,000 tons per day to 2,000 tons per day.[15]

EPA regulated the wood preservation industry. As a result of the Resource Conservation and Recovery Act (1988), EPA promulgated regulations on the wood preserving industry (1990) to control inorganic preservatives containing chromium labeled F035 by EPA. In the Code of Federal Regulations (CFR), EPA specified standards for drip pad design, operation, inspection, and closure, specifically in 40 CFR 262, 264, and 265. EPA announced an administrative stay on the regulation F035 waste, thereby extending the effective date of drip pad standards until October 1992. In effect, EPA required wood preservers to upgrade their drip pad or build new ones to meet EPA standards.[16]

EPA regulated the emission of chromium from toxic waste incinerators. The Resource Conservation and Recovery Act (1976) made EPA responsible for managing hazardous waste disposal. EPA regulated particulate emissions from incinerators. However, EPA found that the particulate standard may not provide sufficient protection if a substantial fraction of the particulate emissions were regulated metals, leading EPA to promulgate separate regulations for toxic waste incinerators. Incineration is a desirable method of toxic waste disposal because organic waste is destroyed, leaving no future cost to society. EPA proposed regulation of chromium emission from devices burning hazardous waste in 1987 and promulgated regulations in 1990. Regulation involves control of chromium (contained in the waste stream) feed rates, chromium emission limits, and site-specific risk assessment. Based on field studies, the emission limits of chromium were complicated by the fact that stainless steel (a chromium-containing alloy) was used in the production and transportation processes.[17]

Albania, a significant producer of chromite ore, gained most-favored-nation status recognition from the United States.

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. World 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.

U.S. chromium dependence on southern African nations was reevaluated. In general, four options were identified as potential countermeasures against a potential national security threat owing to foreign mineral dependence. These are: stockpile the material, encourage domestic production, find alternative sources of the material, and develop alternative materials. Stockpiling of chromium material is currently practiced by the United States. (See Stockpiling section of this report.) The United States has chromium resources and a reserve base but deposits are of low grade or small size, making them commercially insignificant. Adequate monetary incentives could bring domestic chromite into production to augment foreign supply, but could not replace commercially used volumes. The major world chromite ore producers include Kazakhstan and the Republic of South Africa at about one-third of world production each. Many smaller producers make up the remaining one-third. If production from either of the two major world producers were unavailable to the world market, the remaining producers would have to double production to meet demand—a large increase. In its major strategic and commercial end uses, there is no substitute for chromium. Chromium demand could be augmented by the development of alternate materials. The study found that the United States is dependent on foreign chromium supply and is vulnerable to supply disruptions.[18]

The National Technical Information Service published a literature search on chromium as a strategic material.[19]

Use.—Strategic use of chromium is primarily in the metallurgical and chemical industries. Chromium is used in stainless steel and nickel- and cobalt-base superalloys. There are no substitutes for chromium in these uses. Stainless steel is essential to many industrial applications. Superalloys are essential to the production of gas turbine engines and to other high-temperature applications. Chromium chemicals are used for metal surface treatment and pigments.

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.)

As a result of reduced threat to the territory of the United States, stockpile goals have been reduced and may be reduced further. Disposals of stockpile material have been made and were expected to continue until all excess material is disposed. Disposal takes the form of sale or payment for services contracted by DLA. In 1992, the DLA disposed of 27,000 tons of metallurgical-grade chromite ore and 7,000 tons of high-carbon ferrochromium, together containing about 12,720 tons of chromium. *(See table 9.)*

Issues

World ferrochromium production capacity in 1992 significantly exceeded demand, resulting in low capacity utilization. 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 1992, 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 Western World 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. The integration of the former U.S.S.R. with Western country economies started with the dissolution of the U.S.S.R. in 1991. This event complicated the recovery process by introducing additional chromite ore and ferrochromium supply capacity. As a result of political and economic changes, demand for chromium materials in the former U.S.S.R. declined. It was anticipated that a new world market balance would be achieved and that demand in the former U.S.S.R. would recover as production facilities in that region converted to cost-based pricing systems.

Production

The major marketplace chromium materials are chromite ore and chromium metal, ferroalloys, and chemicals. In 1992, the United States produced chromium metal, ferroalloys, and chemicals, but no chromite ore. *(See tables 10 and 11.)*

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 in the United States using Montana chromite ore and discussed agreements to supply chromite ore to a potential Canadian low-carbon ferrochromium producer and to a potential Canadian chromium master alloy producer.

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 of about 60 tons and electrical capacity of 12 megawatts. The furnace was planned to become operational in 1993.

Consumption and Uses

Domestic consumption of chromite ore and concentrate was 362,055 tons in 1992. Of the total chromite consumed, the chemical and metallurgical industry used 334,624 tons, and the refractory industry, 27,431. 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 1992 was in stainless steel. Of the 371,688 tons of chromium ferroalloys, metal, and other chromium-containing materials reported consumed, stainless steel accounted for 79.3%; full-alloy steel, 9.9%; high-strength, low-alloy, and electric, 3.1%; cast irons, 1.7%; superalloys, 1.6%; and other end uses, 4.3%. 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 12 and 13.)*

Stocks

Reported consumer stocks of chromite in the United States decreased from 321,225 tons in 1991 to 320,973 tons in 1992. Chemical and metallurgical industry stocks decreased while refractory industry stocks increased. At the 1992 annual rate of chromite consumption, consumer stocks represented about 11 months of supply in the chemical and metallurgical industry and 6 months of supply in the refractory industry. Producer stocks of chromium ferroalloys, metal, and other materials decreased from 11,832 tons in 1991 to 5,723 tons in 1992. Consumer stocks decreased from 18,800 tons in 1991 to 17,629 tons in 1992. At the 1992 annual rate of chromium ferroalloy and metal consumption, producer plus consumer stocks represented about a 0.8-month supply. *(See table 14.)*

Prices

Chromite ore price data in 1992 were mixed. Published prices indicated an increase for South African ore and a decrease for Turkish ore while trade data indicated a small decrease. The published price of the Republic of South African Transvaal chromite, 44% Cr_2O_3 (no specific chromium-to-iron ratio), increased from a range of $42 to $50 per ton, f.o.b. the Republic of South African ports, to a range of $50 to $60. The published price of Turkish ore decreased from a range of $120 to $130 per ton, f.o.b. Turkish ports, to a range of $105 to $110.

Ferrochromium prices generally declined. The published price of domestic high-carbon ferrochromium

(50% to 55% chromium) increased from 49 to 52 cents per pound of chromium content (¢/lb-Cr). 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 remained at 450 ¢/lb. (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 48.5 to 49 ¢/lb-Cr and ended the year at 36 to 39 ¢/lb-Cr. The published price of imported 60% to 65% high-carbon ferrochromium started the year at a range of 46.75 to 47.5 ¢/lb-Cr from which it decreased to a range of 33.5 to 34.5 ¢/lb-Cr. The published price of imported low-carbon (0.05% carbon) ferrochromium decreased from a range of 85 to 86.5 ¢/lb-Cr to a range of 71.5 to 74 ¢/lb-Cr. *(See table 15 and figures 5 and 6.)*

Foreign Trade

Chromium material exports from and imports to the United States included chromite ore and chromium metal, ferroalloys, chemicals, and pigments. *(See tables 16 through 20.)*

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, Japan, the Republic of South Africa, and Russia are countries that mine chromite ore, produce ferrochromium, and produce stainless steel. In Finland, Outokumpu Oy, a major share of which is state-owned, owns and operates the only chromite mining, ferrochromium production, and stainless steel production facilities, making it completely vertically integrated. In the Republic of South Africa, chromium-related companies are privately owned. Typically, major shares of a company are owned by other companies and the remainder, if any, is openly traded. Samancor owns and operates chromite mining, ferrochromium production, and the only stainless steel production facilities. 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 Acos Especiais Itabira. Other chromite operations in Brazil are also vertically integrated. Bayer AG (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 Japan and Russia, chromite ore production is minor. In Japan, some ferrochromium producers are associated with stainless steel plants by location, ownership, or both. In Russia, production facilities are Government owned. In Kazakhstan, chromite ore mining and ferrochromium production is vertically integrated.

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. *(See figure 8.)*

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.—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. Capacities have been rated for the chromite ore, ferrochromium, chromium chemical, and chromium metal industries. *(See table 21.)*

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 21.)*

Production.—World chromite ore production in 1992 was estimated at about 10.9 tons, a substantial 20% reduction from that of 1991. World ferrochromium production in 1992 was estimated at about 3.04 million tons, a 14% reduction from that of 1991. *(See tables 22 and 23.)*

Albania.—**National Developments.**—The development of international contacts and studies of the mining industry are a departure from Albania's previously isolationist position. Albania gained most-favored-nation status recognition from the United States. Albania pursued development of its chromite mining industry by discussing an agreement with Sweden to improve chromite mining and by making an agreement with Turkey to jointly carry out mining surveys.

Albania, in its effort to promote western investment in its chromite mining industry, sought investors with the assistance of the European Bank for Reconstruction.

Chromite Ore.—The geology and mineral processing of Albania was reviewed. The majority of chromite deposits were formed in the Mesozoic geologic era, during a period of mountain building. Albania operated six chromite processing plants at Bulqize, Diber, Kalimash, Krasta, Kukes, and Mat using sedimentation and concentrating tables. Despite good ore reserves, chromite production has been declining since 1985 because of weak local economic conditions and deteriorating mining operations. Although chromite deposits are faulted, they are not extensively dislocated, resulting in deposits of chromite with geological resources in excess of 10 million tons. Reserves were estimated at 30 million tons, of which 7 million tons was graded at more than 46% Cr_2O_3. Mine production was estimated at about 1 million tons in recent years, of which 300,000 tons exceeded 42% Cr_2O_3. All of Albania's chromite mines are underground operations using open-stoping or cut-and-fill methods, and its major mines are Bulqize and Bater. The reserve base at Bulqize was estimated at 5 million tons at 52% Cr_2O_3. It was reported that, given the current state of the mining industry, investment in exploration and technology could increase production by a factor of three without reduction in grade. Miners at the Bulqize Mine went on strike for about 10 days during November and December, demanding better wages and working conditions.

Ferrochromium.—Albania also operated two ferrochromium plants at Burrel and Elbasan, each with production capacity of about 35,000 tons per year using 9-megavolt-ampere furnaces. The Elbasan ferrochromium plant was reported closed because of a shortage of operating capital. The plant is 40 kilometers southeast of Tirana and has a ferrochromium production capacity of about 35,000 tons per year.

Australia.—Dragon Mining continued development of its Range Well lateritic chromiferous deposit. Dragon increased its ownership interest in the chromiferous deposit to 95%, took a 20-ton bulk sample, and started smelting trials.

Brazil.—**National Developments.**—Electrobras, Brazil's electrical energy supplier, planned to increase its electrical energy price from $52.12 per megawatt-hour to $72 per megawatt-hour. Current electrical energy cost fraction of ferrochromium production in Brazil was in the range of 22% to 26%. Other country ferrochromium producers were reported to have substantially lower electrical energy costs: $27 per megawatt-hour in the Republic of South Africa and $19.8 per megawatt-hour in Turkey. A 6% surcharge was imposed on high-carbon ferrochromium imported from South Africa for 4 months starting in October. Low-carbon ferrochromium from South Africa reached 3,700 tons in 1991 compared with domestic production of 7,400 tons. The Ministry of Industry and Commerce started an antidumping investigation of low-carbon ferrochromium from Kazakhstan, Russia, and Ukraine. January-October imports of low-carbon ferrochromium reached 3,000 tons in 1992 compared with domestic production of 12,000 tons from a production capacity of 14,000 tons. Chromite production of lump and concentrate increased from 256,453 tons in 1990 to 366,900 tons in 1991.

Chromite Ore and Ferrochromium.—Companhia Ferroligas do Amapá (CFA) increased the production capacity of its chromite ore concentrator from a range of 120,000 to 150,000 tons per year to about 250,000 tons per year. Utilization of that production capacity was dependent upon market demand. CFA reported sales of 50% Cr_2O_3 into Europe and Japan on long-term contract at $70 per ton f.o.b. at the port of Santana.

Canada.—**National Developments.**—Canada reviewed its chromium resources. Chromite deposits were in British Columbia, Manitoba, Newfoundland, Ontario, and Quebec. However, only the Quebec and Manitoba deposits were found to be of economic importance. The Bird River deposit in Manitoba is of stratiform type, and the deposit at St. Cyr, Richmond County, Quebec, is of podiform type. Reserves in Quebec were 5.5 million tons at an average grade of 6.63% Cr_2O_3 at the Reed-Belanger property and 1 million tons at an average grade of 4.5% at the Hall deposit. The Bird River Sill had measured plus indicated resources of 19 million tons at an average grade of about 9% Cr_2O_3.

Ferrochromium.—Sherwood Metallurgical Corp. sought a site on which to locate a low-carbon ferrochromium plant south of Lethbridge in Alberta. Sherwood arranged with Boulder Gold (Australia), parent company to Chrome Corp. of America, for chromite ore supply from the Stillwater deposit (United States). The plant was planned to have a production capacity in the range of 20,000 to 25,000 tons per year.

The Provincial government of Manitoba studied the possibility of producing master alloy containing chromium and nickel for the stainless steel industry. Chrome Corp. of America was a potential chromite supplier.

Resources Minières Coleraine Inc. planned a high-carbon ferrochromium plant with production capacity of about 20,000 tons per year. Coleraine holds reserves of about 1 million tons at 4.55% average Cr_2O_3 content at its Hall deposit. That chromite could be upgraded to about 180,000 tons graded at 48.8% Cr_2O_3 with a chromium-to-iron ratio of 2.4:1 at a recovery rate of 85%. That ore could produce a 63% chromium, high-carbon ferrochromium. Coleraine continued to study the American Chrome deposit south of the Hall deposit. The ore was planned to be mined by open pit. Beneficiation was planned to include crushing followed by heavy-media separation. A 1,000-ton-per-day beneficiation plant was estimated to cost about $800,000.[20] The smelter was estimated to cost approximately $26

million. The plant was planned to be near Atlas Steel, a stainless steel producer in Tracey, Quebec. Coleraine estimated that ferrochromium productivity could be increased by 15% while saving electrical energy if molten ferrochromium could be supplied to the stainless steel plant. Coleraine also sought to obtain low-grade chromite ore to augment its high-grade supply. Coleraine, a publicly owned company with no shareholder in excess of 20%, is a part of the Morisco Group.

China.—**National Developments.**—China reported trade statistics for 1991. Chromite ore imports decreased from 641,267 tons in 1990 to 544,648 tons in 1991. Ferrochromium exports increased from 11,463 tons in 1990 to 29,767 tons in 1991.

Ferrochromium.—Xibei Ferroalloy Works, Gansu Province, planned to start production of ferrochromium by converting furnace(s) from ferrosilicon to ferrochromium production. Xibei has been operating four 12.5-megavolt-ampere, six 5-megavolt-ampere, and two 25-megavolt-ampere furnaces for ferrosilicon production. An overland rail link was established between Kazakhstan and Gansu Province in 1991 permitting Xibei to import chromite ore from the Donskoy Chromite Ore Dressing Complex.

Jiangyin City Iron Alloy Plant, Jiangsu Province, started operation of two 6-kilovolt-ampere electric furnaces for the production of ferrochromium with an annual production capacity of about 20,000 tons.

Croatia.—Dalmacija Dugi Rat operated a two 20-megavolt-ampere furnace smelter with annual high-carbon ferrochromium production capacity in the range of 72,000 to 74,000 tons. Dalmacija closed one furnace in June followed by the second in July owing to shortage of electrical power. One furnace was restarted in October with plans to restart the second when electrical power availability was restored. Poor market conditions caused Dalmacija to close again by yearend. Dalmacija had adequate stocks to maintain shipments through the closure. Dalmacija reported production at about 52,000 tons in 1992. Dalmacija's export markets include Austria, Belgium, Italy, Sweden, and the United States. The company attributed loss of market share to the movement of C.I.S. producers into Dalmacija's traditional markets.

Cuba.—Cuba reported chromite ore reserves of 18 million tons.

Egypt.—Chromite occurrences in the Eastern Desert were sampled from two locations, El Galala and Abu Dahr. Samples were found to contain Cr_2O_3 in the range of 7.55% to 51.93% and to have a chromium-to-iron ratio in the range of 1.12 to 4.18.

European Community.—European ferroalloy producers alleged that Kazakhstan, Russia, and Ukraine dumped low-carbon ferrochromium (i.e., less than 0.5% carbon) in Europe. The European Commission initiated an investigation of the complaint. Electrowerk Weisweiler (Germany) and Acciaierie e Ferriere Lombarde Falck (Italy) are the two European companies with low-carbon ferrochromium production capacity in the EC. Aktubinsk (Kazakhstan), with an 80,000-ton-per-year capacity, and Serov (Russia), with a 120,000-ton-per-year capacity, are among the exporters. C.I.S. producers increased EC market share from 4,550 tons (8.9%) to 7,404 tons (19%) in 1991. At the same time, EC capacity utilization dropped from 72% in 1988 to 53% in 1991. One reason for excess low-carbon ferrochromium in Russia is the transition to more efficient stainless steel production technology. The Chelyabinsk stainless steel plant (Russia) introduced argon-oxygen-decarburization in 1991, resulting in decreased low-carbon ferrochromium demand.

Finland.—The chromium industry of Finland is vertically integrated from chromite mining through stainless steel production under Outokumpu Steel Oy. The Kemi chromite deposit was discovered in 1959, followed by a decision to mine in 1964 and industrial scale production in 1968. It is 7 kilometers northeast of Kemi city. Reserves are about 150 million tons of 26% Cr_2O_3 average grade and chromium-to-iron ratio of 1.55. Open pit mining results in an annual production of about 1 million tons from a 12-meter bench, which is drilled and blasted. Overburden in the range of 2 to 25 meters necessitates the annual removal of 200,000 to 300,000 cubic meters (4 to 7 million tons) of waste rock. About 500,000 cubic meters of water is pumped from the pit annually. Ore beneficiation includes crushing, heavy-media separation, grinding, cone concentrating, spiral separation, high-intensity magnetic separation, tabling, and dewatering. The beneficiation plant annual production capacity is 320,000 tons of lumpy ore, 320,000 tons of (fine grained) concentrate for metallurgical or chemical use, and 20,000 tons of foundry sand. Run-of-mine production in 1991 was 900,000 tons, which was beneficiated to 200,000 tons of lump and 300,000 tons of concentrate. The ferrochromium plant is 20 kilometers west of Kemi city. The smelter has an annual production capacity of 220,000 tons from two furnaces: one 40 megavolt-ampere and one 75 megavolt-ampere. Ore concentrate is sintered before smelting. The sinter plant annual capacity is 350,000 tons. The ferrochromium plant set a maximum annual production record in 1991 at 190,000 tons graded at 52% chromium and 6% to 8% carbon. The plant conserves energy by capturing carbon monoxide from the smelting process and using it in the stainless steel production process. About one-half of the ferrochromium is exported and the remainder is consumed by Outokumpu to produce stainless steel. About 70% of internally consumed ferrochromium is in molten form.

Germany.—Metallgesellschaft planned to purchase Chromeurope (France) through its wholly owned French subsidiary MG France. Metallgesellschaft planned to purchase Chromeurope for $3.5 million[21] then to invest $7.0 to $8.7

million to convert the former ferrochromium producer to a stainless steel dust recycler.

Greece.—Hellenic Ferroalloys SA (HFA) closed June 1991 and, under Government administration, was offered for sale. The Government planned to sell Hellenic Ferroalloys, which includes the ferrochromium smelter at Tsingeli and three mines at Vourinos and Skoumisa in Macedonia. The smelter produced high-carbon ferrochromium graded at 52% chromium with annual production capacity of about 50,000 tons from one 27-megavolt-ampere furnace built in 1984 by Krupp (Germany). The Vourinos Mine produced chromite ore with a run-of-mine annual production capacity of 100,000 tons and a concentrator with annual production capacity of 50,000 tons. The Skoumisa Mine produced chromite ore with a run-of-mine annual production capacity of 180,000 tons and a concentrator with annual production capacity of 80,000 tons.

India.—**National Developments.**—The Indian Bureau of Mines reported national chromite ore reserves at about 182 million tons in 1990, of which about 96% was in the Cuttack district of Orissa State. Several ferrochromium producers are in or near Orissa State. Ferrochromium production is an electrical energy intensive process. Electrical energy is produced and distributed by the Orissa State Electricity Board, which coordinates with State boards in the adjacent States of Bihar and West Bengal, among others, to make up the eastern region. In the 1960's Orissa had excess power, but not in 1992. Successful State efforts of industrialization had used up available electrical power. About 60% to 65% of power was hydropower. As such, it is rain dependent. Except during monsoon season, power availability is inadequate. A major problem for ferrochromium had been getting adequate power. Power intensive industries' power supply had been cut by 75% to 80%. As a result, several ferrochromium producers have installed captive powerplants at a cost of about $1.25 million per megawatt of capacity to augment electrical energy when supply is restricted. When proposals were made to export ore from Orissa for smelting elsewhere in India, new export laws were proposed. Eastern region projections indicate growing power deficits in the region.

Chromite.—The podiform chromites in mantle peridotites from the Indus ophiolite belt, Ladakh Himalaya, India, were confined to residual mantle peridotites. Chromites were mostly aluminum-chromite and some chromian spinel. Chromites in dunite and wehrlite were graded in the range of 42% to 63% Cr_2O_3.[22]

Indian Metals and Ferroalloys operated three mines in Orissa State with reserves of 7 million tons. Two of the mines were Chingudipal and Nuasahi. The third was a new operation near Nuasahi. Nuasahi is an open pit mine that was purchased from Serajuddin and Co. and is being developed to increase production from its 1991 level of 13,000 tons.

Tata Iron and Steel Co. commissioned a lump ore processing plant with an annual feed capacity of 200,000 tons at its Sukinda Chromite Mine at a cost of about $500,000. Fines rejected from the lump processing were used as feed material to the existing beneficiation plant. Tata started exporting high-grade chromite ore concentrates from a beneficiation plant built in 1990. Chromite ore grades produced were 58% to 60% Cr_2O_3, chromium-to-iron ratio of 3.5; and 61.0% to 61.5% Cr_2O_3, chromium-to-iron ratio of 3.9.

Ferrochromium.—Ferro Alloys Corp. (Facor) produced ferrochromium at its Ferro Alloys Works (Shreeramnagar, Andhra Pradesh State) and Charge Chrome Plant (Randia, Orissa State). Facor commissioned an electrical powerplant consisting 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 the addition of a third generator.

Indian Metals and Ferro Alloys Ltd. operated two ferrochromium plants, Indian Charge Chrome Ltd. (ICCL) at Choudhar and Indian Metals and Ferro Alloys (IMFA) at Therubali. ICCL operated one 48-megavolt-ampere furnace with an annual charge-grade high-carbon ferrochromium production capacity of 50,000 tons and a captive 108-megawatt coal-fired, powerplant. ICCL produced for export and negotiated a toll refining agreement with Tata Iron and Steel Co., which was to become effective in 1992 and remain in effect for 5 years. ICCL purchased the closed Kemanord smelter (Sweden) and planned to dismantle the plant and reassemble it at Choudhar. IMFA operated one 10-megavolt-ampere furnace and one 24-megavolt-ampere furnace with an annual charge-grade high-carbon ferrochromium production capacity of 50,000 to 52,000 tons. IMFA produced about one-half for domestic consumption and the remainder for export.

Navchrome, Raipur district, Madhur Pradesh State, converted from ferrochromium to ferromanganese production owing to weak ferrochromium market conditions. Navchrome planned to add a 7.5-megavolt-ampere furnace to its current 3.6-megavolt-ampere furnace.

Sarada Ferro Alloys, Srikakulam district, Andhra Pradesh State, expanded its annual ferrochromium production capacity from 6,000 to 10,920 tons by increasing its transformer capacity.

Iran.—Chromite ore production was reported to have been 128,000 tons run-of-mine (79,000 tons lump and concentrate) in 1990 and 165,000 tons run-of-mine in 1991 (95,000 tons lump and concentrate).

Japan.—Japan operated a two-part stockpiling program, Government and private. Japan's long-term 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; the private sector would stockpile and finance the remaining 30%. The 60-day supply target was planned to be reached in 1995.

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 acquired 2,710 tons of ferrochromium in fiscal year 1991 (April 1991-March 1992), reaching a stockpile quantity of about 66,300 tons or about 45.4 days of supply. Japan planned to add about a 2.3-day supply of ferrochromium to its stockpile in fiscal year 1992. It was reported that stockpiled material was acquired from domestic producers. Japan planned to substantially increase its rate of stockpiling to meet the 1995 target date.

Japan planned to make its ferroalloy industry eligible to receive an employment adjustment subsidy in 1993. The subsidy benefits an industry that is not expected to recover from a 5% output decline with no employment increase over 3 months (compared to the same time period of the previous year). Metal Mining Agency of Japan planned a geological research and drilling program to look for chromite on the island of Hokkaido. The program was to cover a 12,000-square-kilometer area around Hidaka city over a 3-year period starting in April 1993. Japan operated a two-tier import tariff system applied to ferrochromium. During 1992, 28,100 tons of ferrochromium from developing nations was permitted to be imported duty free.

Japan imported 724,983 tons of chromite ore, 459,608 tons of ferrochromium, 991 tons of chromium metal, and 175,564 tons of stainless steel scrap. Japan's ferroalloy industry produced about 299,706 tons of ferrochromium, a decline of 0.7% compared to that of 1991. (Japan's annual ferrochromium production has ranged from 260,000 tons to 360,000 tons in the 1980-92 time period.) Japan reported stainless steel production of 2,645,808 tons in 1992, a decrease of 6.8% compared to that of 1991. Japan exported 1,367 tons of ferrochromium and 839,520 tons of stainless steel. Ferrochromium imports represented 60% of the market share, while stainless steel exports represented 31.7% of production.

Nippon Denko reported converting an idle ferrochromium furnace to ferroboron production at its Hokuriku plant in Toyama Prefecture.

Reduced production of stainless steel, low ferrochromium prices, and a strong yen reduced the competitiveness of Japanese ferrochromium producers, making profitable ferrochromium production difficult.

Kazakhstan.—**Chromite Ore.**—The Donskoy Ore Dressing Complex, near Khromtau, started chromite ore production in 1938 and currently operates surface and underground chromite mines and ore beneficiation plants. Proven reserves were estimated to be about 300 million tons with inferred and estimated reserves at about 1,000 million tons. Production at Donskoy was reported to be about 3.6 million tons per year with plans to increase that rate to 4.0 million tons per year by the year 2000. Donskoy started exporting chromite ore in 1985 and reached an export volume of 950,000 tons in 1992 with export for 1993 planned to be 1.2 million tons. Donskoy exported to Asian markets (China and Japan) through the Russian port of Vanino north of Nahodkha. Donskoy operated two ore beneficiation plants with an output capacity of 4.9 million tons of crushed ore and 1.9 million tons of concentrate. Plant development was to increase concentrate output to 3.9 million tons.

Donskoy planned to increase exports into western and Asian markets by entering into joint ventures to develop ore processing capacity and capability. Kazamchrome, a joint venture between AIOC (a U.S. trading company) and Donskoy, was formed in 1991. Donskoy supplies chromite ore and AIOC supplies trade resources (financing, marketing, transportation), beneficiation equipment from the Republic of South Africa, and represents Donskoy chromite ore in the world market. Ore screening plant construction started in June for a 300,000-ton-per-year-capacity plant. Donax, a joint venture between Axel Johnson and Donskoy, is constructing a chrome briquetting plant and planned to start production in 1993. The briquettes were planned to be sold to the ferrochromium production industry. In addition to briquettes, Donskoy planned to construct a 700,000-ton-per-year-capacity pelletizing plant. Karatau Corp., in cooperation with Donskoy, planned to produce 10,000 tons of low-silica chromite in 1993 with target capacity of 100,000 tons per year.

Ferrochromium.—Aktubinsk Ferroalloy Works started production in 1943 and currently produces ferrochromium with an annual net production capacity of about 300,000 tons. Yermakovsky Ferroalloy Works produced ferrochromium with an annual net production capacity of about 270,000 tons. Aktubinsk and Bettino Flavio (Italy) planned a joint venture to recover chromium concentrates from high-carbon ferrochromium slag. The chromium concentrate was to be sold to Fucinati (an Italian ferrochromium producer) as a raw material feed for ferrochromium production. The joint venture was planned to produce 100,000 tons of chromium concentrate from 800,000 tons of slag annually using Flavio magnetic separation equipment. Aktubinsk planned to convert ferrochromiumsilicon furnaces to ferrochromium production.

Korea, Republic of.—Korea reported consumption of 90,797 tons of ferrochromium, a 6.4% decrease over that of 1991.

Madagascar.—Madagascar planned the construction of a ferrochromium plant. Feasibility studies for the location and construction of high-carbon and low-carbon ferrochromium plants were completed.[23]

New Caledonia.—The Bureau de Recherche Géologique et Minière (BRGM) (France) planned the development of a lateritic chromite deposit 40 to 50 kilometers from Noumea. The deposit was thought to have reserves of 2 million tons capable of producing 100,000 tons per year of

product graded at 46% to 48% Cr_2O_3 with a chromium-to-iron ratio in the range of 2.2 to 2.3 to 1. Feasibility studies were planned for 1993 and 1994; production was planned for 1995.

Norway.—In May, the Norwegian Parliament decided to continue charging ferroalloy producers for electrical energy at 50% of the commercial rate. In December, the Parliament approved a refinancing package for Elkem in which it planned to invest about $29 million. Elkem Rana AS, a subsidiary of Elkem As (Norway), reduced production because of weak demand.

Oman.—Oman Chrome Co., a private company, was formed to exploit about 2 million tons of chromite reserves distributed over about 600 sites. Resources were estimated in the range of 5 to 10 million tons. Oman Chrome Co. was capitalized at about $7.5 million through share sales. The Oman Government owns 15% through the petroleum and minerals ministry. Private companies own 45%, and the remainder is held in private shares. Oman Mining Co. is the largest private company shareholder with 10%. Oman Chrome Co. planned to produce chromite for the refractory and chemical industries at an annual capacity of about 13,000 tons. Geologic characteristics of one chromite deposit in the Maqsad area were studied.[24]

Philippines.—**National Developments.**—Mindanao Island experienced severe power shortages that resulted in power reductions. A power reduction of 60% in January dropped to 40% in June, then to 20% in August. Ferrochromium producers are on Mindanao. Electrical power in this area is hydroelectric based on water supply in Lake Lanao. Several years of low rainfall has resulted in low water levels in the lake.

Chromite Ore.—The Governments of Japan and the Philippines started a chromite mineral exploration project targeting Panay and Palawan Islands. Merlin Mining (Australia) bought Voest Alpine's (Austria) interest in the Santa Cruz Mine operated by Acoje Mining. Santa Cruz Mine produces metallurgical-grade chromite and has been producing from stocks. Merlin planned to rehabilitate the mine and to produce about 100,000 tons per year of concentrate.

Ferrochromium.—Ferrochrome Philippines Inc. (FPI) restarted its furnaces in August after closure in December 1991. Lack of electrical power caused the closure. FPI produced and built stocks until December, when it shut down furnaces owing to deteriorating power supply. Integrated Chrome converted a ferrosilicon furnace to ferrochromium production in 1991. The furnace was not started until August 1992 when power supply shortages were relieved.

Russia.—Russia planned to increase trade with the west. Serov Ferroalloy Works and Klyuchevsk Ferroalloy Works entered a joint venture with Minerais (Luxembourg) to form Ferromaximin, a trading company to represent chromium ferroalloy sales in the west. Serov is Russia's largest chromium ferroalloy producer with an annual ferrochromium production capacity in excess of 200,000 tons.

Slovenia.—Tovarna Dušika Ruše produced high-carbon ferrochromium.

South Africa, Republic of.—South African economic policy is one of vertical integration of its industry based on its mineral assets. To this end, the chromium industry of the Republic of South Africa has moved from being a major world chromite ore supplier to being the major supplier of both chromite ore and ferrochromium to western markets and is planning its expansion in stainless steel production.

Chromium production capacity utilization in the Republic of South Africa was low in 1992. The high price of ferrochromium in 1988-89 that resulted from stainless steel demand that could not be meet 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, Consolidate Metallurgical Industries (CMI) added a furnace and acquired Purity Ferrochrome, a new producer; Samancor added furnaces at its Tubatse smelter; Middelburg Steel & Alloys (MS&A) started construction of a new ferrochromium production facility using 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. (Feralloys made no changes.) In 1991, Samancor bought MS&A. During and following the introduction of this new ferrochromium production capacity in South Africa and other capacity around the world, Western stainless steel production continued to grow steadily. However, because ferrochromium production capacity was added faster than stainless steel demand growth, the ferrochromium market moved into excess supply and prices declined. In addition, the collapse of the U.S.S.R. followed by the integration of C.I.S. republics into western economies, a process that may continue changing markets for years to come, changed the chromium markets. Economic recession in the East resulted in declining chromium demand in Eastern markets and the entry of Eastern raw materials suppliers into Western markets exacerbating chromium excess supply and adding to the downward pressure on prices.

With an annual ferrochromium production capacity of nearly 1.6 million tons (gross weight) per year, nearly one-third of world ferrochromium production capacity, the Republic of 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 and about equal to that of platinum-group metal export earnings. South Africa has lost chromium market share because of changing market conditions resulting in low-capacity utilization. South African chromium producers planned mine closings, furnace shut downs, and production rate reductions to accommodate changing market condition.

By yearend 1992, South African ferrochromium producers ranked, by annual gross weight production capacity, as follows: Samancor, 1,000,000 tons; CMI, 320,000 tons; CCT, 200,000 tons; and Feralloys, 100,000 tons. Samancor's annual chromite ore production capacity was about 4,000,000 tons or nearly one-third of world annual production. Hernic's annual chromite ore production capacity was about 300,000 tons.

The Republic of South Africa's Minerals Bureau reported 1991 South African (including Bophuthatswana) chromite ore production at 5,110,000 tons, an increase of 11% over that of 1990. The Minerals Bureau reported 1991 chromite ore sales to have been as follows: domestic, 3,477,000 (up 37% over that of 1990); and foreign, 1,328,000 tons (down 14% over that of 1990). The Minerals Bureau reported 1991 chromium ferroalloy production at 1,126,700 tons, an increase of 10% over that of 1990. The Minerals Bureau reported 1991 sales to have been as follows: domestic, 69,680 tons (up 53% over that of 1989); and foreign, 967,200 tons (up 6% over that of 1990).

The South African Ferroalloy Producers Association petitioned the U.S. Department of Commerce to review the countervailing duty order for ferrochromium. The current deposit rate on South African ferrochromium imported into the United States is 3.47%.

Chromite Ore.—The Cashan Mine was worked out. Chromecorp Technology (CCT) purchased rights to Cashan to use Cashan's shaft for access to CCT's Chroombronne Mine.

CMI studied the feasibility of starting a new chromite mining operation. CMI planned an operation with an annual marketable production capacity to 600,000 tons, primarily to feed its smelter but also for export.

Eerste Geluk Chromite Venture (a joint-venture exploration project between Trojan Exploration and Rhombus Exploration), by drilling, delineated reserves of 25 million tons at depths of 200 to 600 meters with a chromium-to-iron ratio of 1.6:1 in the LG-6 seam. The property is between the Winterveld (Samancor) and Lavino Mines (Anglovaal).

Hernic Pty. Ltd. started operation of additional spiral separators installed in 1991. The additional processing capacity increased Hernic's annual production capacity from 250,000 tons to 300,000 tons. Hernic's production in 1991 was about 130,000 tons. Hernic produces metallurgical-grade concentrates graded at 44% chromic oxide and chemical-grade concentrate graded at 45% to 46% chromic oxide and less than 1% silica.

A group of investors (Switzerland) planned a chromite mine and ferrochromium plant development. The mine was in the Brits, Transvaal, with 23 million tons of reserves in the MG-1 and MG-2 chromite seams. Ferrochromium annual production capacity near the mine site was planned at about 130,000 tons from two furnaces.

Ferrochromium.—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. Slag beneficiation equipment was installed, adding about 20,000 tons per year of production capacity. CCT also operated a captive chromite mine, the Chroombronne Mine. CCT operated at less than 30% of capacity in the first quarter of 1992 and less than 60% of capacity for the remainder of the year. CCT diversified into the production of other raw materials for the steel industry.

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 closed one furnace at Lydenburg and one at Rustenburg owing to weak demand, operating at about 40% of capacity in the first part of the year and increasing capacity utilization to about 70% in the third quarter.

Feralloys, a subsidiary of Associated Manganese Mines of South Africa, operated a ferrochromium plant at Machadodorp with an annual production capacity of about 100,000 tons.

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 to reach from 40% to 60% of production capacity. Samancor closed all except one of its ferrochromium furnaces in the first half of the year then restarted one furnace at each plant in the second half of the year and was operating at about 50% of capacity at yearend. Samancor planned to lay off about 2,000 of its 7,000 employees as a result of production cutbacks.

Stainless Steel.—Columbus Joint Venture (CJV) was organized and scheduled for formal recognition as a new company in January 1993. CJV was to be co-owned by Highveld Steel & Vanadium, Samancor, and Industrial Development Corp. (a state-owned corporation). CJV planned to develop Southern Cross Stainless production from its current annual capacity of 120,000 tons to 500,000 tons in 1995.

Sudan.—The Ministry of Energy and Mining Authority for Geological Research studied the chromite deposits of Blue Nile Province, Sudan. Fourteen deposits were identified, mostly in the Ingessana area.[25]

Swaziland.—Boulder Gold of Australia planned to construct a ferrochromium smelter with production capacity of about 120,000 tons per year. In 1992, Boulder planned to use the CODIR production process developed by Krupp (Germany) for application to ferrochromium production. The process is currently owned and being implemented by Samancor (Republic of South Africa) at its Middelburg ferrochromium plant. The project may be delayed because Samancor has not yet completed startup of the new MS&A plant owing to the need to improve equipment and the excess world ferrochromium production capacity.

Taiwan.—Taiwan reported ferrochromium production and consumption for 1991. No ferrochromium was produced, compared with a 1990 production of 5,952 tons. Ferrochromium consumption was 45,017 tons, up from 1990 consumption of 34,905 tons.

Turkey.—Etibank is Turkey's major chromite producer operating mines in the Guleman and Muğla Provinces. Etibank is also Turkey's only ferrochromium producer and operated a low-carbon and a high-carbon ferrochromium plant. Low-carbon ferrochromium production started at Antalya in 1963. It is exported from that location. Antalya has reached annual production levels of more than 12,000 tons. Low-carbon ferrochromium is graded at 68% to 70% chromium. High-carbon ferrochromium production started at Elaziğ in 1977. High-carbon ferrochromium is shipped by rail to İskenderun for export. Elaziğ has reached annual production levels of 72,500 tons from a theoretical annual capacity of 150,000 tons. Production at Elaziğ is limited by labor, startup of new equipment, supply of chromite, and weather conditions in the winter. High-carbon ferrochromium comes in two grades, one 62% chromium and the other 57% chromium. Etibank's petition for duty-free treatment of low- and high-carbon ferrochromium was granted by the U.S. Trade Representative.

United Arab Emirates.—The Department of Industry and Economy (Al Fujayrah emirate), Derwent Mining (Ireland), and Portman Mining (Australia) agreed to exploit chromite deposits in Al Fujayrah. About 200,000 tons of chromite ore was found grading at 48% Cr_2O_3 with a chromium-to-iron ratio of 3:1. Annual mine production capacity was to be 20,000 to 30,000 tons.

United Kingdom.—Murex Ltd., an aluminothermic chromium metal producer in Rainham, Essex County, ceased production. Cedar Iron opened a new ferrochromium plant at Hatton. The plant was to produce high-carbon ferrochromium for the foundry industry.

Zimbabwe.—Drought in Zimbabwe resulted in reduced power supply by about 20% and some blackouts. Electrical energy cost had risen by 130%. The national utility planned to raise electrical power prices by an additional 48% in 1993.

Two ferrochromium producers operated in Zimbabwe, Zimbabwe Mining and Smelting and Zimbabwe Alloys. Zimbabwe Mining and Smelting is a subsidiary of Union Carbide (United States). It produces high-carbon ferrochromium at Kwekwe with an annual capacity of about 178,000 tons from six electric furnaces. Zimbabwe Alloys is a subsidiary of Anglo American (Republic of South Africa). It produces low-carbon ferrochromium with an annual capacity of about 22,000 tons and ferrochromium-silicon at Gweru. Both companies experienced reduced demand and prices, leading them to plan reduced production rates by furnace closures and layoffs in 1993.

Current Research

Mineral Processing and Industrial Applications.—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 chromium-containing corrosion and wear-resistant steels.

The U.S. Bureau of Mines studied the repassivation of Type 304 stainless steel. Analysis of electrical signals acquired during scratching showed that maximum current density and charge density were linearly dependent on the area fraction of bare surface. Regrowth of the passive film on Type 304 stainless steel was investigated by measuring the current that resulted from forming a scratch. Neither scratch hardness nor wear were affected by the presence or absence of the passive film. The passive layer remained adherent to the surface of the stainless steel during the rubbing mode of wear; i.e., where the surface is plastically deformed and no debris is formed.[26] The Bureau also studied the oxidation and corrosion resistance of two Bureau-developed low-chromium stainless steels[27] and quantitatively analyzed the complex morphologies of metal carbides within high-chromium white cast irons.[28]

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 of an injection process, a fluidized bed process, a transferred plasma arc smelting process, and a variety of stainless steel studies. Mintek developed a solid injection system utilizing a graphite lance to inject reductant and carrier gas into molten

metal or slag. The system was used to inject coal into slag and nitrogen into molten metal for stirring. Mintek is optimizing the system with the expectation that it will be used to improve the productivity and competitiveness of the South African ferrochromium industry.[29] Mintek studied fluidized bed preheating of chromite fines as an energy conserving process to produce ferrochromium. Bench-scale tests found the fluidized bed process capable of saving a substantial fraction of electrical energy requirements. Mintek is scaling up the tests.[30] Mintek reported successfully applying transferred plasma arc technology to recover ferrochromium from submerged arc furnace slag and to melt metallized fines from chromium direct reduction process.[31]

Mintek reported the development and implementation of an integrated approach to the metallurgical optimization and computer-based control of submerged arc furnaces for the production of ferrochromium. Mintek developed a computer-based system to control raw material and electrical energy supply for stable furnace operation. Implementation of the system at ferrochromium smelters resulted in more efficient data acquisition, better furnace operation understanding and control, and better electrode control. As a result of these improvements, productivity increased.[32]

A variety of aspects of chromite reduction were studied. The gaseous residuals from a ferrochromium smelting operation were used in an effort to prereduce chromite ore. It was found that the presence of solid carbon is essential to the reduction process because it promptly restores the reducing potential of the gaseous phase by carbon gasification. The technologic feasibility of prereducing composite chromite-reductant pellets in an externally heated shaft furnace was established.[33]

Kinetic aspects of chromite ore reduction were studied in relation to the CODIR ferrochromium production process. United States and South African chromite ore mixed with anthracite coal and silica were studied thermogravimetrically. Metallization was found complete after 2 hours at 1,550° C.[34]

Carbothermic prereduction of South African chromite from the lower group-6 seam was studied at the laboratory scale. Results showed that at 1,500° C, silica flux enhances the chromite-reduction reaction. Slag composition was characterized.[35]

The development of low-grade chromite fine pretreatment to achieve efficient and competitive ferrochromium production was reported. Production processes were studied under commercial scale, pilot plant, and laboratory conditions to minimize high energy cost and meet demanding environmental regulations applied in Arctic conditions. A variety of processes applied to Kemi chromite ore were discussed.[36]

The melting behavior and slag formation of a variety of chromite ores was studied in the high-carbon ferrochromium production process. It was found that chromium losses to slag occur mainly in the form of metal drops and small particles of ore. Chromium reduction was found to be an autocatalytic process in which early slag formation can inhibit the reduction process. To improve chromium recovery, it was recommended that the melting rate of the chromite ore correspond to its reduction rate.[37]

The development and operation of a direct-current, transferred-arc, open-bath, closed, 1.5-megawatt plasma furnace was described. Ore of Russian or Turkish origin and of less than 6-millimeter size from the NDS was used as feed material. Ore, flux, and reductant were fed both through a hollow cathode and through drop points in the furnace roof. The information obtained from trial operation of the 1.2-megawatt furnace was being used to design a 12-megawatt furnace.[38]

Using chromite from seam 6 of the lower group in the Bushveld Complex, the kinetics of chromium in an iron-chromium-carbon alloy melt were studied using a rotating cylinder with rotation rates between 100 and 800 revolutions per minute and at a temperature of 1,600° C in an argon atmosphere. It was found that chromium recovery was significantly improved by the presence of silicon in the melt.[39]

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.

Chromium recovery from slag resulting from ferrochromium production was studied to improve competitiveness. The slag contained about 3% to 4% ferrochromium. Jigging, magnetic separation, flotation, tabling, spiraling, and dense-media separation methods were evaluated for the recovery of ferrochromium for slag following crushing. Only jigging was found to yield a directly salable product alloy in all size ranges, so it was the only method recommended for reclamation of chromium from ferrochromium slags.[40]

The commissioning and operation of a 6.4-ton induction furnace used for ferrochromium reclamation was reported. The 3.5-megawatt furnace was used to remelt ferrochromium fines (less than 1 millimeter in size) generated in the process of crushing and screening ferrochromium ingots. The otherwise unsalable ferrochromium fines were reclaimed in an electric arc furnace as part of the ferrochromium production process. However, fines were being produced at a rate greater than they could be reclaimed in the electric arc furnaces. Thus, an induction melting furnace was introduced to reclaim ferrochromium fines and, thereby, improve the operation's competitiveness.[41]

The production of and marketing results for intermediate carbon (carbon between 1.5% and 5%) produced by the decarburization of high-carbon ferrochromium was reported. A Cruesot-Loire-Uddholm converter of 50,000-ton-per-year production capacity was satisfactorily used to decarburize high-carbon ferrochromium. End-use markets included foundries (23%), specialty steels (48%), stainless steels (23%), and carbon steels (6%). Most material was used in

Europe with the United States taking about 18% of production.[42]

A wide variety of subjects related to chromium alloys, including novel production technologies, characteristics of certain chromium-iron alloys, and uses were reported. Smelting of chromite ore in an oxygen converter[43] and in a coke bed were reported.[44]

The chromium industry of Finland was reviewed. Outokumpu Steel Oy operated one of the few chromium industries integrated from chromite ore production through ferrochromium, stainless steel, and stainless steel products manufacturing. Chromite ore is mined at Kemi where reserves are about 150 million tons at an average grade of 26% Cr_2O_3. Ore is mined by open pit methods. Extraction, dressing, and smelting are closely integrated. Annual ferrochromium production capacity in 1992 was about 210,000 tons of high-carbon ferrochromium graded at 52% chromium and 7% to 8% carbon.[45]

Environmental.—Environmental concerns about chromium have resulted in a wide variety of studies to determine chemical characteristics, 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.

The National Technical Information Service published a literature search on chromium toxicity.[46]

An in situ remediation process for chromium contaminated soil was reported under development. An electrokinetic process to remove chromate in unsaturated soils was demonstrated. The electrokinetic technique was experimentally applied to partially saturated soil common to the arid southwestern United States as an alternative to digging up the soil and chemically washing it to remover chromium. Field tests were planned.[47]

Chromium contained in spent ore was identified as an important pathway for chromium mobilization into the environment, suggesting the necessity of accurate analysis of chromium in the environment. An EPA analysis was compared with an alternate method and found to be lacking. Modification of the EPA method for total chromium in chromite ore was recommended.[48]

EPA identified opportunities for chromium source release reduction. EPA regulation focused on treatment and disposal of pollutants until the Pollution Prevention Act of 1990, when it started looking at source reduction. EPA presented interesting and stimulating challenges for research in the development of new methods for source reduction and recovery/recycling in the hard chromium plating; plating for appearance; surface etching, preparation, and cleaning; refractories; alloying; catalysts; wood treatment; pigments and oxides; and leather tanning industries.[49] EPA also reported on waste minimization opportunities in the orthopedic implant[50] and metal cutting wheel[51] industries.

The development of a process to eliminate hexavalent chromium disposal problems associated with the combined production of chromium metal and ferrochromium was reported. A process was developed wherein the leach residue resulting from chromium chemical production was used as a furnace feed in the production of high-carbon ferrochromium. A calcium-free roast-leach chemical process was developed for which several advantages were noted. The process resulted in a calcium-free leach residue containing 43% Cr_2O_3 and having a chromium-to-iron ratio exceeding 3:1 that was used as an electric arc furnace feed material. The new process was found to both eliminate the hexavalent chromium disposal problem and improve the economics of smelting.[52]

The leather tanning industry was studied with the objective of reducing water effluent pollution and odor. A substantial fraction of leather production has relocated from developed to developing countries over the 1960-80 time period. Several specific process modifications to reduce waste were identified, as were economic, social, legislative, and industry barriers to changes.[53]

The concentration of chromium in water runoff from municipal and industrial sites in Finland was measured. Median chromium value was found to be 15 micrograms per liter and was compared with another study of landfill leachates for Finland at 9 micrograms per liter, Germany at 97 micrograms, and the United States at 93 to 780 micrograms per liter.[54]

Ion exchange technology was applied to the treatment of chromium-containing ground and storm waters from a wood treatment facility. The ion exchange system design and operation was described. The treatment process recovered hexavalent chromium in a condition suitable for reuse.[55]

Wastewater treatment methods were designed for the recovery of chromium in salable form from industrial wastewater. Typical methods make a sludge which must be disposed of as a toxic waste. The proposed method uses ion exchange to remove chromic acid.[56]

A method was developed for the removal of chromium from ground waters polluted as a result of uncontrolled solid waste disposal. Ground water was pumped into a tank where the iron-to-chromium ratio could be controlled. Chromium compounds were then removed with the aid of iron sulfate. Subsequently, formed hydroxides were flocculated and separated by settling. Chromium concentration was reduced from milligrams per liter to less than 100 micrograms per liter under a pH range from neutral to alkaline.[57]

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.[58]

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 next section and table 24.)*

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.

Since the dissolution of the U.S.S.R. in 1991, the industries of the former U.S.S.R. have been reorganizing and integrating into the rest of the world economy. This process is expected to continue, at different rates for different C.I.S. republics depending on the rate of political, legal, and economic structure within those countries and the conditions of the world economy to accommodate changes. The first impact of this integration has been on the globalized minerals markets. The low cost of chromite ore and ferrochromium from the former U.S.S.R. has resulted in that material displacing former suppliers to western markets. New stable relationships are expected to develop as cost-based pricing is introduced in former U.S.S.R. countries and as those countries complete the process of legal, political, and economic reform that they have begun. It is anticipated that industrial renovation and unfulfilled consumer demand in the former U.S.S.R. could stimulate recovery in those countries and add to world demand for chromium-containing products.

China is emerging as a potential major factor in the world chromium market. China is primarily a chromium processing and consuming country. Chromite ore production in China is minor. Continued industrial growth in China could result in increased demand for stainless steel in China because stainless steel use is characteristic of the larger and more technologically developed economies.

Stainless Steel

As pointed out before, 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 affect 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.[59] 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. Nickel supply and stainless steel demand from the previously centrally planned economy countries is uncertain. Reduction in cost of stainless steel, owing to greater production rates, may offset some nickel cost increases. Stainless steel producers could substitute manganese for nickel in some cases, thereby reducing the impact of nickel cost increases. Short-term fluctuations in demand could exceed these longer term average projections.

Chromium Chemicals[60]

Chromium chemical markets were reviewed in 1991. 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 price in 1991 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 for 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-based 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 (audiotapes and videotapes and computer disks).

EPA regulations 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

PRINCIPAL WORLD CHROMITE PRODUCERS, 1992

Country[1]	Company
Albania	Government owned.
Brazil	Bayer AG (Germany)
	Coitezeiro Mineração S.A.
	Cia. de Ferro-Ligas da Bahia S.A.
	Cia. de Mineração Serra de Jacobina S.A.
	Mineração Vale do Jacurici S.A.
	Industria e Comércio de Minérios S.A.
	Vila Nova Mine.
	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.
Kazakhstan	Donskoy Ore Dressing Complex.
Philippines	Acoje Mining Co. Inc.
	Benguet Corp.
	Philchrome Mining Corp.
Russia	Saranov Complex.
South Africa, Republic of[2]	Anglovaal Ltd.
	Lavino (Pty.) Ltd.
	African Mining and Trust Co. Ltd.
	Zeerust Chrome Mine Ltd.
	Rustenburg Minerals Development Co. (Pty.) Ltd.
	Bayer (Germany).
	Chrome Chemicals SA (Pty.) Ltd.
	Canadian Gold S.A. (Pty.) Ltd.
	Goudini Chrome (Pty.) Ltd.
	Chromecorp Technology (Pty.) Ltd.
	Chroombronne (Pty.) Ltd.
	Genmin Ltd.
	Samancor Chrome Ltd.
	Batlhako Mining Ltd.
	Ruighoek Chrome Mine.
	Henry Gould (Pty.) Ltd.
	Millsell Chrome Mines (Pty.) Ltd.
	Montrose Mine.
	Groothoek Section.
	Montrose Section.
	Mooinooi Mine.
	Tweefontein Mine.
	Waterkloof Mine.
	Winterveld Chrome Mines Ltd.
	Hernic Chrome.
	Hernic Mining (Pty.) Ltd.
	Johannesburg Consolidated Investment Co.
	Consolidated Metallurgical Industries Ltd.
	Purity Chrome (Pty.) Ltd.
	Lebowa Development Corp. Ltd.
	Dilokong Chrome Mine (Pty.) Ltd.
	National Manganese Mines (Pty.) Ltd.
	Buffelsfontein Chrome Mine.
	Tolgate Group Holding (Pty.) Ltd.
	Pilanesberg Chrome (Pty.) Ltd.
	Vereeniging Refractories Ltd.
	Marico Chrome Corp. Ltd.
	Bophuthatswana Chrome Co. (Pty.) Ltd.

See footnotes at end of table.

TABLE 1—Continued

PRINCIPAL WORLD CHROMITE PRODUCERS, 1992

Country[1]	Company
Turkey	Etibank (Government owned).
	Bursa Toros Kromlari AS.
	Egemetal Madencilik AS.
	Sitki Kocman Mines.
	Turk Maadin Sirketi AS.
	Hayri Ogelman Madencilik AS.
Zimbabwe	Zimbabwe Alloys Ltd.
	Zimbabwe Mining and Smelting Co. (Pvt.) Ltd.

[1]Other chromite-producing countries included Bulgaria, China, Cuba, Egypt, Indonesia, Iran, Japan, Macedonia, Madagascar, Morocco, Pakistan, Sudan, and Vietnam.
[2]Includes Bophuthatswana.

TABLE 2

PRINCIPAL WORLD FERROCHROMIUM PRODUCERS, 1992

Country[1]	Company
Brazil	Cia. de Ferro-Ligas da Bahia S.A.
China	Government owned.
Croatia	Tvornica Karbida i Ferolegura Dalmacija.
Finland	Outokumpu Oy (Government owned).
France	Chromeurope S.A.
Germany	Gesellschaft für Elektrometallurgie mbH
	Elektrowerk Weisweiler GmbH.
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.
Kazakhstan	Aktubinsk Ferroalloy Works.
	Yermakovsky Ferroalloy Works.
Norway	Elkem Rana.
Philippines	Ferro Chemicals Inc.
	Ferrochrome Philippines Inc.
	Integrated Chrome Corp.
Russia	Chelyabinsk Electrometallurgical Works.
	Klyuchevsk Ferroalloy Works.
	Serovsk Ferroalloy Works.
Slovenia	Tovarna Dušika Ruše.
South Africa, Republic of	Anglovaal Ltd.
	Feralloys Ltd.
	Chromecorp Technology (Pty.) Ltd.
	Johannesburg Consolidated Investment Co. Ltd.
	Consolidated Metallurgical Industries Inc.
	Purity Ferrochrome (Pty.) Ltd.
	Samancor Ltd.
	Batlhako Ferrochrome Ltd.
	Ferrometals Ltd.
	Middelburg Steel and Alloys Holdings (Pty.) Ltd.
	Alloys Division Middelburg.
	Alloys Division Krugersdorp.
	Tubatse Ferrochrome (Pty.) Ltd.
Sweden	Vargön Alloy AB.
Turkey	Etibank (Government owned).
United States	Elkem Metals Co.
	Macalloy Corp.
Zimbabwe	Zimbabwe Alloys Ltd.
	Zimbabwe Mining and Smelting Co. (Pvt.) Ltd.

[1]Other ferrochromium-producing countries includes Albania, Chile, Czechoslovakia, Poland, Mexico, Romania, Spain, and Taiwan.

TABLE 3

TIME-VALUE[1] 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	r276	228	202	237	r209	242	214
1991	562	r477	209	r177	263	r223	232	r197
1992	368	p304	214	p177	213	p176	226	p187

pPreliminary. rRevised.

[1]Customs 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 1987 GDP divided by annual 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 4

TIME-VALUE[1] 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	r1,759	1,524	r1,404	1,609	r1,483	6,598	r6,081
1990	1,619	r1,430	883	r780	1,017	r898	6,459	r5,706
1991	1,991	r1,690	874	r742	997	r846	7,584	r6,438
1992	1,871	p1,547	875	p724	966	p799	6,671	p5,518

pPreliminary. rRevised. NA Not available.

[1]Customs value per ton of chromium contained in imported material.

[2]Carbon not more than 4%.

[3]More than 4% carbon.

NOTE.—Constant dollar value is actual value multiplied by gross domestic product (GDP) ratio. GDP ratio is 1987 GDP divided by annual 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 Office.

TABLE 5

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	181.0	92	33 - 705
Refractory grade	26.8	87	54 - 180
Total	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		

[1]Cost 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 6

SALIENT CHROMIUM STATISTICS

(Thousand metric tons, gross weight)

	1988	1989	1990	1991	1992
CHROMITE					
United States:					
Exports	4	40	6	9	7
Reexports	1	2	4	—	(1)
Imports for consumption	615	525	306	212	219
Consumption	551	561	405	375	362
Stocks, December 31: Consumer	390	392	355	321	321
World production	r12,896	r14,294	r12,968	r13,445	e10,896
CHROMIUM FERROALLOYS[2]					
United States:					
Net production[3]	120	147	109	68	61
Exports	8	9	9	11	11
Reexports	2	2	2	2	2
Imports for consumption	431	351	420	r460	420
Consumption	413	354	382	r356	359
Stocks, December 31: Consumer	30	19	18	r19	18
World production	r3,800	r3,856	r3,626	r3,534	e3,041

eEstimated. rRevised.

[1]Less than 1/2 unit.

[2]High-, medium-, and low-carbon ferrochromium plus ferrochromium-silicon.

[3]Includes chromium metal, exothermic chromium additives, and other miscellaneous alloys.

TABLE 7

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	r34,415	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	r111,531	42,577	r28,181	31.0
1992	113,944	41,120	27,511	32.8
PROJECTED PERFORMANCE[e]				
1993	179,988	73,255	NA	46.0

[e]Estimated. [r]Revised. NA Not available.

Source: Defense Logistics Agency.

TABLE 8

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	r1,048	$7.3
October 1990 - September 1991	1,090	780	7.0
October 1991 - Septerber 1992	2,049	1,022	10.1
PROJECTED PERFORMANCE[e]			
October 1992 - September 1993	2,894	1,452	13.5

[e]Estimated. [r]Revised.
[1]Nonspecification grade.

Source: Defense Logistics Agency.

TABLE 9

U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND INVENTORIES FOR CHROMIUM IN 1992

(Thousand metric tons, gross weight)

Material	Physical inventory			
	Stockpile goals	Stockpile-grade	Nonstockpile-grade	Total
Chromite, metallurgical	34	1,208	71	[1]1,278
Chromite, chemical		220	—	220
Chromite, refractory	159	355	—	355
High-carbon ferrochromium		707	42	749
Low-carbon ferrochromium	621	274	14	288
Ferrochromium-silicon		52	1	53
Chromium metal	27	4	2	6

[1]Data do not add to total shown because of independent rounding.

Source: Defense Logistics Agency.

TABLE 10

PRINCIPAL U.S. PRODUCERS OF CHROMIUM PRODUCTS IN 1992, 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.
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 11

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		
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
1992	60,945	40,272	68,346	5,723

TABLE 12

CONSUMPTION OF CHROMITE AND TENOR OF ORE USED BY PRIMARY CONSUMER GROUPS IN THE UNITED STATES

Year	Chemical and metallurgical industry		Refractory industry		Total	
	Gross weight (metric tons)	Average Cr_2O_3 (percentage)	Gross weight (metric tons)	Average Cr_2O_3 (percentage)	Gross weight (metric tons)	Average Cr_2O_3 (percentage)
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	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
1992	334,624	47.4	27,431	41.1	362,055	46.9

TABLE 13

U.S. CONSUMPTION OF CHROMIUM FERROALLOYS AND METAL, BY END USE

(Metric tons, gross weight)

End use	Ferrochromium		Ferro-chromium-silicon	Other	Total[3]
	Low-carbon[1]	High-carbon[2]			
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	r4,174	r19,916	1,228	38	r25,356
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	r4,447	r24	r16	r4,487
Superalloys	3,155	3,377	—	3,741	10,273
Welding materials[4]	339	627	2	161	1,129
Other alloys[5]	r140	r247	—	r111	r500
Miscellaneous and unspecified	r160	(6)	(7)	319	r479
Total[3 8]	r22,151	r318,604	r15,125	r 94,721	r360,602
Chromium content	r15,013	r183,105	r5,595	r4,451	r208,164
Stocks, December 31, 1991	r2,455	r15,355	r367	10623	r18,800
1992:					
Steel:					
Carbon	4,618	6,786	209	W	11,613
Stainless and heat-resisting	8,534	275,984	W	89	284,607
Full-alloy	3,005	32,329	W	40	35,374
High-strength, low-alloy and electric	1,865	2,615	6,723	—	11,203
Tool	W	3,317	W	—	3,317
Cast irons	903	5,166	15	19	6,103
Superalloys	2,753	W	—	3,005	5,758
Welding materials[4]	W	W	W	259	259
Other alloys[5]	W	W	—	124	124
Miscellaneous and unspecified	(11)	3,849	(11)	9,481	13,330
Total[3 8]	21,678	330,046	6,947	12 13,017	371,688
Chromium content	14,744	192,635	2,506	7,555	217,440
Stocks, December 31, 1992	2,521	14,218	276	13614	17,629

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

[1]Low-carbon ferrochromium contains less than 3 % carbon.

[2]High-carbon ferrochromium contains 3 % or more carbon.

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

[4]Includes structural and hard-facing welding material.

[5]Includes cutting materials and magnetic, aluminum, copper, nickel, and other alloys.

[6]Revised to zero.

[7]Withheld to avoid disclosing company proprietary data.

[8]Includes estimates.

[9]Includes 3,585 tons of chromium metal.

[10]Includes 433 tons of chromium metal.

[11]Withheld to avoid disclosing company proprietary data; included with "Other."

[12]Includes 2,979 tons of chromium metal.

[13]Includes 426 tons of chromium metal.

TABLE 14

U.S. CONSUMER STOCKS OF CHROMITE, CHROMIUM FERROALLOYS, AND METAL, DECEMBER 31

(Metric tons, gross weight)

Industry	1988	1989	1990	1991	1992
Chromite:					
Chemical and metallurgical	366,268	368,482	333,224	310,111	307,829
Refractory	23,353	23,791	21,437	11,114	13,144
Total	389,621	392,273	354,661	321,225	320,973
Chromium ferroalloy and metal:					
Low-carbon ferrochromium	5,683	4,397	3,276	r2,455	2,521
High-carbon ferrochromium	23,135	14,141	12,929	r15,355	14,218
Ferrochromium-silicon	647	425	455	r367	276
Other[1]	960	523	938	623	614
Total	30,425	19,486	17,598	r18,800	17,629

rRevised.

[1]Includes chromium briquets, chromium metal, exothermic chromium additives, and other miscellaneous chromium alloys.

TABLE 15

PRICE QUOTATIONS FOR CHROMIUM MATERIALS AT BEGINNING AND END OF 1992

Material	January	December
	Dollars per metric ton of product	
Chromite ore:		
South Africa, Republic of	42 - 50	50 - 60
Turkey	120 - 130	105 - 110
	Cents per pound of chromium	
High-carbon ferrochromium:		
Domestic: 50% to 55% chromium	49	52
Imported:		
50% to 55% chromium	48.5 - 49.0	36 - 39
60% to 65% chromium	46.75 - 47.5	33.5 - 34.5
Low-carbon:		
Domestic:		
0.05% carbon	95	95
0.015% carbon (Simplex)	166	166
Imported:		
0.05% carbon	85 - 86.5	71.5 - 74
0.10% carbon	85 - 87	70 - 72
	Cents per pound of product	
Chromium metal (domestic):		
Electrolytic	370.0	370.0
Elchrome	450.0	450.0

Source: Metals Week.

TABLE 16
U.S. EXPORTS OF CHROMIUM MATERIALS, BY TYPE

Type	1990	1991	1992		Principal destinations, 1992
	Gross weight (metric tons)	Gross weight (metric tons)	Gross weight (metric tons)	Value (thousands)	
Chromite ore and concentrate	6,321	8,759	7,042	$1,602	Canada (83%); Mexico (15%).
Metal and alloys:					
Chromium metal[1]	338	424	299	4,176	Japan (37%); Canada (25%); United Kingdom (25%).
Chromium ferroalloys:					
High-carbon ferrochromium[2]	[3]5,795	[4]7,820	[5]8,292	7,188	Mexico (53%); Canada (44%).
Low-carbon ferrochromium[6]	[7]2,521	[8]2,084	[9]1,860	2,808	Mexico (42%); Canada (34%); Venezuela (11%).
Ferrochromium-silicon	[10]802	[11]745	[12]671	737	Canada (81%); Mexico (14%); Venezuela (3%).
Total ferroalloys	[13]9,118	[14]10,649	[15]10,823	10,733	
Chemicals:					
Chromium oxides:					
Chromium trioxide	4,082	3,967	5,269	10,663	Canada (24%); Australia (11%); Japan (7%); Republic of Korea (7%); Taiwan (7%); Italy (6%).
Other	1,226	1,500	1,640	6,559	Canada (32%); Mexico (18%); Japan (12%); France (10%); Philippines (7%).
Chromium sulfates	44	48	6	38	Mexico (100%).
Salts of oxometallic or peroxometallic acids:					
Zinc and lead chromate	209	627	477	1,678	Canada (90%); Taiwan (8%).
Sodium dichromate	16,663	16,860	15,241	9,634	Mexico (20%); China (15%); Thailand (13%); Taiwan (12%); Italy (10%); Colombia (9%).
Potassium dichromate	48	42	48	91	Canada (52%); Brazil (20%); Hong Kong (12%); Mexico (8%).
Other chromates, dichromates, and peroxochromates	228	193	139	662	Canada (44%); Venezuela (31%); United Kingdom (13%); Mexico (10%).
Pigments and preparations	2,643	1,969	2,554	10,413	Philippines (21%); Canada (15%); Hong Kong(7%).

[1]Articles thereof and waste and scrap.
[2]More than 4% carbon.
[3]Contained 3,477 tons of chromium.
[4]Contained 4,617 tons of chromium.
[5]Contained 4,907 tons of chromium.
[6]Not more than 4% carbon.
[7]Contained 1,517 tons of chromium.
[8]Contained 1,263 tons of chromium.
[9]Contained 1,085 tons of chromium.
[10]Contained 333 tons of chromium.
[11]Contained 261 tons of chromium.
[12]Contained 235 tons of chromium.
[13]Contained 5,327 tons of chromium.
[14]Contained 6,141 tons of chromium.
[15]Contained 6,227 tons of chromium.

Source: Bureau of the Census.

TABLE 17

U.S. IMPORTS FOR CONSUMPTION OF CHROMITE ORE, BY COUNTRY

Country	Not more than 40% Cr_2O_3			More than 40% but less than 46% Cr_2O_3			46% or more Cr_2O_3			Total[1]		
	Gross weight (metric tons)	Cr_2O_3 content (metric tons)	Value (thousands)	Gross weight (metric tons)	Cr_2O_3 content (metric tons)	Value (thousands)	Gross weight (metric tons)	Cr_2O_3 content (metric tons)	Value (thousands)	Gross weight (metric tons)	Cr_2O_3 content (metric tons)	Value (thousands)
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]	11,082	3,663	1,408	167,035	74,619	10,674	34,022	16,018	2,881	212,139	94,300	14,963
1992:												
Germany	1,251	230	14	—	—	—	—	—	—	1,251	230	14
Philippines	9,067	2,702	1,052	22	10	5	161	96	35	9,250	2,808	1,092
South Africa, Republic of	—	—	—	61,937	27,870	3,991	128,736	61,039	8,871	190,673	88,909	12,865
Turkey	14,000	5,197	981	4,300	1,749	350	—	—	—	18,300	6,946	1,331
Total[1]	24,318	8,129	2,047	66,259	29,629	4,347	128,897	61,135	8,905	219,474	98,893	15,299

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

Source: Bureau of the Census.

TABLE 18

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 (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)
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
Czechoslovakia	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	8,180	[e]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

See footnotes at end of table.

TABLE 18—Continued

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)
1992:												
Albania	—	—	—	—	—	—	2,200	1,320	$956	2,200	1,320	$956
China	503	329	$631	—	—	—	17,115	10,084	8,282	17,615	10,412	8,913
Croatia	—	—	—	—	—	—	13,975	8,823	7,448	13,975	8,823	7,448
Czechoslovakia	—	—	—	—	—	—	393	277	450	393	277	450
Finland	—	—	—	—	—	—	20,897	11,108	10,339	20,897	11,108	10,339
France	—	—	—	—	—	—	1,227	759	615	1,227	759	615
Germany	10,225	7,262	18,202	—	—	—	59	38	54	10,285	7,300	18,257
India	—	—	—	—	—	—	31,048	18,974	16,183	31,048	18,974	16,183
Japan	290	211	885	—	—	—	5,609	3,593	3,743	5,899	3,804	4,629
Kazakhstan	686	237	456	—	—	—	3,127	2,046	1,308	3,813	2,284	1,763
Norway	—	—	—	—	—	—	28,471	17,921	15,707	28,471	17,921	15,707
Poland	—	—	—	—	—	—	1,192	790	627	1,192	790	627
Russia	850	250	469	—	—	—	4,882	3,162	2,593	5,732	3,412	3,062
Slovenia	—	—	—	—	—	—	1,250	821	641	1,250	821	641
South Africa, Republic of	4,539	2,546	3,412	—	—	—	110,523	57,147	48,429	115,062	59,693	51,841
Sweden	35	26	97	—	—	—	5,461	3,194	2,959	5,495	3,220	3,056
Turkey	9,290	6,446	9,677	—	—	—	66,603	40,680	32,996	75,893	47,126	42,673
Ukraine	60	46	122	—	—	—	—	—	—	60	46	122
U.S.S.R.[2]	39	20	30	—	—	—	235	127	126	274	146	155
United Kingdom	376	281	920	—	—	—	155	86	85	531	367	1,005
Yugoslavia	—	—	—	—	—	—	30,900	19,477	16,630	30,900	19,477	16,630
Zimbabwe	6,978	4,628	6,783	—	—	—	31,604	20,623	23,286	38,582	25,251	30,068
Total[1]	33,871	22,281	41,684	—	—	—	376,926	221,052	193,456	410,798	243,333	235,140

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

[2]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

Source: Bureau of the Census.

TABLE 19

U.S. IMPORTS FOR CONSUMPTION OF CHROMIUM MATERIALS, BY TYPE

Type	1989 Gross weight (metric tons)	1990 Gross weight (metric tons)	1991 Gross weight (metric tons)	1992 Gross weight (metric tons)	1992 Value (thousands)	Principal sources, 1992
METALS AND ALLOYS						
Chromium metal:						
Waste and scrap	50	85	18	192	$891	China (99%).
Other than waste and scrap	4,152	6,579	5,747	5,259	35,470	Japan (32%); China (24%); United Kingdom (21%); France (20%).
Ferrochromium-silicon	r [1]6,803	r [2]3,801	r [3]5,301	[4]9,379	7,666	Zimbabwe (96%); Brazil (4%).
CHEMICALS						
Chromium oxides and hydroxides:						
Chromium trioxide	661	1,677	1,196	390	1,580	Germany (45%); Japan (18%); Mexico (14%); Italy (10%).
Other	3,880	3,512	3,976	3,309	10,762	Germany (54%); Japan (21%); China (11%); Italy (7%).
Sulfates of chromium	313	192	186	122	79	Turkey (98%).
Salts of oxometallic or peroxometallic acids:						
Chromates of lead and zinc	607	425	334	283	793	Japan (33%); Poland (22%); Norway (13%); France (10%); Sweden (9%).
Sodium dichromate	5,489	1,661	4,895	4,372	3,034	United Kingdom (75%); Spain (9%); Mexico (6%); Turkey (6%).
Potassium dichromate	827	680	464	587	1,051	Russia (43%); Germany (31%); United Kingdom (22%).
Other chromates and dichromates; peroxochromates	1,010	1,860	859	782	1,997	United Kingdom (82%); France (12%).
Chromium carbide	108	123	77	103	982	United Kingdom (54%); Japan (34%); Germany (6%).
PIGMENTS AND PREPARATIONS BASED ON CHROMIUM						
Chrome yellow	3,688	3,643	3,468	3,507	7,431	Canada (85%); Mexico (9%).
Molybdenum orange	1,046	916	812	894	2,566	Canada (99%).
Zinc yellow	542	436	218	220	446	Norway (49%); Poland (36%); France (6%); Canada (6%).
Other	687	657	441	2,322	4,865	Germany (91%); France (3%).

rRevised.

[1]Contained 2,756 tons of chromium.

[2]Contained 1,459 tons of chromium.

[3]Contained 2,046 tons of chromium.

[4]Contained 3,643 tons of chromium.

Source: Bureau of the Census.

TABLE 20

U.S. IMPORT DUTIES FOR CHROMIUM-CONTAINING MATERIALS IN 1992

Item	Harmonized Tariff Schedule No.	Most favored nation (MFN)	Non-MFN[1]	Special	
				CA[2]	A, E, IL[3]
Chromite ores and concentrates therefrom:					
Not more than 40% Cr_2O_3	2610.00.0020	Free	Free	NA	NA.
More than 40% and less than 46% Cr_2O_3	2610.00.0040	do.	do.	NA	NA.
Not less than 46% Cr_2O_3	2610.00.0060	do.	do.	NA	NA.
Chromium oxides and hydroxides:					
Chromium trioxide	2819.10.0000	3.7% ad valorem	25% ad valorem	Free	Free.
Other	2819.90.0000	do.	do.	0.7% ad valorem	Do.
Sulfates; alums; peroxosulfates (persulfates):				do.	
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	0.4% ad valorem	Do.
Potassium dichromate	2841.40.0000	1.5% ad valorem	3.5% ad valorem	0.3% ad valorem	Do.
Other chromates and dichromates; peroxochromates	2841.50.0000	3.1% ad valorem	25% ad valorem	0.6% ad valorem	Do.
Carbides, whether or not chemically defined:					
Other: Of chromium	2849.90.2000	4.2% ad valorem	do.	0.8% ad valorem	Do.
Pigments and preparations based on chromium:					
Chrome yellow	3206.20.0010	3.7% ad valorem		0.7% 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	(4)
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	0.7% ad valorem	Free.

NA Not available.

[1]The following countries were non-MFN in 1992; Afghanistan, Albania Azerbaijan, Belarus, Cambodia, Cuba, Kazakhstan, Laos, North Korea, Romania, Tajikistan, Turkmenistan, Uzbekistan, and Vietnam.

[2]United States-Canda Free Trade Agreement.

[3]A—Generalized System of Preferences, E—Caribbean Basin Economic Recovery Act, IL—United States-Israel Free-Trade Area Implementation Act of 1985.

[4]A not applicable; E and IL free.

Source: U.S. International Trade Commission. Harmonized Tariff Schedule of the United States (1992). USITC Publication 2333.

TABLE 21

WORLD CHROMIUM RESOURCES[1] AND ANNUAL PRODUCTION CAPACITY OF CHROMITE ORE, FERROCHROMIUM, CHROMIUM METAL, AND CHROMIUM CHEMICALS IN 1992

(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	—	—	—	—	—	—	6
Australia	—	500	500	—	—	—	—
Brazil	2,300	4,900	4,900	108	89	(4)	12
Canada	—	1,100	1,100	—	—	—	—
Chile	—	—	—	—	2	—	—
China	NA	NA	NA	13	72	2	16
Croatia	—	—	—	—	42	—	—
Cuba	700	700	2,000	14	—	—	—
Czechoslovakia	—	—	—	—	13	—	—
Egypt	NA	NA	NA	1	—	—	—
Finland	8,900	8,900	8,900	211	105	—	—
France	—	—	—	—	12	2	—
Germany	—	—	—	—	42	1	20
Greece	400	400	800	21	19	—	—
Greenland	—	—	26,000	—	—	—	—
India	18,100	23,800	23,800	241	167	(4)	5
Indonesia	200	200	200	20	—	—	—
Iran	700	700	17,700	15	—	—	2
Italy	—	—	—	—	64	—	—
Japan	(4)	100	100	3	218	5	21
Kazakhstan	39,600	39,600	40,600	1,100	330	—	42
Macedonia	NA	NA	NA	3	7	—	5
Madagascar	2,100	2,100	2,100	45	—	—	—
Mexico	—	—	—	—	2	—	5
Norway	—	—	—	—	88	—	—
Oman	NA	NA	NA	1	—	—	—
Pakistan	NA	NA	NA	2	—	—	3
Papua New Guinea	—	—	2,900	—	—	—	—
Philippines	2,300	2,300	2,300	60	45	—	—
Poland	—	—	—	—	35	—	7
Romania	—	—	—	—	32	—	5
Russia	NA	NA	NA	40	233	7	63
Slovenia	—	—	—	—	8	—	—
South Africa, Republic of	295,200	1,704,400	2,973,700	1,505	858	—	—
Spain	—	—	—	—	9	—	—
Sudan	500	500	500	2	—	—	—
Sweden	—	—	—	—	97	—	—
Taiwan	—	—	—	—	1	—	—
Thailand	NA	NA	NA	(4)	—	—	—
Turkey	2,500	6,000	6,800	441	84	—	10
United Kingdom	—	—	—	—	1	4	52

See footnotes at end of table.

TABLE 21—Continued

WORLD CHROMIUM RESOURCES[1] AND ANNUAL PRODUCTION CAPACITY OF CHROMITE ORE, FERROCHROMIUM, CHROMIUM METAL, AND CHROMIUM CHEMICALS IN 1992

(Thousand metric tons, contained chromium)

	Resources[2]			Annual production capacity			
	Reserves	Reserve base[3]	Identified resources	Ore	Ferro-chromium	Metal	Chemicals
United States	—	3,100	35,000	—	83	3	55
Vietnam	NA	NA	NA	1	—	—	—
Zimbabwe	43,500	285,400	285,400	169	125	—	—
Total	418,900	2,086,600	3,441,600	4,234	2,924	24	329

NA Not available.

[1]World resources derived in consultation with the U.S. Geological Survey.

[2]Data and total rounded to nearest 100,000 metric tons.

[3]The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

[4]Less than 1/2 unit.

[5]Less than 50,000 metric tons.

TABLE 22

CHROMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons, gross weight)

Country[2]	1988	1989	1990	1991	1992e
Albania	1,109,000	e1,200,000	910,000	e800,000	150,000
Brazil[3]	410,256	475,949	267,000	r340,000	340,000
China[e]	26,000	25,000	25,000	25,000	25,000
Cuba	52,200	50,600	e50,000	r e50,000	50,000
Eygpt	e800	2,448	399	649	600
Finland[e 4]	700,000	498,000	489,000	r458,000	480,000
Greece[5]	49,535	47,324	r22,400	r31,669	—
India	820,863	1,002,659	939,000	r994,674	1,000,000
Indonesia	7,636	7,635	e8,000	r1,950	2,000
Iran	60,289	72,628	77,189	r90,119	100,000
Japan	9,508	11,674	8,075	r8,000	8,000
Kazakhstan[6]	—	—	—	—	7 3,600,000
Macedonia[8 9]	—	—	—	—	9,000
Madagascar	64,177	62,540	e73,000	r e63,000	63,000
Morocco	1,000	1,000	300	500	500
New Caledonia	70,341	60,281	6,223	—	—
Oman	—	12,810	—	—	—
Pakistan	3,327	27,105	18,191	r31,474	30,000
Philippines	r129,258	216,562	r185,595	r184,010	132,000
Russia[6]	—	—	—	—	7 121,400
South Africa, Republic of[10]	4,244,632	4,950,854	4,618,310	r5,110,000	7 3,361,000
Sudan	8,000	25,000	12,500	e10,000	10,000
Thailand	776	416	—	—	—
Turkey[e 4]	7 851,425	r1,100,000	r800,000	r870,000	850,000
U.S.S.R.[11]	3,700,000	3,800,000	3,800,000	3,800,000	—
Vietnam[e]	4,000	3,500	3,500	3,500	3,500
Yugoslavia[9 12]	11,538	12,721	10,843	e9,000	—
Zimbabwe	r561,477	627,424	r643,098	r563,634	560,000
Total	r12,896,038	r14,294,130	r12,967,623	r13,445,179	10,896,000

[e]Estimated. [r]Revised.

[1]Table includes data through May 26, 1993.

[2]In addition to the countries listed, Bulgaria and North Korea also may 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.

[3]Average Cr_2O_3 content was as follows: 1988—39.0%; 1989—39.5%; 1990—38.9%; 1991—42.0%; and 1992—42.0% (estimated). Brazil also reports run-of-mine crude ore production and Cr_2O_3 content in metric tons as follows: 1988—410,256 (160,000) (revised); 1989-91—1,082,949 (432,900) (revised); and 1992—340,000 (142,800) (estimated).

[4]Direct-shipping lump ore plus concentrate.

[5]Exports of direct-shipping ore plus production of concentrates.

[6]Formerly part of the U.S.S.R.

[7]Reported figure.

[8]Formerly part of Yugoslavia.

[9]All production in Yugoslavia from 1988-91 came from Macedonia.

[10]Includes production by Bophuthatswana, which was as follows, in metric tons: 1988—536,500; 1989—676,154; 1990—468,262; 1991—484,000 (revised); and 1992—350,000 (estimated).

[11]Dissolved in Dec. 1991.

[12]Dissolved in Apr. 1992.

TABLE 23

FERROCHROMIUM: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1988	1989	1990	1991	1992e
Albania	33,700	38,800	24,000	e35,000	15,000
Brazil	130,024	113,267	83,753	82,225	82,000
Chile	2,212	2,840	r1,868	e2,000	2,000
China[e]	(2)	r(2)	(2)	(2)	(2)
Croatia[3]	—	—	—	—	4,56,456
Czechoslovakia[5]	29,183	29,844	31,866	r33,708	4,37,756
Finland	156,000	169,000	r157,000	r190,000	4,187,000
France[e]	r13,200	r18,100	25,000	r23,100	4,6,694
Germany:					
Eastern states[e]	22,000	22,000	21,000	—	—
Western states	r34,900	r33,346	r37,466	r33,654	26,500
Total	r56,900	r55,346	r58,466	r33,654	r26,500
Greece	r44,147	r43,579	30,300	r e10,500	—
India	140,261	135,165	r122,000	r96,007	100,000
Italy	r87,100	r75,567	r53,000	r47,082	62,000
Japan[6]	295,406	324,371	293,345	270,786	268,000
Kazakhstan[7]	—	—	—	—	400,000
Macedonia[3]	—	—	—	—	6,000
Mexico	9,295	2,569	275	r72	70
Norway[e]	—	—	r60,000	r83,000	102,000
Philippines[e]	r73,000	r82,000	r56,000	r e23,730	27,400
Poland	36,316	24,300	13,700	e12,000	10,000
Romania	r23,430	r26,849	r20,633	r20,380	4,6,977
Russia[7]	—	—	—	—	500,000
Slovenia[3]	—	—	—	—	4,17,100
South Africa, Republic of[6 8]	993,685	r1,049,900	1,022,000	r1,126,700	4,665,000
Spain[e]	r25,400	r29,000	r15,000	r6,000	—
Sweden	143,055	r153,800	r117,680	r120,884	130,000
Turkey	54,030	59,715	62,040	r84,651	4,85,755
U.S.S.R.[9]	r1,050,000	r975,000	r e975,000	r e925,000	—
United States[10]	119,645	146,844	108,932	68,327	4,60,945
Yugoslavia[11]	93,349	90,428	82,687	e60,000	—
Zimbabwe	r190,200	r209,807	r211,850	r178,901	4,186,255
Total	r3,799,538	r3,856,091	r3,626,395	r3,533,707	3,040,908

eEstimated. rRevised.

[1]Table includes data available through May 26, 1993.

[2]Estimated production is included in the ferroalloys table under "Other."

[3]Formerly part of Yugoslavia; data were not reported separately until 1992.

[4]Reported figure.

[5]Includes ferrochromium-silicon and ferronickel, if any was produced.

[6]Includes high- and low-carbon ferrochromium and ferrochromium-silicon.

[7]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[8]Includes production from Bophuthatswana.

[9]Dissolved in Dec. 1991.

[10]U.S. output of ferrochromium includes high- and low-carbon ferrochromium, ferrochromium-silicon, chromium metal, and other chromium materials.

[11]Dissolved in Apr. 1992.

TABLE 24

CHROMIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons, contained chromium)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
WORLD PRODUCTION												
Chromite ore (mine)[1]	2,736	2,553	2,472	2,943	r3,292	r3,552	3,588	r3,882	r4,303	r3,904	r4,048	e3,280
Ferrochromium (smelter)[2]	1,760	1,512	1,554	1,862	1,947	1,893	r1,858	r2,166	r2,198	r2,067	r2,014	e1,733
Stainless steel[3]	1,084	r1,361	r1,507	r1,721	r1,696	r1,763	r1,849	r2,092	r2,035	r2,100	r2,108	e2,140
U.S. SUPPLY												
Components of U.S. supply:												
Domestic mines	—	—	—	—	—	—	—	—	—	—	—	—
Secondary	65	61	75	79	85	84	95	119	99	94	90	95
Imports:												
Chromite ore	228	130	53	83	109	133	133	185	162	92	65	68
Chromium ferroalloy	228	79	148	223	173	206	171	255	208	244	234	247
Chromium metal	3	2	3	4	4	4	4	4	4	7	6	6
Chromium chemicals	1	2	4	3	5	4	3	2	5	4	5	4
Chromium pigments	2	1	2	2	2	2	2	4	NA	NA	NA	NA
Stocks, Jan. 1:												
Government	1,051	1,051	1,051	1,051	1,051	[4]1,080	[4]1,110	[4]1,079	[4]1,057	[4]1,097	[4]1,099	[4 5]1,166
Industry	219	232	181	164	114	106	102	119	137	139	117	113
Total U.S. supply[6]	1,798	1,558	1,518	1,609	1,542	1,619	1,620	1,767	1,673	1,676	1,616	1,698
Distribution of U.S. supply:												
Exports:												
Chromite ore	18	2	3	15	27	25	(7)	1	12	2	3	2
Chromium ferroalloy	7	3	2	9	6	3	2	5	6	5	6	6
Chromium metal	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)
Chromium chemicals	6	5	5	7	4	7	6	8	6	7	22	7
Stocks, Dec. 31:												
Government	1,051	1,051	1,051	1,051	1,080	1,110	1,079	1,057	1,097	1,099	1,166	1,197
Industry	232	181	164	114	106	102	119	137	139	118	120	114
Total U.S. distribution[6]	1,314	1,243	1,226	1,197	1,223	1,247	1,207	1,208	1,260	1,231	1,317	1,327
Apparent industry demand	483	315	292	412	349	402	382	537	452	447	366	414

eEstimated. rRevised. NA Not available.

[1]Calculated assuming chromite ore to average 44% Cr_2O_3 that is 68.42% chromium.

[2]Calculated assuming chromium content of ferrochromium to average 57%.

[3]Calculated from World Stainless Steel Statistics, 1992 ed. reported production, assuming chromium content of stainless steel to average 17%. Western World only in 1991.

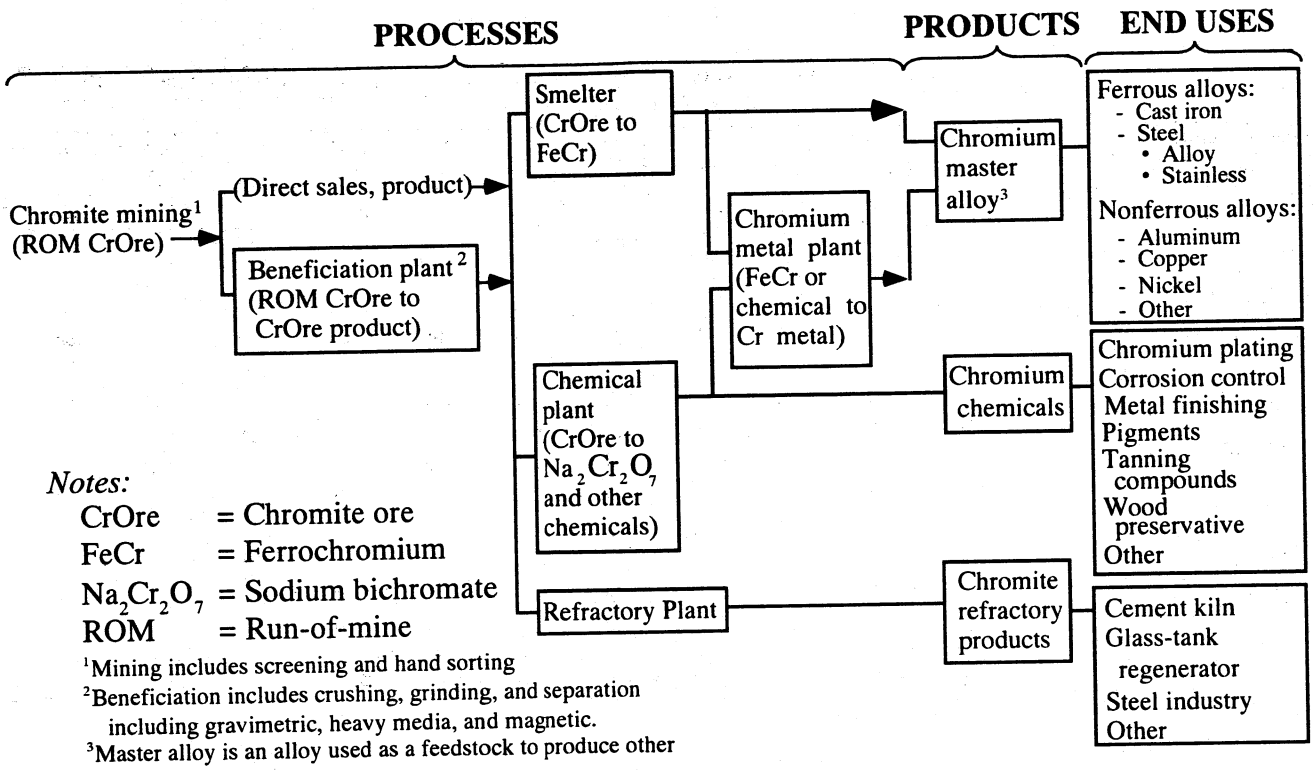
[4]Variation in stockpile quantity does not contribute to apparent industry demand because variation resulted from upgrading programs.

[5]Goverment releases of chromite ore and ferrochromium in 1992 contained about 13,000 tons of chromium.

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

[7]Less than 1/2 unit.

FIGURE 1
CHROMIUM MATERIAL FLOW



Notes:

CrOre = Chromite ore
FeCr = Ferrochromium
$Na_2Cr_2O_7$ = Sodium bichromate
ROM = Run-of-mine

[1]Mining includes screening and hand sorting
[2]Beneficiation includes crushing, grinding, and separation including gravimetric, heavy media, and magnetic.
[3]Master alloy is an alloy used as a feedstock to produce other

FIGURE 2
GENERAL RECYCLING CHROMIUM MATERIAL FLOW INDUSTRY STRUCTURE

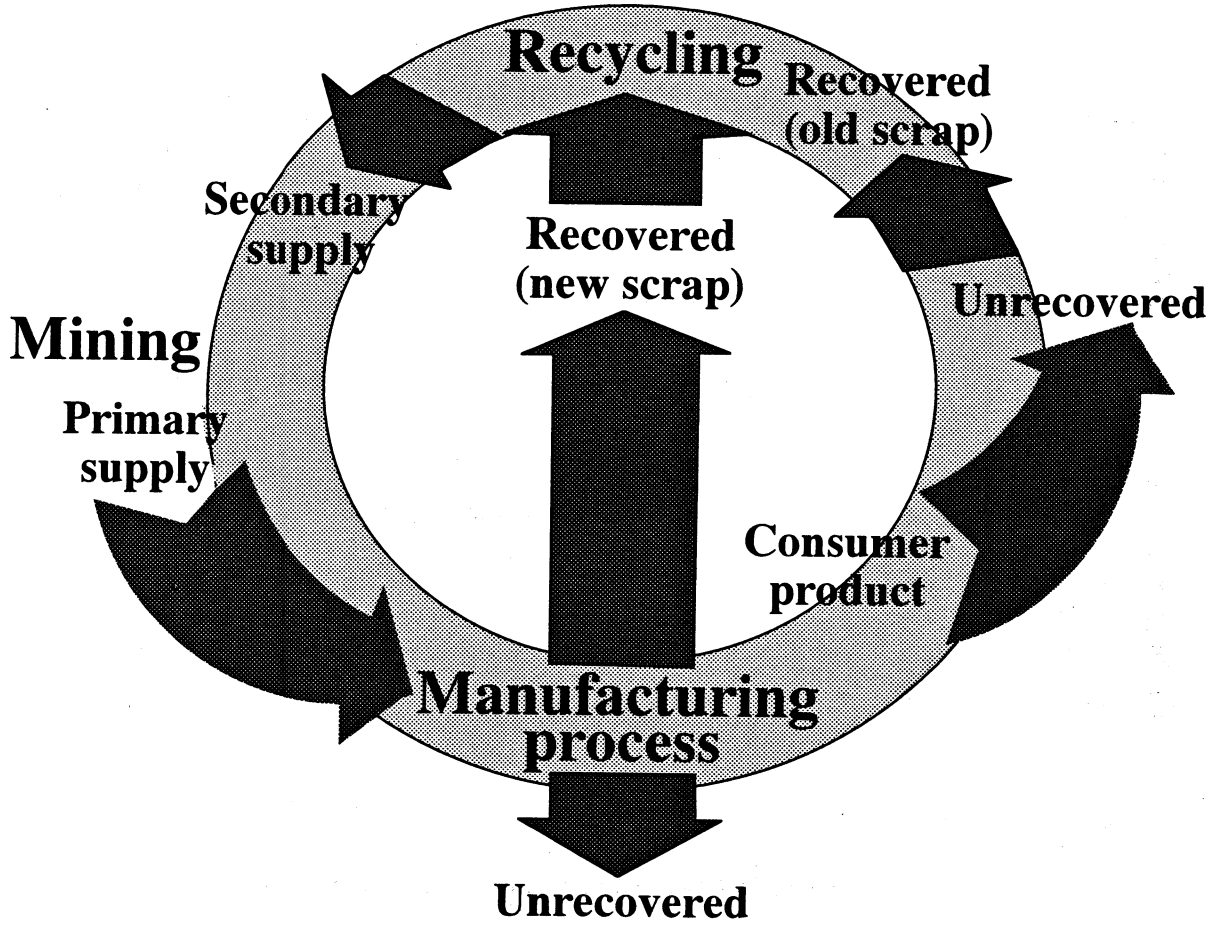
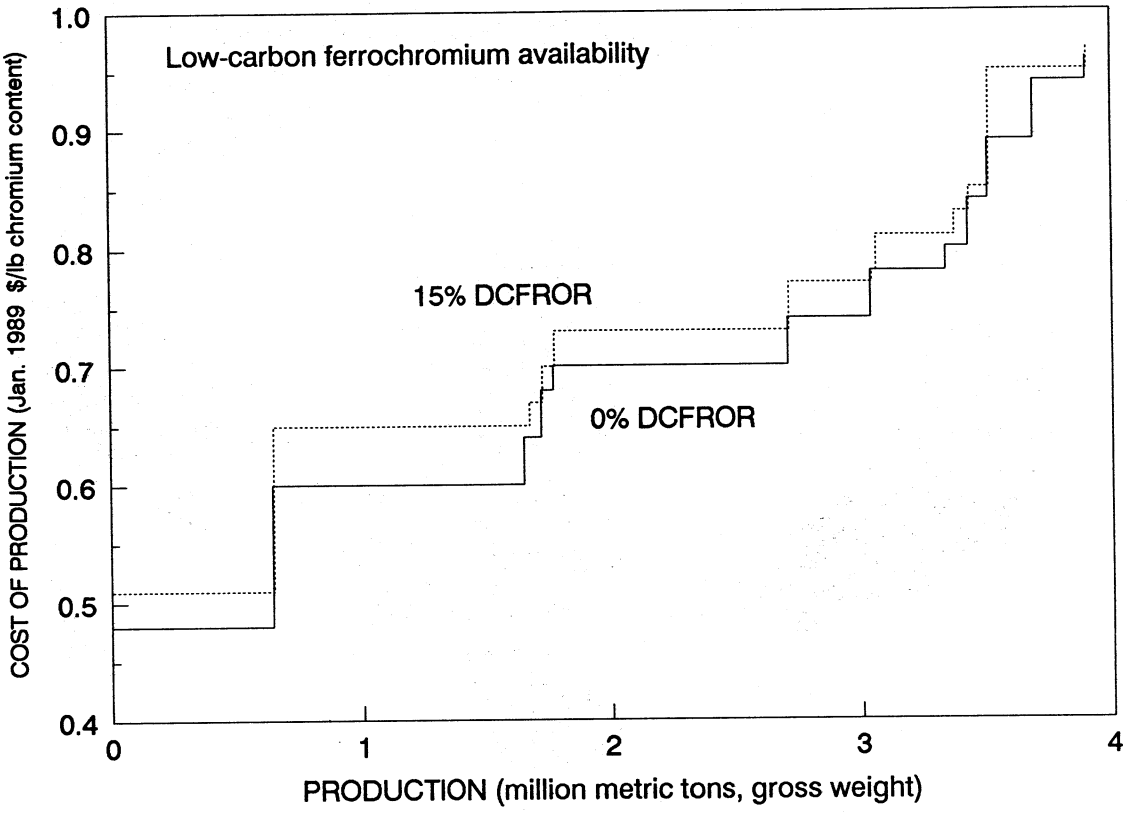


FIGURE 3

COST OF LOW-CARBON FERROCHROMIUM PRODUCTION AT 0% AND 15% DISCOUNTED CASH-FLOW RATE OF RETURN (DCFROR) FOR SELECTED MARKET ECONOMY PRODUCERS

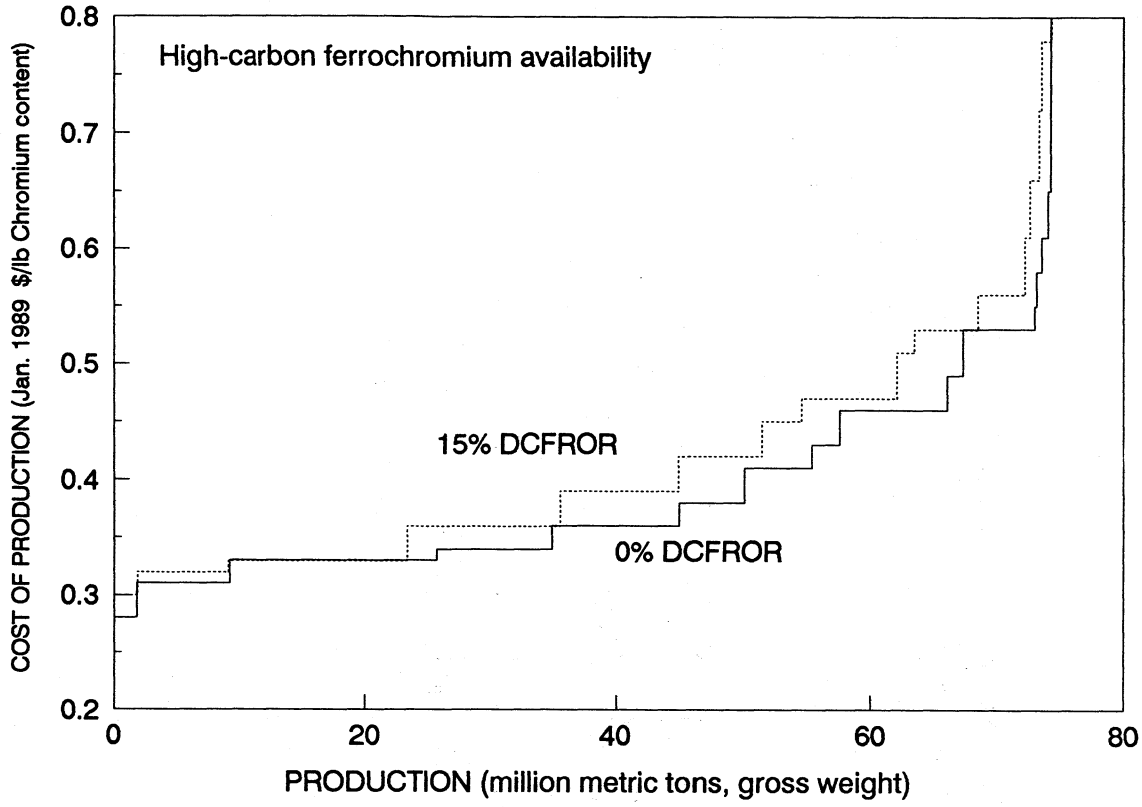


NOTE.--DCFROR is discounted cash-flow rate of return.

Source: U. S. Bureau of Mines, Minerals Availability system cost analysis.

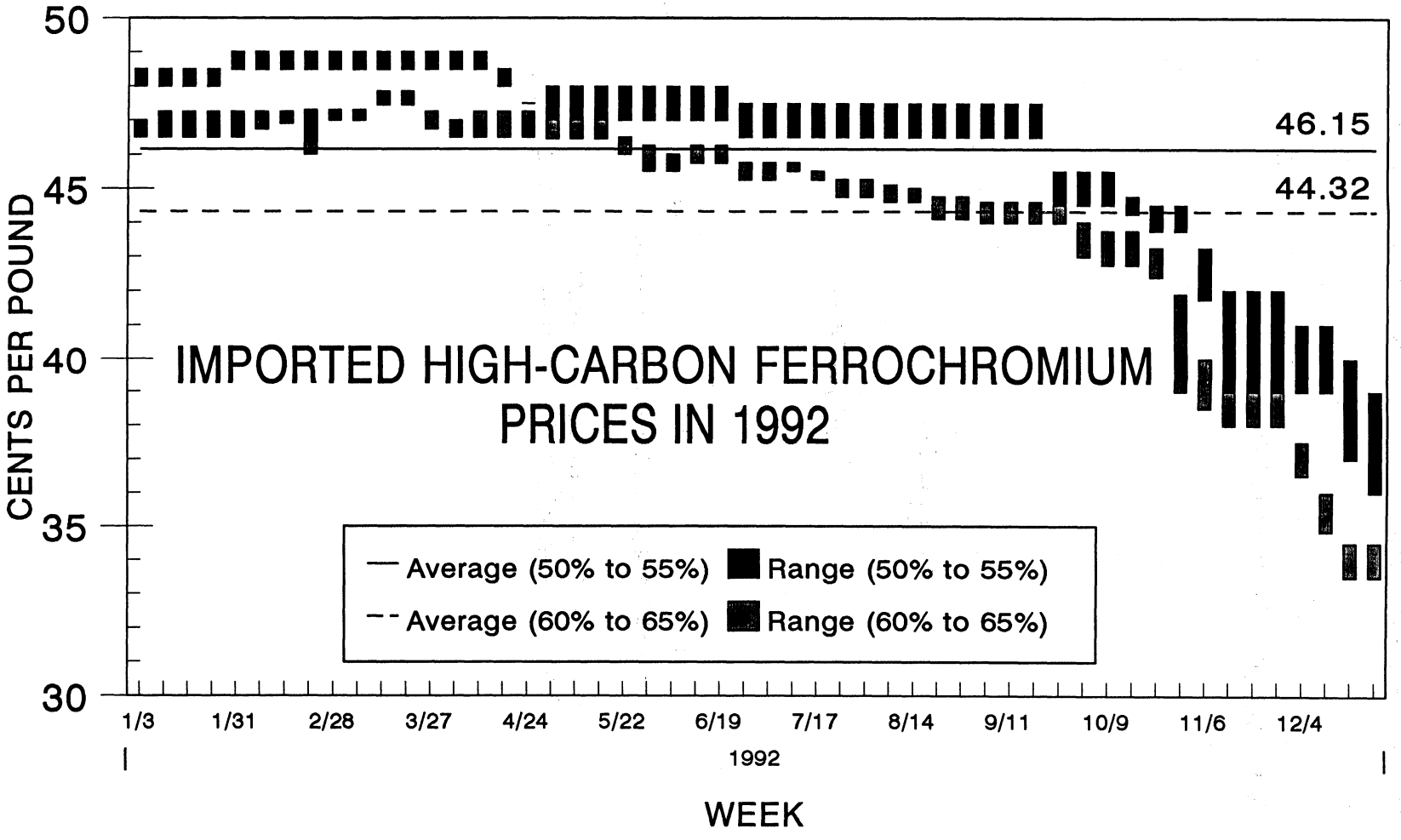
FIGURE 4

COST OF HIGH-CARBON FERROCHROMIUM PRODUCTION AT 0% AND 15% DISCOUNTED CASH-FLOW RATE OF RETURN (DCFROR) FOR SELECTED MARKET ECONOMY PRODUCERS



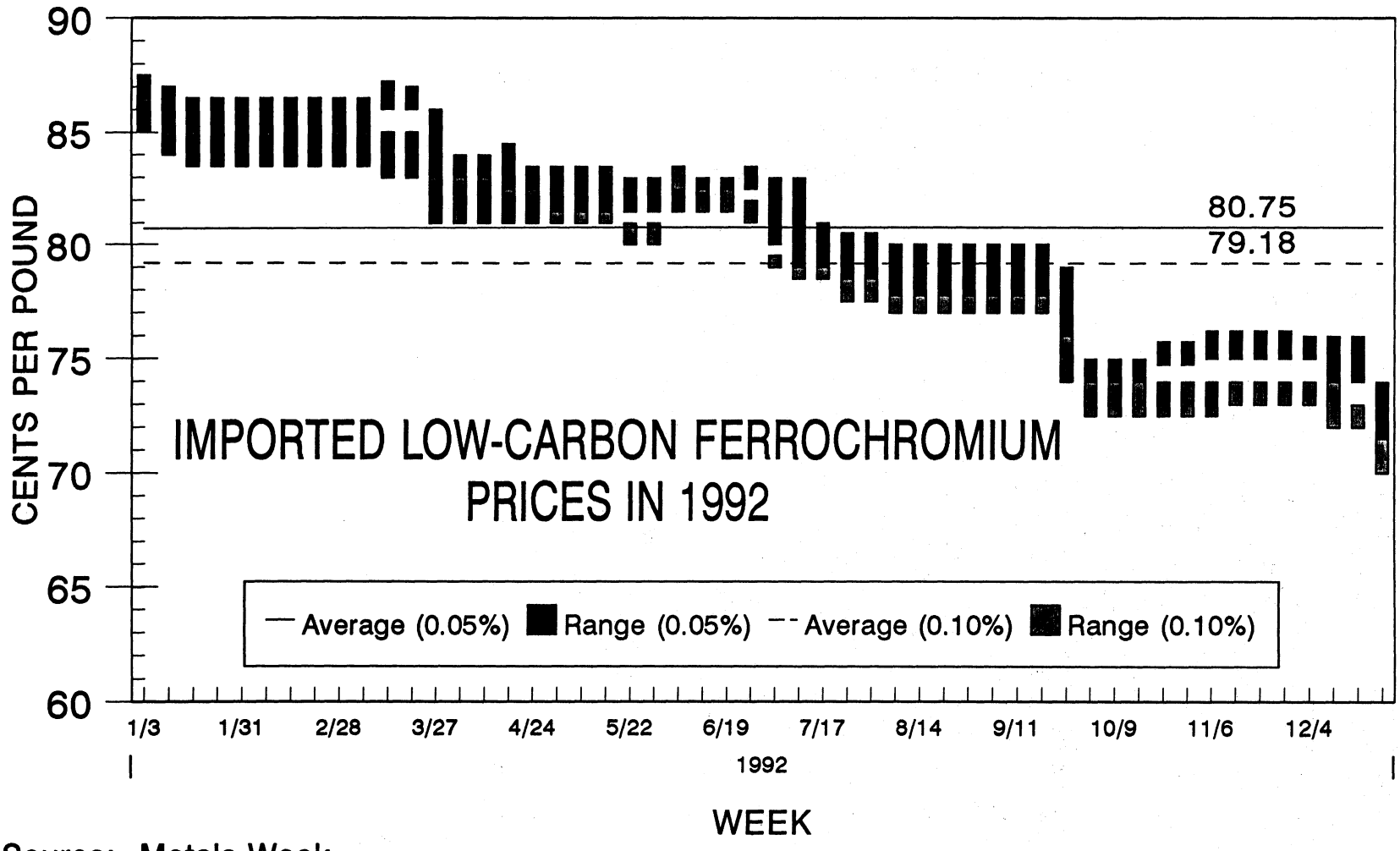
NOTE.--DCFROR is discounted cash-flow rate of return.
Source: U. S. Bureau of Mines, Minerals Availability System cost analysis.

FIGURE 5
IMPORTED HIGH-CARBON FERROCHROMIUM WEEKLY PRICE RANGE AND TIME-AVERAGED ANNUAL PRICE IN 1992



Source: Metals Week.

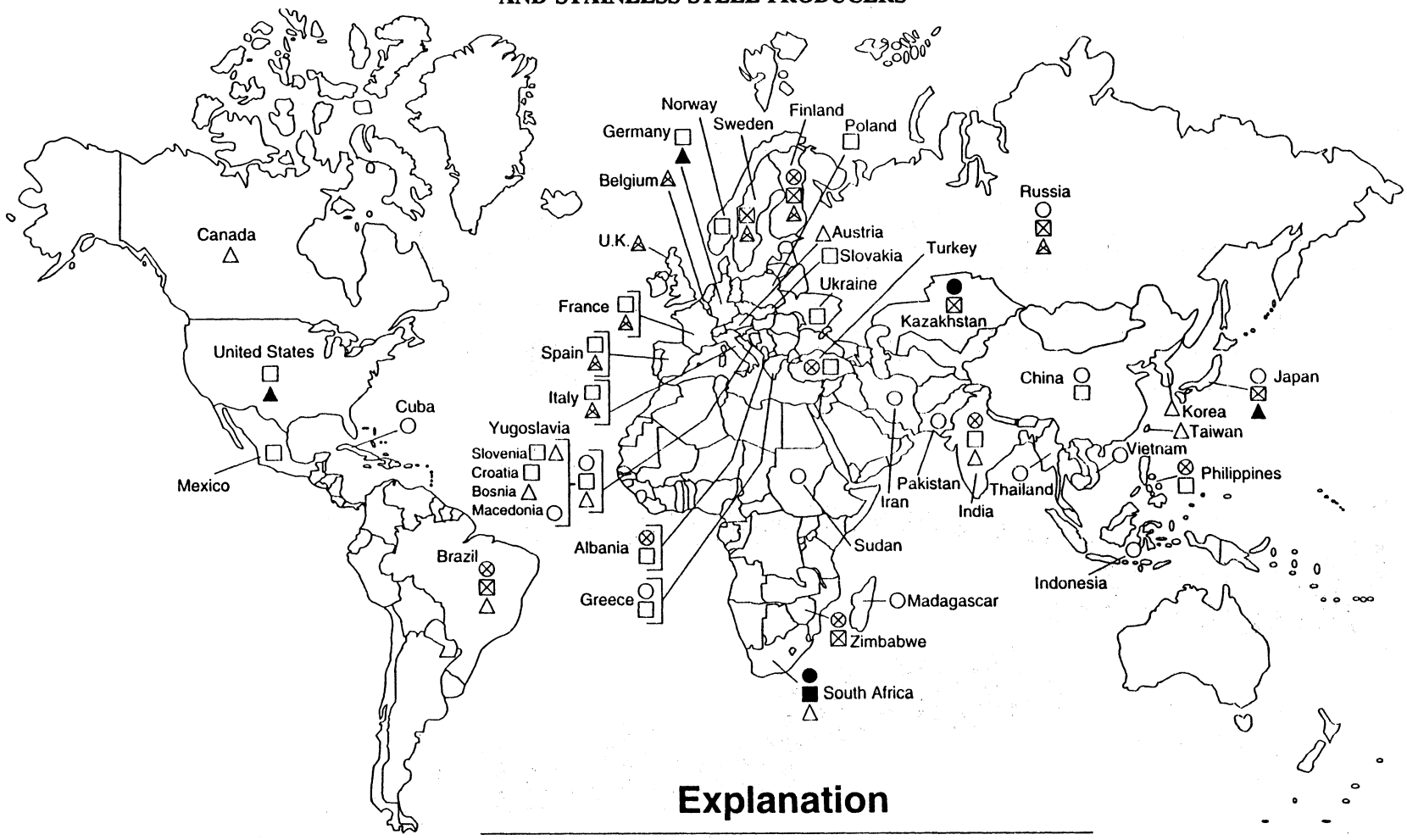
FIGURE 6
IMPORTED LOW-CARBON FERROCHROMIUM WEEKLY PRICE RANGE AND TIME-AVERAGED ANNUAL PRICE IN 1992



Source: Metals Week.

FIGURE 7

WORLD GEOGRAPHIC LOCATION AND SIZE OF CHROMITE ORE, FERROCHROMIUM, AND STAINLESS STEEL PRODUCERS



Explanation

	Producer size		
Material	**Major**	**Intermediate**	**Minor**
Chromite ore	●	⊗	○
Ferrochromium	■	⊠	□
Stainless steel	▲	◬	△

FIGURE 8

STRUCTURE OF THE TURKISH CHROMIUM INDUSTRY IN 1992. MAJOR RELATIONSHIPS AMONG TURKEY'S CHROMITE ORE, CHROMIUM FERROALLOY AND CHEMICAL, AND STAINLESS STEEL PRODUCERS

Company structure	Mine/plant location(s)	MAPCC[1]	Processing industry/location
Akpaş Madencilik ve Paz. ve Ticaret A.Ş.	Erzurum province Erzincan province Kayseri province	B	Concentrator, Kayseri province.
Bilfer Madencilik A.Ş.	Hatay province Kayseri province Malatya province Sivas province	B	Concentrators; Hatay, Sivas, and Malatya provinces.
Birlik İnşaat, Madencilik San. ve Tic. A.Ş.	Erzurum province Erzincan province Kayseri province Muğla province Pozantı province	C	Concentrators, Fethiyi and Pozantı provinces.
Bursa Toros Kromları A.Ş.	Bursa province Adana province	NA	--
Dedeman Madencilik Turizm Sanayi ve Ticaret A.Ş.	Kayseri province	B	Concentrator, Kayseri province.
Egemetal Madencilik A.Ş.	Bursa province Eskisehir province Erzurum province Mersin area, İçel province	B	Concentrators, Bursa and İçel provinces.
Etibank Genel Müdürlüğü (state owned)	Üçköprü district, Muğla province Güleman area, Elaziğ province Harmancık area, Bursa province	C	Concentrators, Elaziğ and Muğla provinces. Etibank Mah. Mes. Antalya Elektrometalurji Sanayii İşl. Mües. Müd. (Antalya Ferrochromium Works). Muğla province. Etibank Mah. Mes. Şark Kromları İşletmesi Mües. Müd. (Eastern Chromite and Ferrochromium Works). Elaziğ province.
Güneydoğu Madencilik	İskenderun area, Hatay province Gaziantep province	A	--
Köyceğiz Kromları İşl.	Köyceğiz area, Muğla province	A	--
Madsaş Madencilik Sanayi ve Ticaret A.Ş.	NA	A	--
Mikro Maden Sanayi A.Ş.	Gaziantap province Hatay province	A	--

See footnotes at end of table.

FIGURE 8—Continued

STRUCTURE OF THE TURKISH CHROMIUM INDUSTRY IN 1992. MAJOR RELATIONSHIPS AMONG TURKEY'S CHROMITE ORE, CHROMIUM FERROALLOY AND CHEMICAL, AND STAINLESS STEEL PRODUCERS

Company structure	Mine/plant location(s)	MAPCC[1]	Processing industry/location
Ögel Madencilik ve Ticaret	Harmancık area, Bursa province	A	Concentrator, Bursa province.
Hayri Ögelman Madencilik Ltd. Şti.	Harmancık operation, Bursa province	A	--
Pınar Madencilik ve Turizm	Kayseri province Adana province	A	Concentrator, Adana province.
Rasih ve İhsan Madencilik	Eskişehir province	A	--
Sino-Çoban Doğu Madencilik	İskenderun area, Hatay province	A	--
Türk Maadin Şirketi (AŞ)	Köyceğiz area, Muğla province Eskişehir province	A	Concentrators; Eskişehir, Denizli, and Muğla provinces.
Makina Kimya Endüstrisi Kurumu (state owned)	--	--	MKEK Çelik Fabrikası (stainless steel producer) Ankara province, Kırıkkale.
T.İş Bankası A.Ş. and T. Şişe Cam Fabrikalari T.A.Ş.	--	--	Kromsan Bileşikleri Sanayi ve Ticaret (plant operator) Soda Sanayii AŞ (Chromium chemical producer) İçel province, Mersin city.

[1]Mine Annual Production Capacity Code: A -- 1,000 - 30,000 tons; B -- 30,000 - 100,000 tons; C -- More than 100,000 tons.

Abbreviations used:

A.Ş. Anonim Şirketi.	Mah. Mahdut.	Mües. Müessesesi.	San. Sanayi.
Işl. İşletmeleri or İşletmesi.	Mes. Mesuliyetli.	NA Not Available.	Şti. Şirketi.
Ltd. Limited.	Müd. Müdürlüğü.	Paz. Pazarlama.	T. Türk or Türkiye.

Note: Some of the operations listed may not have been producing in 1992.

Sources:

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Yüksel, E. Corona Cyndicate, Dardanel Madencilik Sanayi ve Ticaret A.Ş. Private communication.

CLAYS

By Robert L. Virta

Mr. Virta, a physical scientist with 17 years of U.S. Bureau of Mines experience, has been the commodity specialist for clays since 1992. 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 decreased slightly in tonnage to 40.7 million metric tons and increased slightly in value to $1.5 billion. Production of ball clay, bentonite, common clay, fire clay, and fuller's earth increased in 1992. Kaolin production decreased. Common clays accounted for 61% of the tonnage. Kaolin accounted for 63% of the value of clays produced in 1992. Imports increased 17% in tonnage to 41,200 tons and 17% in value to $15.5 million. Exports increased 4% in tonnage to 4.2 million tons and increased 12% in value to $663.5 million. (*See table 1.*)

Clays were produced in 44 States and Puerto Rico. The 10 leading producer States, in descending order, were Georgia, Wyoming, Alabama, Ohio, Texas, North Carolina, California, South Carolina, Michigan, and Missouri. (*See table 2.*)

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 649 operations covered by the survey, 480 responded, representing 73% of the total clay and shale production sold or used shown in table 1. (*See table 1.*)

With the downsizing of the Federal Government, the U.S. Bureau of Mines has experienced reductions in both budget and personnel. As a result, greater emphasis is being placed on reducing the size of commodity chapters (and the workload associated with their preparation) while providing information useful to industry. This year several tables were eliminated. The information in these tables was either available from other sources such as the Bureau of the Census or was duplicative of other tables. Users of this report are encouraged to contact the commodity specialist and indicate the information that is most crucial to their needs.

BACKGROUND

Definitions, Grades, and Specifications

Clays are categorized into six groups by the U.S. Bureau of Mines. The categories are ball clay, bentonite, common clay and shale, fire clay, fuller's earth, and kaolin. The definitions listed in this work for ball clay, fire clay, high-alumina clays, and kaolin are similar to those in U.S. Bureau of Mines Information Circular 8335.[1]

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.

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.

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.

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 alkalies 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 ball clay, bauxitic clay and shale, burley, burley-flint, and diaspore. 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.

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.

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.

The American Society for Testing and Materials, American Foundrymen's Association, American Oil Chemists' 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 385 companies operating 1,139 clays pits or mines reported production in 1992; of these, 85 companies, most with multiple operations, accounted for approximately 41% of the tonnage and 62% 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, 9.0 million tons; Wyoming, 2.5 million tons; Alabama, 2.4 million tons; Ohio, 2.3 million tons; Texas, 2.2 million tons; North Carolina, 2.1 million tons; California, 1.9 million tons; South Carolina, 1.6 million tons; Michigan, 1.3 million tons; and Missouri, 1.2 million tons. (*See table 2.*) Most of the clay is mined by open pit methods. Less than 1% of U.S. clay output was from underground mines in 1992. Most of the underground production was in Pennsylvania, Ohio, and West Virginia, where the clays are mainly underclays associated with coal and suitable for refractory uses.

The ball clay industry was small, with 6 producers operating 36 mines in 5 States in 1992. Three of the producers were large, diversified firms with widespread foreign and domestic mineral interests. Tennessee ball clay production represented about 76% of the total output.

Firms producing bentonite operated 144 mines in 13 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 76% of the total output. Swelling-type bentonite was produced mainly in Wyoming and Montana and nonswelling-type bentonite was produced in Mississippi and Texas. The United States was the world's largest producer and exporter of bentonitic clays.

Firms producing common clay and shale in 1992 were manufacturers of structural clay products, clay pipe, lightweight aggregates, and cement. Most companies mined the clays used in making their products. Less than 10% of the total output is usually sold. 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 to cover a large market area. The economic radius for shipment of common clay or shale products was usually 320 kilometers 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.

Fireclay producers were mostly refractories manufacturers that used the clays in firebrick and other refractories. Seventy-eight mines were operated in 1992 by 19 firms in 9 States.

Nineteen companies produced fuller's earth from 37 mines in 11 States. Eleven of the mines were in the attapulgite-fuller's earth areas of Florida and Georgia. These two States accounted for most of the domestic attapulgite 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.

Forty-two firms operated 141 kaolin mines in 11 States. In 1992, three large, diversified firms accounted for about 60% of total domestic kaolin output. Most large kaolin producers have operations in Georgia, which accounted for 85% of the kaolin production.

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 feldspar, iron oxides, micas, and quartz. 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 earths 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 Georgia and Florida 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 are 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 different ways. Processing can consist of very simple and inexpensive grinding or shredding and screening for some common clays. Very complex and expensive grinding or shredding, sizing, leaching, delamination, etc., may be required 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 feldspar, iron-bearing minerals, mica, and quartz.

Ball Clay.—Processing involves drying, shredding, pulverizing, air floating, and slurrying.

Bentonite.—Processing involves weathering, drying, grinding, sizing, granulation, and the use of additives for cation exchange.

Common Clay and Shale.—Processing involves shredding, 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.

Fire Clay.—Processing involves shredding, calcining, and blending.

Fuller's Earth.—Processing involves blunging, extruding, drying, crushing, grinding, sizing, and dispersing.

Kaolin.—Processing involves one or more of the following: shredding, blunging with dispersant, degritting, water fractionation, magnetic separation, ultraflotation, acid treatment, calcination, air floating, attrition grinding, slurrying, and delaminating. Kaolins used for paper coating applications may be leached and further delaminated by grinding, deflocculation, and centrifugation to special sizes. Ultraflotation or wet magnetic separation treatment may be used to remove iron- or titanium-bearing minerals to obtain a whiter 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 clay 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 attapulgite-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 1992 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 prevent or 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. The Mine Health and Safety Administration has proposed enacting a similar HCS.

Although domestic clay resources are more than adequate, the prices for clays are expected to rise. The increase reflects 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.

Production

Ball Clay.—Production of domestic ball clay increased 9% to 853,828 tons valued at about $36 million. Tennessee supplied 67% of the Nation's output, followed by, in descending order of production, Kentucky, Texas, Mississippi, and Indiana. Production increased in Tennessee and Texas, was unchanged in Indiana and Mississippi, and decreased slightly in Kentucky. (*See table 3.*)

United Clays of Texas Inc., a subsidiary of Watts Blake Bearne and Co. PLC, purchased the ceramics division of Southern Clay Products Inc. Included in the purchase were the ball clay and soapstone mining and processing facilities.[7]

Bentonite.—The quantity and value of bentonite sold or used increased slightly to 3.35 million tons and $125.4 million, respectively. Wyoming was the largest bentonite producer, accounting for 76% of the total bentonite production and 90% of the swelling bentonite production. Mines in Alabama and Mississippi accounted for more than 61% of the nonswelling or calcium bentonite production. Production of swelling bentonites increased in Wyoming and Montana. Increases in production of nonswelling bentonite were reported in Arizona and Mississippi. Decreases were reported in other producing States. (*See table 5.*)

Bentonite Corp. began construction of a new processing plant. The plant will manufacture two products that contain between 50% to 99% bentonite for the metal casting industry. The plant will have a capacity of 127,000 tons and will consume 90,000 tons of bentonite per year.[8]

Common Clay and Shale.—Domestic sales or use of common clay and shale increased slightly in tonnage to 25.0 million tons and increased 4% in value to $136.7 million. The 10 major producing States were Texas, Ohio, North Carolina, Alabama, California, Georgia, Michigan, South Carolina, Missouri, and Indiana, in descending order of tonnage. Of these States, production increased in Georgia, Michigan, Missouri, North Carolina, Ohio, and Texas. Common clay and shale represented about 61% of the quantity but only 9% of the value of total domestic clay production. (*See table 7.*)

Fire Clay.—Fire clay sold or used by domestic producers increased significantly in tonnage and value to 1.1 million tons and $15.8 million, respectively. The large increase resulted from the reclassification of a kaolin producer with mines in Alabama and Georgia to the fire clay category, based on the mineralogy of the deposits and the end-use applications for the clay. Georgia was the leading producing State, followed by Alabama, Missouri, Ohio, Arkansas, Colorado, New Mexico, New Jersey, and Washington. (*See table 9.*)

Fuller's Earth.—Production of fuller's earth increased 4% to 2.4 million tons valued at $242 million. Production was reported in 11 States. Production from the region that includes Attapulgus, Decatur County, GA, and Quincy, Gadsden County, FL, was composed predominantly of the lath-shaped amphibolelike clay mineral attapulgite. Florida and Georgia accounted for most of the domestic attapulgite production. Most of the fuller's earth produced in other areas of the United States contains varieties of montmorillonite and/or other clays. Illinois, Mississippi, and Missouri accounted for more than one-half of the domestic montmorillonite-fuller's earth production. (*See table 11.*)

Kaolin.—Domestic production of kaolin decreased 16% to 8.1 million tons. The value of production increased slightly

to $926.6 million. The decline resulted from the reclassification of a kaolin producer with mines in Alabama and Georgia to the fire clay category based on the mineralogy of the deposits, end-use applications, and unit value for the clay. Kaolin was produced in 14 States. Georgia was the largest kaolin producer with 85% of U.S. production, followed by South Carolina with 6% of production. Georgia accounted for 95% of the total production value of kaolin. (*See table 13.*)

More than 50% of the kaolin produced was water-washed; followed by delaminated, 16%; air-floated, 14%; calcined, 9%; and unprocessed, 9%. (*See table 14.*) Delaminated kaolin was produced exclusively in Georgia. Georgia also accounted for 99% of the production of water-washed kaolin and 78% of the calcined kaolin. Georgia and South Carolina accounted for 94% of the air-floated kaolin and 48% of the unprocessed grades. (*See tables 14, 15, 16, and 18.*)

ECC International began expanding the production capacity of its kaolin operations in Georgia. Capacity will be increased by 650,000 tons per year upon completion of the expansion. ECC began the project in anticipation of increasing demand in Europe, the Far East, and the United States.[9]

Albion Kaolin Co. completed its new kaolin slurry plant. The company constructed the new plant because of rising demand for slurried products.[10] Albion Kaolin also formed a joint venture with Old Hickory Clay Co. to provide kaolin and ball clay products to the ceramic and refractory industries.[11]

Kemira Inc. announced its intention to acquire 20% of Nord Kaolin Co. Nord Kaolin produces approximately 300,000 tons of kaolin per year from mines near Jeffersonville, GA. The company markets kaolin for the paper industry.[12]

Consumption and Uses

Ball Clay.—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.

The principal ball clay markets were dinnerware, floor and wall tile, and sanitaryware with 15%, 22%, and 15%, respectively, of the domestic consumption. Consumption of ball clay for dinnerware, floor and wall tile, and refractories increased in 1992. (*See table 4.*)

Bentonite.—The swelling sodium bentonites were used largely in drilling muds, in foundry sands, and in pelletizing taconite iron ores. The nonswelling or calcium bentonites were 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.

Bentonite also was used for foundry casting by the steel, iron, and nonferrous casting. The bentonite provided good green strength and desirable dry strength characteristics. Sodium bentonites were used in steel casting. Ion-exchanged bentonites were used for iron and nonferrous casting. There has been an increased use of mixtures of ion-exchanged and sodium bentonites to meet the more stringent demands of the casting industry. Calcium bentonite produced in Alabama and Mississippi was suitable for the production of absorbent, acid-activated, and foundry products.

The three major end uses were drilling mud, foundry sand, and iron ore pelletizing with 22%, 17%, and 23%, respectively, of total domestic sales. Sales of bentonite for foundry sand applications increased 4%. Sales of bentonite for drilling and pelletizing applications each decreased 7% and 6%, respectively. Producers that sold bentonite for pelletizing iron ore did not separate domestic and foreign shipments, in all cases. An estimated 100,000 to 130,000 tons was exported for pelletizing, making U.S. markets about 540,000 to 570,000 tons. Increases in consumption were reported for animal feed, foundry sand, and water proofing and sealing. (*See table 6.*)

Common Clay and Shale.—Common clay was used most frequently in the manufacture of heavy clay products, including (1) building brick; flue linings, sewer pipe, drain tile, structural tile, and terra cotta; (2) portland cement clinker; and (3) lightweight aggregate, accounting for 51%, 31%, and 14%, respectively, of total domestic consumption. Consumption increased 4% for heavy clay products and decreased 6% and 2% for lightweight weight aggregates and portland cement clinker, respectively. A large increase in consumption reported for floor and wall tile does not correspond to construction trends. It possibly represents a better accounting of end-use consumption as shown by the smaller tonnages reported under the "Other" category. (*See table 8.*)

Fire Clay.—Fire clays were used mostly in commercial refractory products such as firebrick and block, grogs and calcines, high-alumina brick and specialties, saggers, refractory mortars and mixes, and ramming and gunning mixes. Fire clays also were used to produce lightweight aggregates, portland cement, pottery, and common brick. Fire clay was used to increase the vitrification range of sewer pipes and bricks.

Consumption of fire clay for firebrick declined sharply in 1992 yet still accounted for 16% of consumption. There was a large increase in calcine use in 1992. This resulted from the reclassification of a kaolin producer to the fire clay category based on mineralogy and end-use applications. Grogs, calcines, high-alumina brick, and specialties accounted for 71% of fire clay use. (*See table 10.*)

Fuller's Earth.—Fuller's earth and calcium bentonite were used for decolorizing and purifying mineral, vegetable, and animal oils. Clays activated by acid treatment were used to process animal or vegetable oils. Acid treatment produced a highly absorbent sievelike structure. Attapulgite is used in

drilling muds instead of sodium bentonites for drilling saltwater formations. Sodium bentonite flocculates in brine, thereby destroying the gel-like colloidal suspension required for drilling. The major uses for attapulgite and montmorillonite types of the fuller's earths were in pet waste and oil and grease absorbents because of their absorbent properties.

Attapulgite, a fuller's earth-type clay, found wide application in both absorbent and gelling and/or thickening areas. The thixotropic properties of attapulgite clays provided important thickening and viscosity controls necessary for suspending solids. Mineral thickeners were used in such diverse markets as paint, joint compound cement, and saltwater drilling mud.

The major use for fuller's earths was in pet waste absorbents, which accounted for 59% of the fuller's earth consumption. Other major domestic uses were oil and grease absorbents (19%) and pesticide carriers (7%). The use of montmorillonite for oil and grease absorbent applications increased in 1992. Consumption of fuller's earth did not change significantly for other applications. (*See table 12.*)

Kaolin.—Kaolin had many industrial applications, and many grades were specifically designed for use as a filler in paper, paint, rubber, plastics,[13] and ceramics.[14] 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.[15]

Kaolin producers reported major domestic end uses as paper coating, 43%; paper filling, 18%; fiberglass, 6%; paint, 4%; rubber, 3%; brick, 3%; portland cements, 3%; and grogs and calcines, 3%. (*See table 20.*) There was a large apparent decrease in calcines and grog production in 1992. The decline resulted from the reclassification of a kaolin producer with mines in Alabama and Georgia to the fire clay category, based on the mineralogy of the deposit, end-use applications, and unit value.

There were distinct differences in markets for kaolin from Georgia and South Carolina. Major domestic markets for kaolin from Georgia were paper coating (52%), paper filling (21%), fiberglass (5%), and paint (4%). Major markets for kaolin from South Carolina were rubber, fiberglass, catalyst, and adhesives, in decreasing order of consumption. (*See tables 17 and 19.*)

Absorbent Uses.—Absorbent uses for clays accounted for about 2.2 million tons or 5% of total clay consumption. Consumption was for oil and grease absorbents, 21%; pet waste absorbents, 65%; and miscellaneous absorbent applications, 14%. Demand for absorbents increased 5% in 1992. Fuller's earth was the principal clay used for absorbent purposes (1.9 million tons), followed by bentonite (299,000 tons). (*See tables 6 and 12.*) Small amounts of ball clay and kaolin also were used for absorbent applications.

Ceramics.—Pottery and related products required good ceramic qualities, including plastic formation, desirable firing temperatures, color, etc. The principal clays meeting these and other specifications were ball clay, common clay, and kaolin. Total demand for clay in the manufacture of pottery, sanitaryware, china and dinnerware, and related products (excluding clay flower pots) exceeded 871,000 tons. Common clay and shale, ball clay, and kaolin, in order of volume, were used in manufacturing floor, wall, and quarry tile. Demand in floor, wall, and quarry tile applications increased to 619,000 tons in 1992. (*See tables 4, 8, 10, and 20.*)

Construction.—Common clays and shales were used to manufacture a wide variety of construction materials such as expanded aggregates, hydraulic cement, and structural clay products.

Expanded Clay and Shale.—Materials with specific bloating properties and strength are required for this use. Lightweight concrete blocks, floors, walls, and other products made from expanded clay and shale have a lower overall weight and better insulating qualities than equivalent products made with sand and gravel and crushed stone aggregates.

Consumption of common clay and shale in the production of lightweight aggregate decreased 6% to 3.4 million tons. Concrete block, which accounted for 62% of total lightweight aggregate production, decreased 13%. Structural concrete, which accounted for 21% of the market, decreased 2%. Highway surfacing, with 8% of lightweight aggregate production, declined slightly. (*See tables 8, 10, and 21.*)

Neutralysis Industries Development Co. announced plans to develop a lightweight aggregate plant that utilizes municipal waste in the process. Pulverized waste will be mixed with milled clay and liquid wastes and pelletized. The pellets will be fed into a multiple kiln plant. The waste in the pellets will be gasified and oxidized in the first and second kilns, respectively. A third will be used to vitrify the expanded clay.[16]

Hydraulic Cement.—Clays provide the alumina and silica required to manufacture hydraulic cements. Common clays, kaolin, fuller's earth, fire clay, and bentonite, in decreasing order of consumption, were used in cement products. Approximately 97% of the clay consumed by the cement industry was common clay. (*See tables 8, 12, and 20.*)

Structural Clay Products.—Structural clay products include such items as building brick, drain tile, flue linings, roofing tile, sewer pipe, and terra cotta. Clays for structural applications must be plastic and easily shaped, must not warp during firing, and must produce

a product with adequate strength. Common clay is most commonly used in these applications (99% of clay consumption for structural clay products). Other clays, such as ball clay, bentonite, fire clay, and kaolin, are not used in large tonnages because of their higher cost.

Slightly more than 12.9 million tons of clay was consumed for structural clay products. Common and face brick accounted for 94% of this total or 12.1 million tons. Other markets, in decreasing order of consumption, were sewer pipe, flue linings, structural tile, terra cotta, drain tile, and roofing tile. (*See tables 8, 10, 20, and 22.*)

The value reported by the Bureau of the Census for shipments of building and face brick was 5.8 billion bricks valued at $885 million, an increase from that of 1991. Shipments of clay floor and wall tile increased to almost 44 million square meters of tile valued at $638 million. Shipments of vitrified clay and sewer pipe fittings decreased to 138,000 tons valued at $35 million.

Drilling Mud.—Drilling mud is a scientifically designed mixture of several items. The clays are used to adjust the viscosity and gel strength of the drilling fluid and to coat the drill-hole walls to prevent fluid loss. Drilling muds contain, in addition to bentonite or attapulgite, ground barite for its high specific gravity.[17] Demand for clays in rotary-drilling muds decreased to about 663,000 tons. 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 also were used to a limited extent. (*See tables 6 and 12.*)

Filler.—Clays are used as binders, extenders, and fillers in a wide variety of products, ranging from adhesives to flooring products to paint to rubber. They are added to products for widely varying reasons. For example, clays displace more expensive product components in paint, paper, and plastics; improve the ink retention and opacity in paper; prevent pigment settling in paints; act as carriers for fertilizers and pesticides; and increase the strength of plastics.

More than 4.4 million tons of clays was used as fillers and extenders. Kaolin accounted for approximately 90% of this amount, followed by fuller's earth, bentonite, ball clay, and common clay, in decreasing order of consumption. (*See tables 4, 6, 8, 12, and 20.*) Slightly less than 80% of the kaolin was used for paper-coating and paper-filling applications. Kaolin also was used in the manufacture of products such as adhesives, cosmetics, fertilizer, ink, linoleum, paint, pesticides, plastics, and rubber. (*See table 20.*) Fuller's earth was used mainly in pesticides, fertilizers, and animal feed. Lesser amounts were used in adhesives, asphalt emulsion, and paint, in decreasing order of consumption. (*See table 12.*) Bentonite was used mainly in animal feed with smaller amounts used for the manufacture of adhesives, asphalt emulsions, cosmetics, paint, and pesticides. (*See table 6.*) Major ball clay uses were in animal feed, asphalt emulsion, asphalt tile, paper, and wall board. Common clay was used mainly in animal feed and asphalt emulsions. Small amounts of fire clay were used in animal feeds.

Glass.—Exacting chemical and physical specifications are required for clay used in glass manufacturing. More than 379,000 tons of kaolin, or 99% of all clay used for glass manufacture, was used in fiberglass. Small amounts of kaolin and bentonite were used as a raw material feed in formulating bottle and plate glass batches and mineral wool. (*See table 20.*)

Iron Ore Pelletizing.—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. Demand decreased from 717,000 tons in 1991 to 675,000 tons in 1992. (*See table 6.*) Small amounts of common clay also were used for iron ore pelletizing. (*See table 8.*)

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. It serves to provide a smooth coating to paper, improves its ink retention and brightness, increases the paper density, fills interstices in the paper, and improves opacity. Kaolin accounted for essentially all of the clay used for paper coating (2.7 million tons) and 99% of the clay used for paper filling (1.1 million tons). (*See table 20.*) Small amounts of ball clay and fuller's earth were used in paper-filling applications and a small amount of bentonite was used for paper coating.

Clays also were important for newspaper recycling. During recycling, either washing or flotation is used to remove the ink from the newspaper stock. In the flotation process, clay was added to the pulp slurry. The clay absorbed ink on its surface and floated to the surface, where it was skimmed off, leaving clean, ink-free pulp.[18]

Refractories.—Refractories require strength at high temperatures, resistance to corrosion, low coefficient of expansion, and many other physical and chemical properties, depending on application. Clays with physical properties most suitable for general refractory use have been classified as fire clays. The current trend is for refractories designed for a specific use and castable mixes containing refractory aggregates and calcium aluminate cements.[19] Bentonite, both swelling and nonswelling, was used as a bonding agent in proprietary foundry formulations imparting both hot- and green-strength to the sand.

More than 1.7 million tons of clays was used for the manufacture of refractories. Ball clay, bentonite, common clay, fire clay, and kaolin accounted for 3%, 27%, 6%, 52%, 12%, respectively, of the refractories markets. Major uses were firebrick for ball clay and common clay; foundry sand for bentonite; grogs, calcines, and firebrick for fire clay; and grogs and calcines for

kaolin. (*See tables 6, 10, and 20.*)

Markets and Prices

Ball Clay.—The average unit value for ball clay reported by domestic producers was $42.42 per ton. The unit value of imported ball clay was $329.04. The unit value of exported ball clay was $63.67 per ton.

Bentonite.—The unit value reported by domestic producers for nonswelling bentonite was $47.84 per ton. The unit value for swelling bentonite was $35.39 per ton. The unit value for all bentonite was $37.38 per ton. The unit value of imported bentonite was $497.43 per ton. The unit value of exported bentonite was $90.78 per ton.

Common Clay and Shale.—The average unit value for all common clay and shale produced in the United States and Puerto Rico was $5.44 per ton. The unit value of clay and shale used in lightweight aggregate was $8.34 per ton.

Fire Clay.—The unit value for fire clay reported by domestic producers was $15.02 per ton. The unit of imported fire clay was $115.84 per ton. The unit value of exported fire clay was $103.23 per ton.

Fuller's Earth.—The unit value of attapulgite-fuller's earth reported by domestic producers was $137.46 per ton. The unit value of montmorillonite-fuller's earth was $77.81 per ton. The average unit value of all types of fuller's earth was $100.14 per ton. The unit value of imported fuller's earth was $193.75 per ton. The unit value of exported fuller's earth decreased to $148.96 per ton.

Kaolin.—The unit value of kaolin increased to $114.91 per ton for all kaolin grades. The unit value for air-float kaolin was $53.10 per ton; for calcined kaolin, $313.51 per ton; for delaminated, $113.79 per ton; for water-washed kaolin, $112.38 per ton; and for unprocessed kaolin, $19.56 per ton. The unit value of the imported kaolin was $502.72 per ton. The unit value of exported kaolin was $163.62 per ton.

Foreign Trade

Ball Clay.—Ball clay exports decreased 16% to 49,000 tons valued at $3.1 million, according to the Bureau of the Census. Shipments were made to 19 countries. The major importer was Mexico, with 71% of the exports. (*See table 23.*) Domestic ball clay producers reported that 99,678 tons of ball clay was exported in 1992. The exports were used mainly for floor and wall tile production and sanitaryware production. Other uses include asphalt emulsions (4%), miscellaneous filler and extender applications, wallboard, and miscellaneous ceramics applications. (*See table 4.*)

The discrepancy between the Bureau of the Census and the tonnage producers reported as exports probably resulted because some shipments of clays may be classified under a nonspecific mineral category by the Bureau of the Census. Shipments classified under the nonspecific mineral category would not appear in the Bureau of the Census' ball clay export statistics.

Ball clay was imported only from the United Kingdom. Imports decreased 7% to 699 tons valued at $230,000. (*See table 24.*)

Bentonite.—Bentonite exports decreased 10% to 591,000 tons valued at $53.7 million. Bentonite was exported to 58 countries with Japan and Canada accounting for 55% of the exports. Domestic bentonite producers reported exports of 471,916 tons. This is 120,000 tons less than the Bureau of the Census data show but is accounted for by the inclusion of 100,000 to 130,000 tons of bentonite for Canadian iron ore pelletizing under domestic sales. Estimated markets for exported bentonite were foundry sand (49%), drilling mud (20%), and iron ore pelletizing (20%). Bentonite also was exported for absorbents, decolorizing and clarifying animal oils, desiccants, fertilizer carriers, ink, cosmetics, paint, and waterproofing. (*See tables 6 and 23.*)

Bentonite imports consisted mainly of untreated bentonite clay and chemically or artificially activated materials. Imports of untreated bentonite increased 14% to 2,527 tons valued at $1.3 million. Most of this material was imported from Canada (47%). Imports of chemically activated material increased 5% to 15,070 tons valued at $9.8 million. Mexico supplied 83% of the chemically activated bentonite imported into the United States. (*See table 24.*)

Fire Clay.—Exports of fire clay increased 15% to 228,000 tons valued at $23.5 million. Fire clay was exported to 33 countries. The major importers were the Netherlands, Mexico, and Japan. These countries accounted for 71% of the exports. According to the Bureau of the Census, 8,089 tons of fire clay valued at $937,000 was imported in 1992. Most of the fire clay was imported from China (94%). Fire clay also was imported from Spain, Canada, the United Kingdom, and Japan. (*See tables 23 and 24.*)

Fuller's Earth.—Exports of fuller's earth were 27,000 tons valued at $4 million. Fuller's earth was exported to 27 countries. The major importers were Canada (30%) and the Netherlands (26%). Domestic producers reported more than 82,000 tons of bentonite exports in 1992. (*See table 12.*) As with ball clay, the discrepancy between the producers' and the Bureau of the Census' statistics is probably one of clay classification (see discussion under Ball Clay). The major market for exported fuller's earth was pet waste absorbents. Other markets were ceramic tile, foundry sand, cosmetics, oil and grease absorbents, paint, and pesticide carriers. Small amounts of decolorizing fuller's earth were imported from Canada and Germany. (*See tables 12, 23, and 24.*)

Kaolin.—Exports of kaolin reported by the Bureau of the Census increased 5% to 3 million tons valued at $491 million. Kaolin was exported to 69 countries. Major importers were Japan, Canada, Finland, the Netherlands, and Italy.

Major end-use markets reported by producers were paper coating (75%) and paper filling (11%). (*See tables 20 and 23.*) Other markets included catalysts, fiberglass, paint, rubber, and sanitaryware production.

Kaolin imports for consumption increased 25% to 4,221 tons valued at $2.1 million. The United Kingdom supplied 75% of the kaolin imports. (*See table 24.*)

World Review

World production of kaolin decreased 10%, bentonite production decreased 5%, and fuller's earth production decreased 8% from productions of 1991. (*See tables 25, 26, and 27, respectively.*)

Brazil.—Rio Capim Quimica Companhia Vale do Rio Doce and Caemi Mineracao e Metalurgia SA began planning for a kaolin mining operation in northern Brazil. The kaolin deposit has measured reserves of 40 million tons and estimated reserves of 150 million tons. The companies will focus sales on the papermaking markets in Europe and Asia.[20]

Caulim da Amazonia S.A. awarded a contract for the installation of a high-gradient magnetic separator (HGMS). The HGMS, which can process 20 to 40 tons of kaolin per day, will be installed at the plant in Porto de Munguba.[21]

Eucatex Mineral Ltda. and Elf-Atochem initiated a joint venture to produce activated clay for bleaching markets. The plant will be built in Maua and will use clays from Eucatex's Paraiba Valley Mine. The clay will be used for filtration and clarification of mineral and vegetable oils, fats, waxes, and margarines.[22]

Finland.—Engelhard Corp. began operating its kaolin production plant at Mussalo, near Kotka.[23]

South Africa, Republic of.—Serina Kaolin Ltd. received permission to mine kaolin at Nordhoek. The deposit contains 3.2 million tons of kaolin. The company will operate a processing plant at the site. The kaolin will be sold for ceramics, paint, and paper applications.[24]

United Kingdom.—Laporte Absorbents PLC announced plans to build a 750-ton-per-year plant to manufacture synthetic smectite clays similar to hectorite. The plant will cost $9.4 million and will increase Laporte's production capacity to 2,000 tons of synthetic smectite clay per year. Markets for the synthetic smectite range from cosmetics to toothpaste to gellants to thickeners.[25]

OUTLOOK

U.S. clay demand between 1982 and 1992 has rebounded slowly from 32 million tons to 44 millon 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 due to a slow economy. 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.

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TABLE 1
SALIENT U.S. CLAY STATISTICS[1]

(Thousand metric tons and thousand dollars)

	1988	1989	1990	1991	1992
Domestic clays sold or used by producers:					
Quantity	44,515	42,254	42,904	r41,017	40,712
Value	$1,390,908	$1,515,300	$1,619,824	r$1,455,816	$1,481,893
Exports:					
Quantity	3,535	3,755	4,123	3,997	4,158
Value	$516,566	$550,343	$584,404	$590,174	$663,478
Imports for consumption:					
Quantity	33	28	30	35	41
Value	$8,835	$10,928	$11,988	$13,249	$15,503

rRevised.
[1]Excludes Puerto Rico.

TABLE 2

CLAYS SOLD OR USED BY PRODUCERS IN THE UNITED STATES[1] IN 1992, BY STATE

(Thousand metric tons and thousand dollars)

State	Ball clay	Bentonite	Common clay and shale	Fire clay	Fuller's earth	Kaolin	Total	Total value
Alabama	—	130	2,007	244	—	W	[2]2,381	[2]26,200
Arizona	—	W	102	—	—	—	[3]102	[3]463
Arkansas	—	—	837	W	—	W	[2 4]837	[2 4]6,855
California	—	143	1,635	—	W	128	[5]1,906	[5]26,173
Colorado	—	W	242	W	—	—	[3 4]242	[3 4]1,796
Connecticut	—	—	W	—	—	—	W	W
Florida	—	—	W	—	332	35	[6]367	[6]37,201
Georgia	—	—	1,484	W	591	6,888	[4]8,963	[4]970,905
Idaho	—	—	W	—	—	—	W	W
Illinois	—	—	535	—	W	—	[5]535	[5]2,362
Indiana	W	—	842	—	—	—	[7]842	[7]3,016
Iowa	—	—	389	—	—	—	389	1,612
Kansas	—	—	544	—	—	—	544	3,921
Kentucky	W	—	760	—	—	—	[7]760	[7]3,777
Louisiana	—	—	384	—	—	—	384	3,589
Maine	—	—	W	—	—	—	W	W
Maryland	—	—	227	—	—	—	227	980
Massachusetts	—	—	W	—	—	—	W	W
Michigan	—	—	1,265	—	—	—	1,265	4,345
Minnesota	—	—	W	—	—	W	W	W
Mississippi	W	200	575	—	345	—	[7]1,120	[7]38,090
Missouri	—	—	1,018	178	W	—	[5]1,196	[5]8,326
Montana	—	W	35	—	—	—	[3]35	[3]101
Nebraska	—	—	183	—	—	—	183	879
Nevada	—	14	—	—	W	W	[2 5]14	[2 5]8,272
New Hampshire	—	—	W	—	—	—	W	W
New Jersey	—	—	W	W	—	—	W	W
New Mexico	—	—	33	W	—	—	[4]33	[4]79
New York	—	—	415	—	—	—	415	2,412
North Carolina	—	—	2,120	—	—	W	[2]2,120	[2]9,775
North Dakota	—	—	W	—	—	—	W	W
Ohio	—	—	2,180	108	—	—	2,288	12,062
Oklahoma	—	—	622	—	—	—	622	3,296
Oregon	—	19	203	—	—	—	222	1,199
Pennsylvania	—	—	633	—	—	16	649	3,455
South Carolina	—	—	1,085	—	—	523	1,608	27,694
South Dakota	—	—	W	—	—	—	W	W
Tennessee	574	W	W	—	W	—	[3 5 6]574	[3 5 6]36,181
Texas	W	W	2,237	—	W	W	[2 3 5 7]2,237	[2 3 5 7]22,244
Utah	—	W	243	—	W	—	[3 5]243	[3 5]4,411
Virginia	—	W	753	—	W	—	[3 5]753	[3 5]10,081
Washington	—	—	306	(e)	—	—	306	1,889
West Virginia	—	—	80	—	—	—	80	221

See footnotes at end of table.

TABLE 2—Continued

CLAYS SOLD OR USED BY PRODUCERS IN THE UNITED STATES[1] IN 1992, BY STATE

(Thousand metric tons and thousand dollars)

State	Ball clay	Bentonite	Common clay and shale	Fire clay	Fuller's earth	Kaolin	Total	Total value
Wyoming	—	2,535	W	—	—	—	[6]2,535	[6]83,094
Undistributed	280	313	998	525	1,145	474	3,735	114,937
Total	854	3,354	24,972	1,055	2,413	8,064	40,712	1,481,893

W Withheld to avoid disclosing company proprietary data; included with "Total" and/or "Undistributed."
[1]Excludes Puerto Rico.
[2]Excludes kaolin.
[3]Excludes bentonite.
[4]Excludes fire clay.
[5]Excludes fuller's earth.
[6]Excludes common clay.
[7]Excludes ball clay.
[8]Less than 1/2 unit.

TABLE 3

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[1]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1991								
Tennessee	231	11,597	129	5,610	154	4,418	514	21,625
Other[2]	128	6,887	—	—	141	4,909	270	11,796
Total[1]	360	18,483	129	5,610	295	9,327	784	33,421
1992								
Tennessee	307	13,813	103	5,101	164	5,183	574	24,097
Other[2]	128	6,857	—	—	152	5,277	280	12,133
Total	435	20,670	103	5,101	316	10,460	854	36,230

[1]Data may not add to totals shown because of independent rounding.
[2]Includes Indiana, Kentucky, Mississippi, and Texas.

TABLE 4

BALL CLAY SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons)

Use	1991				1992			
	Airfloat	Water-slurried	Unprocessed	Total	Airfloat	Water-slurried	Unprocessed	Total
Ceramics[1]	W	—	W	9	—	—	W	W
Dinnerware[2]	89	—	28	117	97	—	27	124
Fillers, extenders, and binders[3]	102	—	18	120	98	—	19	117
Floor and wall tile	16	W	132	148	38	W	153	191
Refractories[4]	32	W	6	38	34	W	11	45
Sanitaryware	W	110	45	155	W	85	45	130
Miscellaneous	54	19	43	107	90	18	39	147
Exports	67	—	23	90	78	—	22	100
Total	360	129	295	784	435	103	316	854

W Withheld to avoid disclosing company proprietary data; included in "Total" and/or "Miscellaneous."
[1]Includes catalyst (oil refining); fiberglass; glazes, glass, and enamels.
[2]Includes crockery and other earthenware; fine china and dinnerware.
[3]Includes animal feed; asphalt emulsions, asphalt tile; pesticides and related products; rubber; wallboard; other uses not specified.
[4]Includes electrical porcelain; firebrick, block and shapes; high-alumina brick; and specialties.

TABLE 5

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
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[1]	r48	1,031	r337	r18,336	r350	r15,377
Total	475	22,969	r2,833	r101,013	r3,308	r123,982
1992						
Alabama and Mississippi	330	10,669	—	—	330	10,669
Arizona	W	W	—	—	W	W
California	W	W	W	W	143	13,069
Colorado	(2)	9	—	—	(2)	9
Nevada	W	W	W	W	14	3,442
Oregon	W	W	W	W	19	873
Utah	—	—	W	W	W	W
Wyoming	—	—	2,535	83,094	2,535	83,094
Other[1]	207	15,029	282	16,584	313	14,231
Total	537	25,707	2,817	[3]99,680	3,354	125,387

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Other" and/or "Total."

[1]Includes Montana, Tennessee (1992), Texas, and Virginia (1992).

[2]Less than 1/2 unit.

[3]Data do not add to total shown because of independent rounding.

TABLE 6

BENTONITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY KIND AND USE

(Thousand metric tons)

Use	1991			1992		
	Non-swelling	Swelling	Total[1]	Non-swelling	Swelling	Total[1]
Domestic:						
Absorbents	129	175	305	140	159	299
Adhesives	—	11	11	—	9	9
Animal feed	9	91	100	14	106	120
Catalysts (oil-refining)	W	—	W	W	—	W
Drilling mud	1	r679	r680	W	632	632
Filtering, clarifying, decolorizing:						
Animal oils, mineral oils and greases, and vegetable oils	W	W	5	W	W	W
Desiccants	W	—	W	W	—	W
Foundry sand	W	r474	r474	W	494	494
Medical, pharmaceutical, cosmetic	W	W	W	W	W	W
Paint	—	15	15	—	15	15
Pelletizing (iron ore)	—	717	717	—	675	675
Pesticides and related products	W	W	W	W	W	W
Water treatment and filtering	W	W	W	W	W	W
Waterproofing and sealing	r11	r131	r141	11	171	182
Miscellaneous[2]	r318	r109	r422	346	111	456
Total[1]	468	r2,402	r2,870	511	2,372	2,882
Exports:						
Drilling mud	—	107	107	—	120	120
Foundry sand	W	272	272	W	279	279
Other[3]	W	53	53	W	46	46
Total[1]	7	431	438	27	445	472
Grand total[1]	475	r2,833	r3,308	537	2,817	3,354

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous" and/or "Total."

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

[2]Includes 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.

[3]Includes absorbents; animal feed; asphalt emulsions; cement; filtering, clarifying, decolorizing; paint; plastics; waterproofing and sealing; and uses not specified.

TABLE 7

COMMON CLAY AND SHALE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1991		1992	
	Quantity	Value	Quantity	Value
Alabama	r2,008	r18,386	2,007	15,292
Arizona	r148	r638	102	463
Arkansas	645	2,632	837	2,972
California	r1,745	r9,485	1,635	8,146
Colorado	261	1,938	242	1,787
Connecticut and New Jersey	147	1,899	155	1,944
Georgia	1,382	10,464	1,484	15,312
Illinois	514	2,442	535	2,362
Indiana	930	3,516	842	3,016
Iowa	r385	r1,643	389	1,612
Kansas	r515	r2,232	544	3,921
Kentucky	708	2,942	760	3,777
Louisiana	360	3,646	384	3,589
Maine and Massachusetts	59	264	48	248
Maryland	259	1,141	227	980
Michigan	r1,187	r5,375	1,265	4,345
Mississippi	648	6,608	575	6,170
Missouri	r974	r3,732	1,018	4,449
Montana	r27	r71	35	101
Nebraska	198	909	183	879
New Mexico	28	74	33	79
New York	421	2,417	415	2,412
North Carolina	2,064	9,015	2,120	9,775
Ohio	2,116	8,171	2,180	8,804
Oklahoma	r553	r3,469	622	3,296
Oregon	194	300	203	326
Pennsylvania	701	2,890	633	2,531
Puerto Rico	145	335	W	527
South Carolina	1,154	2,225	1,085	3,147
South Dakota and Wyoming	224	939	129	634
Texas	r2,179	r12,895	2,237	1,266
Utah	210	1,028	243	2,714
Virginia	723	3,248	753	3,367
Washington	r169	r1,541	306	1,889
West Virginia	134	322	80	221
Other[1]	r612	2,846	668	14,356
Total	r24,727	r131,678	[2]24,972	136,709

rRevised. W Withheld to avoid disclosing company proprietary data.

[1]Includes Florida, Idaho, Minnesota, New Hampshire, North Dakota, and Tennessee.

[2]Data do not add to total shown because of independent rounding.

TABLE 8

COMMON CLAY AND SHALE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons)

Use	1991	1992
Ceramics and glass:		
Pottery	35	161
Other[1]	217	157
Civil engineering and sealing	84	84
Floor and wall tile:		
Ceramic	279	426
Quarry tile	50	54
Other[2]	W	W
Heavy clay products:		
Brick, extruded	r8,742	10,305
Brick, other	2,645	1,604
Drain tile	13	16
Flowerpots	25	45
Flue linings	47	52
Portland and other cements	r7,885	7,697
Structural tile	36	36
Other[3]	688	684
Lightweight aggregate:		
Concrete	2,438	2,114
Highway surfacing	274	253
Structural concrete	707	724
Other[4]	180	310
Pelletizing iron ore	W	10
Refractories[5]	98	100
Other[6]	284	140
Total	r24,727	24,972

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

[1]Includes crockery and other earthenware, mineral wool and insulation, roofing granules, abrasives, and miscellaneous ceramics.

[2]Includes miscellaneous floor and wall tile.

[3]Includes roofing tile, sewer pipe, terra cotta, and miscellaneous clay products.

[4]Includes miscellaneous lightweight aggregates.

[5]Includes firebrick, block and shapes, mortar and cement, and miscellaneous refractories.

[6]Includes exports, fillers, extenders, and binders, uses unknown, and uses indicated by the symbol W.

TABLE 9

FIRE CLAY[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1991		1992	
	Quantity	Value	Quantity	Value
Alabama	81	3,494	244	5,622
Colorado	3	26	W	W
Georgia	—	—	W	W
Missouri	251	5,476	178	3,878
Ohio	89	2,844	108	3,258
Other[2]	51	1,338	525	3,090
Total	[3]474	13,178	1,055	15,848

W Withheld to avoid disclosing company proprietary data; included in "Other."
[1]Refractory uses only.
[2]Includes Arkansas, New Jersey, New Mexico, and Washington (1992).
[3]Data do not add to total shown because of independent rounding.

TABLE 10

FIRE CLAY SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons)

Use	1991	1992
Ceramics and glass:		
Pottery	W	16
Heavy clay products:		
Brick, extruded	W	W
Other	21	9
Lightweight aggregate:		
Other	—	W
Pelletizing iron ore	—	(1)
Refractories:		
Firebrick, block and shapes	319	170
Foundry sand	W	9
Mortar and cement	W	18
Other[2]	108	747
Other[3]	26	86
Total	474	1,055

W Withheld to avoid disclosing company proprietary data; included in "Other."
[1]Less than 1/2 unit.
[2]Includes grogs and calcines, high-alumina brick, high-alumina specialities, and miscellaneous refractories.
[3]Includes exports, uses unknown, and uses indicated by the symbol W.

TABLE 11

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
1991						
Florida	332	35,598	(1)	(1)	332	35,598
Georgia	509	63,273	108	13,134	617	76,407
Southern States[2]	—	—	r546	r37,301	r546	r37,301
Western States[3]	(4)	(4)	r823	r83,340	r823	r83,340
Total	5758	98,871	r 51,560	r133,775	r2,318	r232,646
1992						
Florida	332	33,767	(1)	(1)	332	33,767
Georgia	591	76,665	(1)	(1)	591	76,665
Southern States[2]	—	—	575	41,747	575	41,747
Western States[3]	(4)	(4)	915	89,448	915	89,448
Total[5]	902	123,985	1,512	117,642	2,413	241,627

rRevised.
[1]Included under attapulgite.
[2]Includes Mississippi, Tennessee, and Virginia.
[3]Includes California, Illinois, Missouri, Nevada, Texas, and Utah (1992).
[4]Included under montmorillonite.
[5]Data do not add to total shown because of independent rounding and/or proprietary coverage of individual kinds.

TABLE 12

FULLER'S EARTH SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons)

Use	1991			1992		
	Attapulgite	Montmorillonite	Total[1]	Attapulgite	Montmorillonite	Total[1]
Domestic:						
Adhesives	W	—	W	W	—	W
Drilling mud	32	—	32	31	—	31
Fertilizers	39	W	39	48	W	48
Filtering, clarifying, decolorizing mineral oils and greases	r14	W	r14	12	W	12
Medical, pharmaceutical, cosmetic	W	—	W	W	—	W
Oil and grease absorbents	167	r174	r341	190	258	448
Paint	W	—	W	W	—	W
Pesticides and related products	57	r106	r164	46	127	173
Pet waste absorbents	224	r1,188	r1,412	370	1,045	1,415
Portland and other cement	26	—	26	19	—	19
Other[2]	W	—	W	W	—	W
Miscellaneous[3]	r120	60	r181	104	82	186
Exports	79	r29	r109	82	W	82
Total[1]	758	r1,560	r2,318	902	1,512	2,413

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Other" and/or "Miscellaneous."
[1]Data may not add to totals shown because of independent rounding.
[2]Includes roofing tile and vegetable oils.
[3]Includes 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 13
KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1991		1992	
	Quantity	Value	Quantity	Value
Arkansas	r190	W	W	W
California	113	4,865	128	4,958
Florida	31	3,552	35	3,434
Georgia	7,519	862,866	6,888	878,928
South Carolina	555	23,437	523	24,547
Other[1]	1,145	r26,524	490	14,751
Total	r9,553	r921,244	8,064	926,618

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Other."
[1]Includes Alabama, Minnesota, Mississippi, Nevada, North Carolina, Pennsylvania, and Texas.

TABLE 14
KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY KIND

(Thousand metric tons and thousand dollars)

Kind	1991		1992	
	Quantity	Value	Quantity	Value
Airfloat	1,142	63,654	1,120	59,472
Calcined[1]	2,444	290,990	755	236,699
Delaminated	996	110,997	1,257	143,031
Unprocessed	r785	r11,834	720	14,082
Water-washed	4,186	443,769	4,212	473,334
Total	r9,553	r921,244	8,064	926,618

rRevised.
[1]Includes both low-temperature filler and high-temperature refractory grades.

TABLE 15

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
1991				
Alabama and Georgia	1,509	32,417	[1]718	[1]245,240
Other	[r] [2]109	[2]4,292	[3]107	[3]9,041
Total	[r]1,618	36,709	825	254,281
1992				
Alabama and Georgia	W	W	W	W
Other[2] [3]	208	26,396	547	210,303
Total	208	26,396	547	210,303

[r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Excludes Alabama.
[2]Includes Arkansas, California, Colorado (1991), Idaho (1991), and South Carolina (1991).
[3]Includes Alabama (1992), Arkansas, Georgia (1992), Pennsylvania, and South Carolina.

TABLE 16

GEORGIA KAOLIN SOLD OR USED BY PRODUCERS, BY KIND

(Thousand metric tons and thousand dollars)

Kind	1991		1992	
	Quantity	Value	Quantity	Value
Airfloat	702	34,790	685	30,001
Calcined[1]	1,500	269,457	587	226,935
Delaminated	996	110,997	1,257	143,031
Unprocessed	178	5,589	190	6,953
Water-washed	4,144	442,032	4,169	472,008
Total[2]	7,519	862,866	6,888	878,928

[1]Includes both low-temperature filler and high-temperature refractory grades.
[2]Data may not add to totals shown because of independent rounding.

TABLE 17

GEORGIA KAOLIN SOLD OR USED BY PRODUCERS, BY USE

(Thousand metric tons)

Use	1991				1992			
	Air-float	Unprocessed[1]	Water-washed[2]	Total[3]	Air-float	Unprocessed[1]	Water-washed[2]	Total[3]
Domestic:								
Adhesives	W	—	26	26	30	—	28	58
Aluminum sulfate and other chemicals	—	W	—	W	—	W	—	W
Asphalt tile and linoleum	W	W	—	W	W	W	—	W
Catalysts (oil-refining)	W	—	35	35	W	—	45	45
Face brick	—	4	—	4	—	4	—	4
Fiberglass and mineral wool	223	—	W	223	259	W	W	259
Fine china and dinnerware; crockery and earthenware	W	—	W	W	W	—	W	W
Firebrick, blocks and shapes	W	9	—	9	W	—	—	W
Grogs and calcines, refractory	W	W	W	W	W	—	W	W
Medical, pharmaceutical, cosmetic	W	—	W	W	W	—	W	W
Paint	W	—	200	200	W	—	199	199
Paper coating	—	—	2,604	2,604	—	—	2,675	2,675
Paper filling	147	—	905	1,052	W	W	1,059	1,059
Plastics	W	—	50	50	W	—	30	30
Pottery	W	—	—	W	W	—	—	W
Refractories[4]	7	23	8	38	32	8	8	48
Roofing granules	W	W	—	W	W	—	W	W
Rubber	14	—	40	54	25	—	26	51
Sanitaryware	33	—	—	33	W	W	W	W
Miscellaneous, airfloat:								
Common brick, fertilizers, gypsum products, pesticides and related products, roofing and structural tile, other uses not specified	247	—	—	247	309	—	—	309
Miscellaneous, unprocessed:								
Fertilizers, pesticides and related products, other uses not specified	—	879	—	879	—	173	—	173
Miscellaneous, water-washed:								
Gypsum products, ink, pesticides and related products, waterproofing and sealing, fertilizers, other uses not specified	—	—	185	185	—	—	218	218
Total[3]	671	915	4,053	5,639	655	185	4,288	5,128
Exports:								
Paint	—	—	W	W	—	—	27	27
Paper coating	—	W	1,321	1,321	—	W	1,358	1,358
Paper filling	—	—	386	386	9	—	191	200
Rubber	—	—	16	16	—	—	17	17
Undistributed	30	44	83	157	20	68	69	157
Total[3]	30	44	1,805	1,879	29	68	1,662	1,759
Grand total[3]	702	959	5,858	7,519	685	253	5,950	6,888

W Withheld to avoid disclosing company proprietary data; included in "Undistributed" and/or "Total."

[1]Includes high-temperature calcined.

[2]Includes low-temperature calcined and delaminated.

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

[4]Includes electrical porcelain; floor and wall tile, ceramic; flue linings; glazes, glass, and enamels; high-alumina brick and specialties; kiln furniture; refractory mortar and cement.

TABLE 18
SOUTH CAROLINA KAOLIN SOLD OR USED BY PRODUCERS, BY KIND

(Thousand metric tons and thousand dollars)

Kind	1991		1992	
	Quantity	Value	Quantity	Value
Airfloat	352	21,765	370	23,728
Unprocessed	203	1,672	154	819
Total	555	23,437	524	24,547

TABLE 19
SOUTH CAROLINA KAOLIN SOLD OR USED BY PRODUCERS, BY KIND AND USE

(Thousand metric tons)

Kind and use	1991	1992
Airfloat:		
Adhesives	W	W
Animal feed and pet waste absorbent	W	W
Ceramics[1]	3	3
Fertilizers, pesticides and related products	8	8
Fiberglass	W	W
Paint	W	W
Paper coating and filling	4	4
Plastics	W	W
Rubber	167	165
Refractories[2]	W	W
Other uses[3]	r141	160
Exports[4]	29	30
Total	r352	370
Unprocessed: Face brick and other uses	203	154
Grand total	555	524

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Includes crockery and earthenware; electrical porcelain; fine china and dinnerware; floor and wall tile; pottery; and roofing granules.
[2]Includes refractory calcines and grogs; firebrick, blocks and shapes; refractory mortar and cement; and high-alumina refractories.
[3]Includes animal oil; catalysts (oil refining); chemical manufacturing; ink; medical; sewer pipe; and unknown uses.
[4]Includes ceramics; adhesives; paper filling; pesticides and related products; and rubber.

TABLE 20

KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons)

Use	1991				1992			
	Air-float	Unprocessed[1]	Water-washed[2]	Total[3]	Air-float	Unprocessed[1]	Water-washed[2]	Total[3]
Domestic:								
Adhesives	27	—	26	52	41	—	28	69
Aluminum sulfate and other chemicals	—	W	W	170	—	W	—	W
Animal feed	W	—	—	W	W	—	W	2
Brick, extruded and other	—	231	W	231	—	180	W	180
Catalysts (oil and gas refining)	W	—	38	38	W	—	47	47
Cement, portland	—	180	—	180	—	179	—	179
China and dinnerware	15	—	W	15	15	—	W	15
Crockery and other earthenware	1	—	W	1	4	—	W	4
Electrical porcelain	6	—	3	9	9	—	3	12
Fertilizers[4]	W	—	W	5	W	—	W	6
Fiberglass, mineral wool and other insulation	328	W	W	400	340	W	W	379
Firebrick, blocks and shapes	67	W	—	r67	21	W	—	21
Floor and wall tile, ceramic; glazes, glass, enamels	W	W	W	W	1	(5)	W	2
Flue linings, high-alumina brick and specialities	W	W	W	W	W	W	W	W
Foundry sand	—	—	W	W	30	—	W	30
Grogs and calcines, refractory	W	1,633	W	1,633	W	159	W	159
Gypsum products and wallboard	W	W	W	3	W	W	W	5
Ink	—	—	7	7	—	—	8	8
Kiln furniture; refractory mortar and cement	W	—	W	W	2	—	W	2
Linoleum and asphalt tile	W	—	W	W	3	—	—	3
Medical, pharmaceutical, cosmetic	W	—	W	1	W	—	W	1
Paint	3	W	225	228	19	W	223	242
Paper coating	W	—	2,604	2,604	W	—	2,675	2,675
Paper filling	152	—	905	1,057	85	W	1,059	1,144
Pesticides and related products	7	—	16	23	7	W	6	13
Plastics	5	—	50	55	20	—	29	49
Pottery	22	—	—	22	22	—	W	22
Roofing granules	W	W	—	11	W	—	W	11
Rubber	181	W	40	221	190	—	26	216
Sanitaryware	35	—	—	35	12	W	W	41
Waterproofing and sealing	W	—	W	W	1	—	W	1
Miscellaneous	219	r308	288	r541	222	342	249	720
Total[3]	1,068	r2,352	4,201	r7,621	1,044	860	4,353	6,257
Exports:								
Ceramics	44	—	W	44	31	W	22	53
Foundry sand, grogs and calcines; other refractories	—	6	—	6	—	W	—	W
Paint	—	—	W	W	—	—	27	27
Paper coating	—	W	1,321	1,321	—	W	1,358	1,358
Paper filling	—	—	386	386	9	—	191	200
Rubber	29	—	16	45	30	—	17	47
Miscellaneous	1	44	r84	r129	6	68	48	122
Total[3]	74	51	1,807	1,931	76	68	1,663	1,807
Grand total[3]	1,142	r2,403	6,008	r9,553	1,120	928	6,016	8,064

rRevised. W Withheld to avoid disclosing proprietary data; included with "Total" and/or "Miscellaneous."

[1]Includes high-temperature calcined.

[2]Includes low-temperature calined and delaminated.

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

[4]Includes soil conditioners and mulches.

[5]Less than 1/2 unit.

TABLE 21

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
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	466	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	—	275	2,188
Texas	49	157	222	31	459	2,518
Utah and Virginia	243	15	6	—	264	1,472
Total[1]	2,438	707	274	180	3,599	30,014
1992						
Alabama and Arkansas	670	88	14	13	785	10,427
California	87	75	—	7	169	696
Florida and Indiana	132	36	—	38	206	1,619
Kansas, Kentucky, Louisiana	295	128	—	55	478	1,078
Mississippi and Missouri	15	1	2	103	121	1,387
New York and Montana	179	92	—	—	271	1,683
North Carolina	245	82	—	—	327	3,696
Ohio, Oklahoma, Pennsylvania	173	36	5	19	233	1,808
Texas	49	157	222	31	459	2,518
Utah and Virginia	269	29	9	43	350	3,434
Total[1]	2,114	724	253	310	3,400	28,348

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

TABLE 22

COMMON CLAY AND SHALE USED IN BUILDING BRICK PRODUCTION IN THE UNITED STATES, BY STATE[1]

(Thousand metric tons and thousand dollars)

State	1991		1992	
	Quantity	Value	Quantity	Value
Alabama	794	r3,778	825	3,725
Arizona[2] and New Mexico[2]	65	201	67	192
Arkansas	279	r693	395	307
California	396	r2,014	323	1,389
Colorado	233	r1,805	215	1,676
Connecticut, New Jersey,[2] New York[2]	297	2,612	299	2,652
Georgia	938	r8,007	1,041	12,857
Idaho, Washington, Wyoming,[2] Montana[3]	97	613	236	783
Illinois	464	r1,643	454	1,687
Indiana and Iowa	r322	1,610	303	1,629
Kansas	r120	r458	125	475
Kentucky[2] and Tennessee[2]	635	2,933	738	3,508
Louisiana	75	2,852	89	3,165
Maine, Massachusetts,[2] New Hampshire[2]	62	283	54	288
Maryland and West Virginia[4]	244	r1,013	205	828
Michigan[2] and Minnesota[2]	121	422	119	415
Mississippi	390	2,124	[5]504	2,250
Missouri	r49	r267	W	394
Nebraska and North Dakota[2]	146	435	144	438
North Carolina	1,722	r5,262	1,776	6,017
Ohio	949	r3,996	978	4,234
Oklahoma	r220	r1,246	273	1,403
Oregon	20	68	28	95
Pennsylvania	576	2,156	523	1,947
South Carolina	594	r1,465	685	1,965
Texas	r974	r5,055	896	6,226
Utah[2]	94	r411	70	376
Virginia	511	2,067	541	2,185
Total[6]	r11,387	r55,489	11,909	63,106

rRevised. W Withheld to avoid disclosing company proprietary data.

[1]Includes extruded and other brick.

[2]Extruded brick only.

[3]Includes Montana only for 1991.

[4]Other brick only.

[5]Includes Missouri.

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

TABLE 23
U.S. EXPORTS OF CLAYS IN 1992, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	Ball clay		Bentonite		Fire clay		Fuller's earth		Kaolin		Clays, n.e.c.[1]		Total	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Argentina	—	—	(2)	38	1	47	—	—	7	2,828	1	687	9	3,600
Australia	—	—	6	965	16	1,459	(2)	3	16	6,739	1	1,590	39	10,756
Belgium—Luxembourg	—	—	9	1,782	13	1,231	(2)	23	101	21,926	5	464	128	25,426
Brazil	(2)	5	(2)	62	—	—	(2)	17	5	1,750	1	2,201	6	4,035
Canada	—	—	141	8,932	8	1,402	8	1,011	563	72,113	103	21,870	823	105,328
Chile	1	79	1	263	2	102	(2)	5	11	2,315	(2)	384	15	3,148
Colombia	—	—	1	181	—	—	—	—	18	3,353	7	1,700	26	5,234
Ecuador	—	—	1	132	(2)	22	—	—	4	146	1	274	6	574
Finland	—	—	(2)	23	—	—	—	—	382	55,206	7	699	389	55,928
France	—	—	35	1,930	2	356	(2)	60	16	3,028	6	978	59	6,352
Germany			1	672	2	216	(2)	25	59	14,233	5	2,375	67	17,521
Hong Kong	(2)	13	3	575	(2)	10	—	—	7	1,660	1	710	11	2,968
Italy	—	—	2	1,002	2	208	(2)	132	201	26,941	4	922	209	29,205
Japan	1	180	187	14,552	33	3,727	(2)	38	722	129,432	16	7,609	959	155,538
Korea, Republic of	(2)	25	5	767	5	973	(2)	9	128	26,961	4	2,709	142	31,444
Mexico	35	1,570	10	1,139	48	3,321	2	196	106	12,881	6	1,238	207	20,345
Netherlands	(2)	10	6	1,548	80	8,832	7	512	211	25,769	27	8,461	331	45,132
Peru	—	—	(2)	41	—	—	—	—	1	628	1	151	2	820
Philippines	2	232	5	496	—	—	—	—	6	1,698	1	542	14	2,968
Saudi Arabia	—	—	36	2,069	1	65	(2)	19	(2)	70	(2)	208	37	2,431
Singapore	(2)	11	8	915	—	—	2	240	2	729	2	2,206	14	4,101
South Africa, Republic of	(2)	23	(2)	82	—	—	2	581	27	5,048	1	590	30	6,324
Spain	—	—	1	250	—	—	1	57	8	1,969	(2)	57	10	2,333
Sweden	(2)	10	1	366	(2)	3	(2)	3	117	20,772	12	2,284	130	23,438
Switzerland	—	—	(2)	59	—	—	—	—	(2)	94	(2)	44	(2)	197
Taiwan	(2)	7	29	3,219	10	710	—	—	109	18,398	4	1,561	152	23,895
Thailand	—	—	8	912	(2)	26	(2)	5	15	4,217	(2)	648	23	5,808
United Kingdom	—	—	24	3,952	5	325	1	186	70	8,787	19	8,933	119	22,183
Venezuela	1	58	20	1,585	(2)	100	—	—	23	3,852	7	2,258	51	7,853
Other	9	897	51	5,143	(2)	402	4	900	65	17,326	20	13,925	150	38,593
Total	49	3,120	591	53,652	228	23,537	27	4,022	3,000	490,869	262	88,278	4,158	663,478

[1]Also includes chamotte or dinas earth, activated clays and earths, and artifically activated clays.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 24

U.S. IMPORTS FOR CONSUMPTION OF CLAYS IN 1992, BY KIND

Kind	Quantity (metric tons)	Value (thousands)
China clay or kaolin:		
Australia	15	$7
Canada	46	6
Denmark	6	4
Germany	326	118
Italy	3	2
Japan	1	2
Mexico	7	2
Netherlands	5	2
New Zealand	641	391
Singapore	1	4
United Kingdom	3,170	1,587
Total	4,221	[1]2,122
Fire clay:		
Canada	165	36
China	7,573	516
Japan	1	3
Spain	304	225
United Kingdom	46	158
Total	8,089	[1]937
Decolorizing earths and fuller's earth:		
Canada	106	15
Germany	54	15
Total	160	[1]31
Bentonite:		
Canada	1,195	363
Denmark	1	3
France	1	2
Germany	210	705
Japan	270	60
Mexico	704	48
Switzerland	3	6
United Kingdom	143	69
Total	2,527	[1]1,257
Common blue clay and other ball clay:		
United Kingdom	699	230
Other clay:		
Canada	8,127	202
France	7	6
Germany	15	57
Hong Kong	500	26
Italy	2	7
Japan	3	8
Mexico	1	5
Netherlands	35	17

See footnotes at end of table.

TABLE 24—Continued

U.S. IMPORTS FOR CONSUMPTION OF CLAYS IN 1992, BY KIND

Kind	Quantity (metric tons)	Value (thousands)
Other clay—Continued:		
Thailand	35	$55
United Kingdom	1,752	722
Total	10,477	[1]1,104
Chamotte or dina's earth:		
Canada	6	33
Artificially activated clay and activated earth:		
Austria	1	5
Belgium	19	21
Canada	446	229
Denmark	17	9
Finland	19	87
Germany	1,838	5,131
Italy	20	6
Japan	25	89
Mexico	12,510	3,902
Netherlands	90	24
Sweden	28	133
Taiwan	1	15
United Kingdom	21	131
Venezuela	35	7
Total	15,070	9,789
Grand total	41,249	15,503

[1]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 25

KAOLIN: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Algeria	17,800	18,000	r18,000	r21,460	21,500
Argentina	93,871	45,598	e50,000	e50,000	45,000
Australia[e]	3 4159,067	185,000	200,000	190,000	180,000
Austria (marketable)	89,491	85,312	81,265	e80,000	80,000
Bangladesh[5]	10,097	7,092	r7,223	r7,338	7,300
Belgium[e]	40,000	35,000	35,000	30,000	30,000
Bosnia and Herzegovina[6]	—	—	—	—	5,000
Brazil[7]	940,518	r714,647	r658,927	r746,000	750,000
Bulgaria	220,000	e220,000	186,467	e180,000	180,000
Burundi	4,021	4,305	5,281	r6,682	6,000
Chile	54,464	58,512	32,416	62,991	63,000
Colombia[e]	4408,141	540,000	540,000	r900,000	900,000
Czechoslovakia	685,958	698,000	r872,000	r705,000	700,000
Denmark (sales)	39,324	16,029	17,423	e17,000	17,000
Ecuador	16,700	22,576	r e20,000	e25,000	24,000
Egypt	124,122	121,515	49,032	r192,870	190,000
Ethiopia (including Eritrea)[e 8]	750	390	670	r370	500
France (marketable)[e 9]	338,000	346,000	367,000	r360,000	350,000
Germany:					
Eastern states (marketable)[e]	r300,000	r310,000	r200,000	—	—
Western states (marketable)	673,000	r738,000	684,000	—	—
Total[e]	r973,000	r1,048,000	r884,000	r660,000	645,000
Greece	127,395	67,234	r169,986	r189,235	100,000
Guatemala	3,459	2,573	2,050	r3,281	3,300
Hungary	29,572	24,824	r22,000	18,000	18,000
India:					
Salable crude	471,000	464,000	631,000	628,000	625,000
Processed	107,381	110,505	104,000	r113,000	110,000
Indonesia	147,109	157,122	160,098	139,915	140,000
Iran[e]	r150,000	r150,000	r150,000	r 4150,473	150,000
Israel	30,600	r31,245	42,212	r53,000	53,000
Italy:					
Crude	71,522	64,196	67,321	r49,000	45,000
Kaolinitic earth	18,636	18,924	17,946	r16,000	15,000
Japan	167,771	155,073	164,802	129,942	4123,154
Kenya	42	r—	—	—	—
Korea, Republic of	832,110	1,219,174	1,446,598	1,755,255	1,800,000
Madagascar	365	1,315	485	r496	500
Malaysia	116,869	108,347	152,972	186,699	4244,573
Mexico	162,415	141,519	156,140	166,640	167,000
Mozambique[e]	r—	r—	r—	—	—
New Zealand	r24,020	26,324	r25,435	r21,338	25,000
Nigeria	r150	r500	1,356	e1,300	1,300
Pakistan	41,968	39,907	61,630	r44,738	45,000
Paraguay[e]	476,000	474,000	74,000	74,000	74,000
Peru[e]	48,849	7,000	8,000	r7,100	7,000
Poland	59,000	50,000	48,000	e45,000	45,000
Portugal	71,200	58,297	73,849	e74,000	70,000

See footnotes at end of table.

TABLE 25—Continued

KAOLIN: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Romania[e]	400,000	400,000	250,000	200,000	150,000
Serbia and Montenegro[6]	—	—	—	—	100,000
Slovenia[6]	—	—	—	—	30,000
South Africa, Republic of	152,500	139,711	132,421	r134,485	4131,765
Spain (marketable)[10]	438,160	436,335	435,000	e400,000	400,000
Sri Lanka	7,100	7,761	7,731	7,737	7,700
Sweden[e]	492	100	100	100	100
Taiwan	81,879	98,115	105,084	92,970	100,000
Tanzania	528	1,554	2,021	r1,739	1,700
Thailand	269,976	328,824	347,690	381,839	370,000
Turkey	204,478	238,251	230,000	r275,000	300,000
U.S.S.R.[e] [11]	2,000,000	2,000,000	1,800,000	1,600,000	1,300,000
United Kingdom	3,276,795	3,139,672	3,037,486	r2,911,000	2,450,000
United States[12]	8,973,097	8,973,668	9,761,775	9,575,000	48,063,877
Venezuela	28,000	15,000	12,000	39,000	40,000
Vietnam[e]	700	750	750	800	800
Yugoslavia[13]	218,673	260,141	198,513	e170,000	—
Zimbabwe	95	r17	—	r65	50
Total	r22,984,830	r23,177,954	r23,925,155	r23,890,858	21,502,119

[e]Estimated. [r]Revised.

[1]Table includes data available through July 26, 1993.

[2]In addition to the countries listed, China, Lebanon, Morocco, and Suriname also may have produced kaolin, but information is inadequate to make reliable estimates of output levels.

[5]May include ball clay and other clays grouped for statistical purposes as kaolin.

[4]Reported figure.

[5]Data for year ending June 30 of that stated.

[6]Formerly part of Yugoslavia; data were not reported separately until 1992.

[7]Until 1988, series included beneficiated kaolin, direct sales, and direct use. Beginning in 1989, series refers to beneficiated kaolin only. Direct sales and direct use in 1988 totaled 144,626 metric tons.

[8]Data for year ending July 6 of that stated.

[9]Includes kaolinitic clay.

[10]Includes crude and washed kaolin and refractory clays not further described.

[11]Dissolved in Dec. 1991. This commodity is believed to be produced mainly in Uzbekistan and Ukraine; however, information is inadequate to formulate reliable estimates of individual country production.

[12]Kaolin sold or used by producers.

[13]Dissolved in Apr. 1992.

TABLE 26

BENTONITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992e
Algeria[3]	25,600	39,200	r33,700	r25,803	25,000
Argentina e	4173,930	150,000	150,000	100,000	120,000
Australia e 3	435,671	35,000	35,000	35,000	35,000
Bosnia and Herzegovina[5]	—	—	—	—	3,000
Brazil	147,149	r113,720	r105,109	r140,051	140,000
Burma	418	711	r416	r e600	500
Chile	529	2,005	2,207	1,054	1,500
Croatia[5]	—	—	—	—	20,000
Cyprus	90,300	59,744	r82,000	58,500	60,000
Egypt	3,166	3,512	r4,904	r4,900	4,900
France e	8,000	8,000	10,000	10,000	10,000
Germany: Western states	197,000	200,000	r223,000	r224,000	250,000
Greece	r730,525	1,096,177	r592,864	r600,286	600,000
Guatemala	973	8,236	r e5,000	e12,000	12,000
Hungary	66,014	59,973	r25,000	r18,000	18,000
Indonesia	8,266	3,863	5,914	21,512	20,000
Iran[6]	37,028	31,547	51,096	r40,452	40,000
Israel (metabentonite) e	r—	r—	r—	r—	—
Italy	319,127	234,212	228,153	r385,000	360,000
Japan	455,137	526,131	549,414	554,145	4534,445
Kenya e	r—	—	—	—	—
Macedonia[5]	—	—	—	—	60,000
Mexico	163,916	123,927	144,895	134,384	135,000
Morocco	3,445	3,970	r e4,000	r9,228	9,000
Mozambique	986	126	—	r682	700
New Zealand (processed)	1,255	1,342	1,393	r—	—
Pakistan	4,880	5,466	3,235	r5,106	5,000
Peru	50,741	e40,000	r e45,000	r55,300	55,000
Philippines	2,030	r5,961	16,484	r39,529	35,000
Poland e	80,000	80,000	80,000	70,000	70,000
Romania e	180,000	180,000	150,000	120,000	120,000
Serbia and Montenegro[5]	—	—	—	—	15,000
South Africa, Republic of[7]	66,750	62,987	66,059	64,600	440,888
Spain	103,753	143,398	r151,226	e145,000	150,000
Tanzania e	75	75	75	75	70
Turkey	80,218	93,256	e100,000	r e116,000	120,000
U.S.S.R. e 8	2,900,000	2,900,000	2,700,000	2,400,000	2,000,000
United States	2,870,971	3,112,365	3,473,595	e3,432,000	43,354,299
Yugoslavia[9]	125,069	128,593	102,681	e85,000	—
Zimbabwe[7]	113,157	104,865	99,854	e100,000	100,000
Total	r9,046,079	r9,558,362	r9,242,274	r9,008,207	8,524,302

eEstimated. rRevised.

[1]Table includes data available through July 26, 1993.

[2]In 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.

[3]Includes bentonitic clays.

[4]Reported figure.

[5]Formerly part of Yugoslavia; data were not reported separately until 1992.

[6]Year beginning Mar. 21 of that stated.

[7]May include other clays.

[8]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

[9]Dissolved in Apr. 1992.

TABLE 27

FULLER'S EARTH: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Algeria[e]	3,500	3,500	[r e]4,000	[3]4,526	4,500
Argentina[e]	2,000	2,000	2,000	2,000	1,500
Australia (attapulgite)[e]	15,000	15,000	20,000	15,000	15,000
Germany: Western states (unprocessed)	670,000	636,000	653,000	[r]708,000	710,000
Italy	38,955	43,550	45,800	[e]45,000	40,000
Mexico	37,226	24,603	29,865	27,800	28,000
Morocco (smectite)	52,694	48,820	45,230	[r]37,552	38,000
Pakistan	12,395	15,436	16,489	[r]22,075	20,000
Senegal (attapulgite)	118,725	98,882	114,610	[r]129,403	130,000
South Africa, Republic of (attapulgite)	7,161	6,609	7,628	8,109	[3]8,235
Spain (attapulgite)	43,585	23,990	[e]25,000	[e]25,000	25,000
United Kingdom[e]	213,000	210,000	205,000	[r]189,000	190,000
United States[4]	1,792,232	1,881,511	2,307,475	2,740,000	[3]2,413,453
Total	3,006,473	3,009,901	[r]3,476,097	[r]3,953,465	3,623,688

[e]Estimated. [r]Revised.

[1]Excludes 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 17, 1993.

[2]In 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.

[3]Reported figure.

[4]Sold or used by producers.

COBALT

By Kim B. Shedd

Ms. Shedd is a physical scientist (geologist) with more than 13 years of combined experience working for the U.S. Bureau of Mines (USBM) in research and mineral commodities. She has been the commodity specialist for cobalt since 1988. Domestic survey data were prepared by Jo-Ann S. Sterling and trade data were prepared by Dwayne E. Penn, statistical assistants. International production data were prepared by Amy Burk and Ronald Hatch, international statistical assistants, in coordination with USBM 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; pigments for ceramics, paints, and plastics; rubber additives for steel-belted radial tires; and additives to iron oxide particles in magnetic recording media.

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.

Demand for cobalt fell in 1992 owing to recessionary economic conditions, cutbacks in defense spending, and a drawdown of stocks by cobalt users. Where possible, consumers adapted their processes to use less expensive lower grade Russian cobalt. Free market prices steadily decreased during the year from the high levels set in late 1991/early 1992. The decrease in prices occurred despite ongoing concerns over supplies from Zaire and to a lesser extent from Russia, and strong demand from China early in the year. The African producers maintained their producer price at $25 per pound for most of the year, resulting in a growing differential between the producer price and market price, a loss of sales, and subsequent buildup of producer stocks. In November, the African producers lowered their price to $18 per pound to bring it closer to market prices.

DOMESTIC DATA COVERAGE

Domestic data on cobalt processing and consumption are developed by the USBM from three separate, voluntary surveys of U.S. operations. In the cobalt processors survey, all eight companies canvassed responded. Most of the data on cobalt chemical use 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. For this survey, more than 100 cobalt consumers were canvassed on a monthly or annual basis. The USBM also canvasses 13 superalloy scrap recyclers to determine the consumption of secondary cobalt in superalloy production. 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 (^{60}Co) is produced by irradiating cobalt metal in a nuclear reactor. This radioactive isotope is used in radiation therapy, for the sterilization of medical supplies, and more recently, to treat fresh foods (see Consumption and Uses section of this report).

Currently, there are no internationally recognized specifications for cobalt metal. The two leading Western World producers, La Générale des Carrières et des Mines du Zaire (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

Less than one-half of the cobalt used in the United States was consumed as primary cobalt metal. Most of this metal is in the form of electrolytic cobalt (cathode or rounds), granules (shot), or metal powder of various grades (particle

size ranges.) Some of the Russian cobalt metal is in ingot form and some of the Zambian cobalt is produced as crushed bar. About one-fourth of U.S. reported consumption in 1992 was from purchased scrap. Cobalt-bearing scrap originates from alloy processing, parts manufacturing, and used cobalt-containing products. The remainder of the cobalt used in the United States, about one-third of total consumption, was 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 cobalt content of the oxides depends on the relative amounts of cobalt(II)oxide, CoO, and cobalt(II)dicobalt(III)tetroxide, Co_3O_4, 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 mining and refining 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 1992, Zaire was the world's leading producer of refined cobalt, followed by Zambia, Russia, Norway, Canada, and Finland. These six countries represented 94% of world cobalt refinery production. Zairian and Zambian production was from domestic ores. Canada and Russia 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 in tables 1 and 2. *(See tables 1 and 2.)*

Cobalt processors represent an important source of supply for various industries. Processors differ from producers in the feed materials they use and the products they make, although some overlap exists. Producers refine cobalt primarily from materials originating from mining or refining operations—ores, concentrates, mattes, or residues—although some refineries supplement their feedstock with cobalt-bearing scrap. In contrast, processors use refined cobalt metal or cobalt-bearing scrap as feed materials. In terms of products, both producers and processors can make cobalt metal powders, oxides, and salts (acetate, carbonate, chloride, hydroxide, nitrate, and sulfates.) However, other metal forms, such as cathode and granules, are only made by producers, and organic cobalt compounds such as cobalt carboxylates are only made by processors. The world's largest cobalt processor is Union Minière S.A. in Belgium (formerly Metallurgie Hoboken-Overpelt S.A.) Other cobalt processors are in Africa, Asia, Europe, and North America (see Production section of this report).

Byproducts and Coproducts

Cobalt is rarely produced as the primary product from mining and refining operations. Nearly one-half of world cobalt supply is produced as a byproduct of copper in Zaire and Zambia. Cobalt production in most other countries is a byproduct of nickel. Exceptions are 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.

Economic Factors

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.

Operating Factors

The U.S. 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). In addition to these regulatory agencies, the following groups issue guidelines or develop scientific positions for consideration by government agencies when making regulations: American Conference of Governmental Industrial Hygienists (ACGIH), International Agency for Research on Cancer (IARC), and Agency for Toxic Substances and Disease Registry (ATSDR).

In April 1992, ACGIH published a review of cobalt and proposed that cobalt be given an "A3 Animal Carcinogen" classification. The A3 classification is defined as follows. "The agent is carcinogenic in experimental animals at a relatively high dose, by routes(s) of administration, at site(s), of histological type(s), or by mechanism(s) which are not considered relevant to worker exposure. Available epidemiologic studies do not confirm an increased risk of cancer in exposed humans. Available evidence suggests that the agent is not likely to cause cancer in humans except under uncommon or unlikely routes or levels of exposure."[2] ACGIH also issued a notice of its intention to decrease its threshold limit value (TLV) for cobalt from an 8-hour time-weighted average of 0.05 milligram per cubic meter (mg/m^3) to 0.02 mg/m^3. ACGIH TLV's are used by regulatory agencies such as OSHA in setting permissible exposure levels. The proposed change in the TLV was still under consideration at yearend.

In July 1992, ATSDR published a toxicological profile of cobalt as required by section 110 of the Superfund Amendments and Reauthorization Act of 1986.[3] The profile summarized toxicological and epidemiological literature on health effects from exposure to cobalt. The profile also presented information on the potential for human exposure to cobalt from data in EPA's Toxics Release Inventory (TRI).

The USBM completed an initial evaluation of the flow of cobalt-containing materials in the United States.[4] The objective of the study was to characterize the inputs, outputs, and losses of cobalt at various stages in the life-cycle of cobalt-containing materials and products. The study addressed cobalt released during the mining and processing of other metals and minerals; scrap generation and subsequent recycling or cobalt recovery; and cobalt losses resulting from the generation of wastes, dissipative uses, and disposal of used products.

Even though the United States does not mine or refine cobalt, preliminary estimates from the study indicated that significant quantities of cobalt are released during the production of other metals and minerals. On an annual basis, an estimated 480 tons of cobalt is released from the burning of coal and at least 1,700 tons of cobalt is released from mining and processing lead and copper ores.

Industrial losses of cobalt from chemical and metal powder processing, alloy processing, and parts and product manufacturing were estimated to be 410 tons to 440 tons per year. This estimate is roughly equal to annual releases and transfers of cobalt and cobalt compounds reported by U.S. industries to the EPA for 1987 (441 tons contained cobalt), 1988 (462 tons), 1989 (591 tons), and 1990 (521 tons).[5] The study determined that industrial losses are outweighed by the loss of cobalt in products discarded following use. An estimated 2,780 tons of cobalt is consumed in the United States each year to make products that will ultimately be discarded.

The superalloy, magnet alloy, cemented carbide, tool steel, and hardfacing alloy industries have well-established recycling or cobalt recovery practices. These industries recycle home scrap, prompt scrap, and in some cases, obsolete scrap as well. Some metallic scrap is downgraded. Although this is a loss of usable cobalt, it is not an environmental loss. The petroleum industry has established recycling and metal-recovery practices for spent catalysts, and some chemical catalysts are also recycled.

Most cobalt uses are not dissipative in character. The annual amount of cobalt lost from the dissipation of agricultural products, the attrition of cemented carbides, and losses during the recycling of homogeneous catalysts is estimated to be about 120 tons.

ANNUAL REVIEW

Legislation and Government Programs

In February, the Department of Defense (DOD) presented its 1992 Report to the Congress on National Defense Stockpile Requirements. In the report, DOD proposed decreasing the quantities of materials held in the NDS to reflect a reduction in potential threats to U.S. national security. DOD proposed that the goal for cobalt be revised to 18,346 tons (40,446,597 pounds). Because the proposed goal was less than the existing cobalt inventory, adoption of the goal would result in excess cobalt available for disposal. In October, Congress passed and the President signed the Defense Authorization Act. The Act authorized the disposal of excess stockpile materials, including 5,897 tons (13,000,000 pounds) of cobalt. Before the Defense Logistics Agency (DLA) could begin cobalt sales, a revised Annual Materials Plan (AMP) outlining details of the disposals for fiscal year 1993 had to be approved by Congress. The revised AMP was submitted to Congress in late November. It listed 2,087 tons (4,600,000 pounds) as the maximum quantity of cobalt that could be sold during fiscal year 1993, although actual sales levels would depend on market conditions. In anticipation of congressional approval of the AMP, DLA prepared a draft Invitation for Bids (IFB) for NDS cobalt and invited industry to comment on the terms of the sale. The comments were used to prepare a final IFB, scheduled for release in early February 1993. At yearend, the cobalt inventory reported by the DLA was 24,070 tons, contained cobalt.

On June 17, 1992, the United States granted most-favored-nation (MFN) status to the Russian Federation as part of a comprehensive trade agreement between the two countries.[6] Russian products can now be imported into the United States under MFN duty rates, which are significantly lower than the rates for non-MFN countries. The change to MFN status will have the greatest impact on imports of cobalt chemicals, cobalt alloys, wrought cobalt, and cobalt articles. The change in status will not affect cobalt metal, cobalt ores and concentrates, or cobalt matte, waste, and scrap, which were already duty free.

Under the Emergency Planning and Community Right-to-Know Act, industries manufacturing, processing, or using certain chemicals in quantities above defined threshold limits must report estimates of emissions each year to the EPA. The data are compiled into EPA's TRI. In 1992, EPA published data on releases and transfers for the years 1987 through 1990.[7] In 1990, U.S. industry released 36 tons of cobalt metal and 162 tons of cobalt compounds. Releases of cobalt metal were distributed as follows: 46% was released as air emissions, 11% was discharged to water, and 43% was released to land. Releases of cobalt compounds were distributed as follows: 15% was released as air emissions, 30% was discharged to water, and 55% was released to land. Transfers in 1990 included 124 tons of cobalt metal and 199 tons of cobalt compounds. Most of these transfers were to offsite treatment and/or disposal facilities other than municipal wastewater treatment plants.

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 1992, the United States consumed about one-third of estimated world refinery production. There was no domestic production, so demand was met primarily from imports, with the exception of about 25% 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 (see Legislation and Government Programs section of this report).

World cobalt production is concentrated in a limited number of geographic areas. Political and economic conditions in these areas can impact cobalt production, transportation, and/or supply. Roughly one-half of the world's supply of refined cobalt originates in central Africa, primarily from Zaire and Zambia. Zaire is the world's largest producer, but its production has decreased significantly over the past few years as the result of a mine collapse, a continuing political stalemate, declining economic conditions, and periodic social unrest. Russia is also a significant cobalt producer and recently began exporting the metal to Western markets.

Production

There was no domestic mine or refinery production of cobalt in 1992. Blackbird Metals Inc. of New York continued to seek financing for the construction of a U.S. cobalt refinery.

The Knox Nickel Corp., a subsidiary of Black Hawk Mining Inc. of Toronto, Canada, continued with its plans to develop the Knox nickel-copper-cobalt deposit near Warren, ME. At midyear, residents of the town of Warren passed a local mining ordinance with more stringent regulations than those passed by the State of Maine in 1991. Knox Nickel decided to address the issues raised by the ordinance and continue with the permitting process.

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. Hecla Mining Co. of Coeur d'Alene, ID, began trial production of cobalt sulfate from secondary materials at its Apex Unit's hydrometallurgical processing plant in St. George, UT. The sulfate was used by the U.S. copper industry as an additive in the electrowinning process. Cobalt sulfate inhibits the corrosion of lead anodes, thereby reducing the level of lead contamination in electrowon copper.

Two cobalt processors produced extra-fine cobalt metal powder in the United States. Carolmet, owned by Union Minière of Belgium, produced cobalt metal powder from imported primary metal at its Laurinburg, NC, plant. GTE Products Corp. produced cobalt metal powder from recycled materials in Towanda, PA. In August, GTE Corp. reached an agreement with OSRAM GmbH, a subsidiary of Siemens AG of Germany, for the sale of its Electrical Products Group. The Electrical Products Group is made up of six units, including the Chemical and Metallurgical Div., which includes GTE Products Corp.'s Towanda plant. Production and shipments of extra-fine cobalt metal powder are withheld to avoid disclosing company proprietary data.

Domestic cobalt processors produced 1,969 tons of cobalt oxide and hydroxide, inorganic cobalt compounds, and organic cobalt compounds in 1992. 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 1992, shipments by domestic cobalt processors included 1,838 tons of cobalt oxide and hydroxide, inorganic cobalt compounds, and organic cobalt compounds. Production and shipments each decreased about 3% in 1992 compared with production and shipments in 1991.

Consumption and Uses

Apparent consumption, as calculated from net imports, consumption from purchased scrap, and changes in Government and industry stocks, decreased to 6,526 tons. U.S. reported consumption decreased 11% in 1992 compared with that of 1991. In 1992, the amount of cobalt consumed as metal decreased to 43% of all forms consumed, while cobalt consumed in scrap increased to 25% and cobalt consumed as chemicals increased to 33%. *(See tables 3 and 5 and figure 1.)*

As a whole, metallurgical industries (producers of cemented carbides, magnetic alloys, mill products, steels, superalloys, welding materials, etc.) consumed 15% less cobalt in 1992 as compared with consumption in 1991. Superalloy melters' cobalt consumption continued to decrease from the record-high amount used in 1990, dropping just below the levels consumed in the late 1980's. Cutbacks in military programs, the economic recession and poor financial condition of commercial airlines, and the reduction of superalloy product inventories by jet engine manufacturers were cited as reasons for the continued decline. The steel industry used significantly less cobalt in 1992; producers of magnetic alloys and welding materials also used less cobalt than they had in 1991. In contrast, producers of cemented carbides used basically the same amounts of cobalt in both years.

Cobalt consumption by chemical industries as a whole was unchanged in 1992 as compared with that in 1991. However, only the catalyst industry showed an increase in cobalt use. Cobalt use in feeds, glass decolorizers, ground coat frits, paint driers, and pigments decreased.

The first plant in North America to use ^{60}Co for the irradiation of fresh foods began operations in 1992. The plant was built in Mulberry, FL, by Vindicator, Inc. In the plant, foods are treated with gamma rays from a ^{60}Co source to delay spoilage and kill organisms that cause illness. The first foods to be processed were fruits and vegetables. The company planned to eventually process poultry and seafood as well.

Stocks

Cobalt stocks held by U.S. processors and consumers decreased significantly during 1992. By yearend, total stocks of metal, scrap, and chemicals had decreased 45% from 1991 yearend stock levels. The largest decrease was in cobalt metal stocks, which dropped from more than 1,000 tons at yearend 1991 to 400 tons at yearend 1992. Yearend stocks of cobalt chemicals and scrap also decreased. *(See table 6.)*

In contrast, African producers' inventories accumulated during the second half of 1992 as the difference between the $25 per pound producer price and declining free market prices widened. By November, African producer inventories were estimated to be in the 3,000- to 5,000-ton range.[8]

Markets and Prices

The producer price for cobalt was $25 per pound for most of the year. When the 1992 price was first announced in December 1991, it was to be effective for 6 months, subject to review and a possible revision in June 1992. In early June, Gécamines and ZCCM announced that they would keep the price at $25 per pound with the intention of maintaining confidence and stability in the market. On November 20, the African producers announced a new producer price of $18 per pound, effective immediately, to be held for 12 months.

Prior to the announcement of the African producer price, a delegation from Gécamines visited Russian cobalt producers and Government officials to discuss the cobalt market. The delegation, headed by the presidents of Gécamines Commerciale and Gécamines Exploitation, met with the heads of Severonickel, Norilsk Nickel, Yuzhural Nickel, and Ufaley Nickel, the Deputy Minister of Foreign Economic Relations of the Russian Federation, the Executive Ministry of Economy of the Russian Federation, Raznoimport (the Russian state trading organization), and the directors of the Government stockpile. Gécamines and Raznoimport issued the following joint statement after the meeting. "It was recognized by all the parties of the necessity to cooperate, to regularly consult each other and to coordinate actions in order to stabilize the cobalt market, which will enable cobalt producers to obtain a realistic price for their products and to achieve a better return." The meeting and statement were an indication of the growing importance of Russian cobalt on Western markets. Estimates of the quantity of Russian cobalt entering Western markets during 1992 ranged from 2,500 to 6,000 tons. The Bureau of the Census reported that in 1992 439 tons, or 8% of U.S. cobalt imports, was from Russia.

The free market price for cobalt cathode steadily dropped from a high of more than $30 per pound in January to about $15 per pound in October. The decrease was attributed to reduced consumption because of recessionary economic conditions in the United States, Europe, and Japan; a drawdown of consumer stocks; and the availability of lower priced Russian cobalt in Western markets. These factors outweighed concerns over reduced production from Zaire and increased demand from China. By October, the differential between the African producer price and the free market price was about $10 per pound. The free market price increased slightly in late October/early November, then stabilized at approximately $16 per pound following the announcement of the $18 producer price. The weighted average free market price for the year was $22.93 per pound. *(See tables 3 and 7 and figure 2.)*

A third price series for cobalt developed during the year—prices at which Russian cobalt was sold. Metal Bulletin began reporting free market prices for 99.3% minimum cobalt from Russia in November. Prices for Russian cobalt were between $10.80 and $12.70 per pound during November and December, generally $4 to $5 per pound lower than Metal Bulletin's free market prices for higher grade minimum 99.8% cobalt.

Foreign Trade

U.S. imports of unwrought cobalt and cobalt in chemicals decreased 17% in 1992. Cobalt imports from Zaire decreased significantly to less than 600 tons. Zambia became the leading supplier of cobalt to the United States in 1992, providing 27% of cobalt imports; followed by Norway, supplying 16%; Canada, 15%; Zaire, 10%; Belgium, 8%; and Russia, 8%. In 1992, 37% of U.S. cobalt imports was from central Africa. In addition to the cobalt imported directly from Zaire and Zambia, some of the cobalt metal powders and oxides imported from Belgium were made from Zairian cobalt metal. Thirty-two percent of U.S. imports was from Canada and Norway. Some of the cobalt produced in Norway originates from ores mined in Canada. Imports of cobalt metal from Russia increased more than 50% to 439 tons. Russia 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. *(See figure 3 and tables 8 and 9.)*

In 1992, the United States imported 90 tons, gross weight, of unwrought cobalt alloys valued at $3.1 million. Five countries supplied 93% of these materials: France (37%), Sweden (20%), the United Kingdom (18%), Canada (12%), and Japan (6%). The United States imported 584 tons, gross weight, of cobalt matte, waste, and scrap, valued at $7.5 million. Seven countries supplied 93% of these materials: the United Kingdom (38%), Japan (17%), Sweden and Germany (each 10%), Mexico (8%), and Canada and France (each 5%). The United States also imported 131 tons, gross weight, of wrought cobalt and cobalt articles valued at $8.6 million. The leading suppliers of these materials were the United Kingdom (54%) and Japan (28%), followed by France (9%) and Canada (5%).

U.S. net import reliance as a percentage of apparent consumption was estimated to be 75% in 1992. The net import reliance would be 100% if no cobalt were recovered from secondary sources (scrap).

The import duty on cobalt acetates, carbonates, and chlorides was 4.2% ad valorem for MFN and 30% ad valorem for non-MFN. The duty on cobalt oxides and hydroxides was $0.026 per kilogram for MFN and $0.44 per kilogram for non-MFN. The duty on cobalt sulfates was 1.4% for MFN and 6.5% for non-MFN. Imports of unwrought cobalt metal; cobalt ores and concentrates; and cobalt matte, waste, and scrap were duty free. The duty on unwrought cobalt alloys and wrought cobalt and cobalt articles was 5.5% for MFN and 45% for non-MFN. Special rates of duty are applied to certain cobalt-containing materials under the following programs: Andean Trade Preference Act, Caribbean Basin Economic Recovery Act, Generalized System of Preferences, United States-Canada Free-Trade Agreement, and the United States-Israel Free Trade Area.[9]

In 1992, the United States exported an estimated 1,424 tons of unwrought cobalt and cobalt contained in chemicals valued at $39.7 million. This represented a 7% decrease as compared with exports in 1991. More than one-half of this cobalt was shipped to four countries: Mexico (20%), Canada (18%), Guinea (12%), and Brazil (8%). The remainder was shipped to 42 other countries. *(See table 10.)*

Exports also included 405 tons, gross weight, of wrought metal and cobalt articles valued at $13.2 million. More than three-fourths of these materials was sent to seven countries: the Netherlands (19%), Japan (15%), the United Kingdom (13%), Sweden (11%), Canada (7%), France (6%), and Hong Kong (5%). The remainder was shipped to 20 other countries. In addition, the United States exported 6 tons, gross weight, of material under the category entitled, "Cobalt ores and concentrates." The material, valued at $82,632, was sent to Canada.

World Review

World cobalt production decreased for the second consecutive year in 1992. Refinery production reported by the seven Cobalt Development Institute (CDI) member producers[10]—Falconbridge Ltd.; Gécamines; Inco Ltd.; OM Group, Inc.; Sherritt Gordon Ltd.; Sumitomo Metal Mining Co. Ltd.; and ZCCM—decreased 8% from 19,486 tons in 1991 to 17,891 tons in 1992. The decrease was primarily due to a significant decrease in production by Gécamines—the world's largest cobalt producer. If production by Gécamines is excluded, production by the remaining six CDI member producers shows an increase of 5% as compared with production in 1991. Two producers, Falconbridge and OM Group, reported record-high production levels in 1992. Production by Inco also increased, while production by Sherritt and Sumitomo decreased. The CDI estimated total 1992 world production at 22,780 tons, with nonmember production primarily from Russia (4,000 tons), the Republic of South Africa (500 tons), China (300 tons), and Brazil (100 tons.) An additional 2,000 tons of cobalt was estimated to be available as nonconsumer stocks. The CDI estimate for 1992 demand was 21,500 tons, leaving approximately 3,000 tons of cobalt available as nonconsumer stocks.

Capacity.—The data in table 11 are rated capacity for refineries as of December 31, 1992. 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, changes in the grade of raw materials processed, and/or changes in knowledge about the facilities. *(See table 11.)*

Albania.—Mining of nickel-cobalt laterites was assumed to have largely ceased in late 1991. The last production at the Elbasan plant was reported to have been in 1990.

Australia.—The Queensland Nickel Joint Venture (QNJV) produced cobalt sulfide as a byproduct of lateritic nickel mining and refining. QNJV operates the Yabulu nickel-cobalt refinery in Townsville, Queensland, and the Greenvale lateritic nickel mine, also in Queensland. At the beginning of 1992, 72% of QNJV was controlled by a consortium of financial institutions and 28% was owned by the Queensland Government under Nickel Resources North Queensland (NRNQ), a limited partnership. The consortium continued with efforts begun in 1991 to sell the majority share. The share came under control of the consortium in July 1991 when former owner Dallhold Investments Pty. Ltd. went into receivership. Inco Ltd., the Canadian nickel and cobalt producer, held negotiations toward the purchase of the 72% share, but withdrew its bid when it could not reach agreements with the Queensland Government on future plans for expansion of the refinery and protection of QNJV's patented cobalt-recovery technology. Rather than sell the 72% interest to a single buyer, the consortium opted for a public float. In June, QNI Resources Pty. Ltd., wholly owned subsidiary of newly incorporated QNI Ltd., purchased the 72% share in QNJV. Subsequently, shares in QNI were offered to the public in August. In addition, QNI Resources entered into an agreement with the State of Queensland whereby QNI Resources would acquire an additional 8% interest from NRNQ. In exchange, the State of Queensland would become a major shareholder in QNI through preference shares. Eventual ownership of the joint venture was to be 80% QNI Resources and 20% NRNQ.

QNI outlined the current and future ore sources for the Yabulu refinery. Mining at the company's Greenvale mine

was expected to end in October 1992, and the last stockpiled ore from Greenvale was expected to be delivered to Yabulu in March 1993. The company had contracts with various miners in Indonesia and New Caledonia to supply lateritic nickel ore through 1995 with options to extend the contracts through 1997. In addition, QNI received approval from the Queensland Government to develop the Brolga laterite deposit near Rockhampton in central Queensland. Mining at Brolga was expected to last 4 years beginning about April 1993. The company anticipated that by June 30, 1993, 80% of its feed would be from imported ore.

QNI also presented a capital expenditure program. The company planned to spend A$53 million over 2 years ending June 30, 1994. Included in the program were improvements to the Port of Townsville, extensions and improvements to the Yabulu refinery, and the construction of a cobalt pilot plant. The Yabulu refinery produces cobalt sulfide, which is further refined to cobalt metal powder, oxide, and salts by OM Group Inc.'s refinery in Kokkola, Finland.

Western Mining Corp. (WMC) produced nickel-cobalt sulfide as a byproduct of nickel mining and refining in Western Australia. WMC completed trial mining at the Bulong nickel-cobalt deposit east of Kalgoorlie in Western Australia. About 20,000 tons of lateritic nickel ore was produced, and a report on the mining and ore characteristics was initiated. In metallurgical tests on the ore, high-pressure acid leaching dissolved more than 90% of the nickel and cobalt. Solvent extraction of nickel and subsequent extraction of cobalt were also studied. WMC is studying the Bulong deposit under an agreement with owners Resolute Resources Ltd. and Energy Oil and Gas NL. Under the agreement, WMC will earn a 70% share in the property in exchange for a feasibility study on the project and the design, construction, and operation of a pilot plant.

MIM Holdings Ltd. continued work on a cobalt pilot plant. The company planned to use bioleaching technology to recover cobalt from its Mount Isa copper concentrates.

Belgium.—The merger between Acec-Union Minière, Metallurgie Hoboken-Overpelt (MHO), Vieille-Montagne, and Mechim was effectively completed in 1992. Shareholders voted to change the name of the resulting company from ACEC-Union Minière to Union Minière S.A. Union Minière produced extra-fine cobalt metal powder in Laurinburg, NC, and cobalt metal powders and oxides at Olen, Belgium. During 1992, the company compensated for problems with supplies of raw materials from Zaire by diversifying its sources of supply and operating its unit for recovery of cobalt from secondary materials at full capacity. Research and development efforts focused on the recovery of cobalt from various raw materials and the production of submicrometer cobalt metal powders. Union Minière's production capacity at Olen was 1,500 tons per year of extra-fine cobalt metal powder, 1,000 tons per year of cobalt mesh powders, and 2,000 tons per year of cobalt oxides. The capacity to produce extra-fine cobalt metal powders in Laurinburg was 550 tons per year.[11]

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 1992, Falconbridge produced 800 tons of cobalt from nickel ores at its Sudbury, Ontario, operations and 900 tons of cobalt from custom-feed smelting.[12] The company developed a pyrometallurgical process to remove unwanted elements from cobalt-bearing scrap prior to smelting. Cobalt-containing nickel-copper matte from the Sudbury smelter 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 increased 6% in 1992; the company produced 1,465 tons of cobalt in 1992 compared with 1,385 tons in 1991.[13] Inco's 1992 cobalt deliveries, including cobalt contained in alloys and engineered products, were essentially unchanged from deliveries in 1991 at 1,402 tons.[14]

Sherritt Gordon refined nickel-cobalt materials from Cuba, Canada, and elsewhere at its Fort Saskatchewan refinery in Alberta. During 1992, Sherritt completed the first phase of reconfiguring its refinery to improve processing of Cuban nickel-cobalt sulfides. The reconfiguration included a newly developed, more flexible cobalt-nickel separation process. As a result of the reconfiguration, the refinery's annual cobalt capacity increased to about 1,350 tons (3 million pounds.) However, Sherritt's 1992 production of cobalt metal powder decreased 17% from production in 1991 to 685 tons.[15] The decrease was partly a result of problems that occurred during integration of the new cobalt facilities with the nickel refinery. The second phase of the reconfiguration was to include construction of a new cobalt reduction plant in early 1993 and a gradual increase in annual cobalt capacity to about 2,000 tons (4.5 million pounds) by yearend 1993.

Sherritt introduced a new cobalt product in 1992—ultrafine cobalt metal powder. The ultrafine powder particles were between 0.6 micrometer (μm) to 1.0 μm, as compared with the 1.0-μm to 1.6-μm particles in the extra-fine cobalt metal powder introduced by Sherritt in 1991. Markets for the ultrafine cobalt powder included binders for sintered tungsten carbides and diamond tools.

China.—Cobalt was produced at various locations in China from both domestic and imported raw materials. At Jinchuan, Gansu Province, cobalt metal was produced as a byproduct of nickel from the refining of domestic nickel sulfide ores. The Ganzhou cobalt refinery in Jiangxi Province produced cobalt metal and salts from cobalt arsenide concentrates imported from Morocco. Minor production sites included the Zibo Cobalt Works in Shandong Province, where cobalt metal was produced from iron ore from Shandong Province and copper ore from Shanxi Province.

China is a net importer of cobalt. Official Chinese customs statistics indicated that 636 tons of cobalt was imported during 1992. More than three-quarters of these imports was from the former U.S.S.R. Zaire and Zambia each supplied about 10% and Canada supplied the remaining 5%. Much of the cobalt that entered China was shipped through Hong Kong. In addition to the cobalt recorded in official Chinese statistics, approximately 400 tons of cobalt imported to Hong Kong and other Pacific Rim countries was believed to have been reexported to China. An additional 400 tons of cobalt was estimated to have been built up as stocks in Hong Kong during 1992. These stocks were expected to be drawn down during 1993.

Chinese cobalt consumption in 1992 was estimated to be about 1,500 tons. The cobalt was used to produce cemented carbides, cobalt oxide, samarium-cobalt powders and finished samarium-cobalt magnets, Alnico magnets, and superalloys for the aircraft industry. Following a short-term slowdown owing to overexpansion, cobalt consumption in China was expected to increase with the growing Chinese economy.[16]

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 percentage 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 Yuzhural Nickel refinery at Orsk in the southern Ural Mountains in Russia. Beginning in 1991, some of the sulfides were refined at Sherritt's Fort Saskatchewan nickel-cobalt facility in Canada under a long-term feed supply agreement. Reports indicate that a barter agreement established between Cuba and Russia at the end of 1992 included the export of some nickel-cobalt sulfides from Moa Bay to Orsk.[17]

Czechoslovakia.—Production at the Niklovà Huta Sered nickel-cobalt plant near Bratislava was expected to end during the second half of 1992. The plant used lateritic ore from Albania to produce about 3,000 tons of nickel and 50 tons of cobalt per year. Disruptions in feed supplies and environmental problems were reported to be the reasons for the closure.

Finland.—Outokumpu Metals & Resources Oy increased its ownership in OM Group, Inc. (OMG) to 96% by redeeming shares held by a consortium of Finnish insurance and investment companies. OMG produced cobalt products at three locations: the Kokkola Chemicals Oy refinery in Kokkola, Finland; the Vasset S.A. chemical plant in Ezanville, France; and the Mooney Chemicals, Inc. chemical plant in Franklin, PA. OMG companies' production of cobalt contained in metal powders, inorganic salts, and carboxylates increased 23% in 1992 to 2,610 tons.[18] This production included a record 2,100 tons of cobalt in products refined at the Kokkola plant, a 40% increase from Kokkola's refinery production in 1991.[19] In addition to extra-fine cobalt metal powders, cobalt oxides, and inorganic cobalt salts, the Kokkola plant recently began producing two new cobalt products—coarse-grade cobalt metal powder and 400-mesh cobalt metal powder. The coarse-grade powder is sold to chemical processors as feedstock for cobalt carboxylates and inorganic salts. The 400-mesh powder is sold to magnet producers.

During 1992, OMG completed a 2-year $25 million capital expenditure program at its Kokkola refinery. The program included improvements in processing technology and plant equipment that would enable the plant to handle more diverse feedstocks, including cobalt-bearing slag and secondary (recyclable) materials. In November, OMG signed a contract with Gécamines to purchase cobalt slag from Zaire. OMG planned to begin processing the slag during the second quarter of 1993. The company expected the slag to represent up to one-half of Kokkola's total annual cobalt raw materials supply. The refinery has used cobalt sulfide from QNJV in Queensland, Australia, as a raw material since 1987. Kokkola's contract to purchase QNJV's entire production of cobalt sulfide continues until yearend 1996.[20]

France.—Chempro, owned by Sassoon Metals & Chemicals AG of Switzerland, announced plans to increase the cobalt chemicals capacity at its Mirecourt plant in eastern France. Chempro produces organic cobalt compounds for use as adhesion promoters in the radial tire industry.

The French Government was reported to have offered 50 to 100 tons of stockpiled cobalt for sale in December.

India.—Hindustan Zinc Ltd. reportedly produced about 1 ton of cobalt metal at its newly commissioned pilot plant. The solvent extraction-electrowinning plant is installed at the Debari zinc smelter in Udaipur, Rajasthan State.

Indonesia.—State-owned PT Aneka Tambang (ANTAM) was under contract to supply 1 million wet tons of lateritic nickel ore to QNJV's Yabulu nickel-cobalt refinery in Queensland, Australia. The ore was to come from ANTAM's Oeboelie Mine on Gebe Island in eastern Indonesia.

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),[21] 1992 Japanese cobalt consumption decreased 26% to 2,230 tons. Cobalt consumption decreased in each industry reported to MITI as follows: catalysts down 14% to 358 tons, hard metal tools down 19.5% to 294 tons, magnetic materials down 30% to 438 tons, special steels down 27% to 654 tons, and other uses down 36% to 451 tons. Demand for cobalt catalysts is tied to the petroleum and chemical industries. Demand for hard metal tools is tied to the Japanese automotive industry. The decrease in cobalt consumption in magnetic materials was attributed to the continued substitution of lower priced neodymium-iron-boron magnets for samarium-cobalt magnets. Japanese demand for cobalt was met primarily from imports, which decreased 37% in 1992 to 4,243 tons. Zaire, Zambia, and Belgium remained the three leading suppliers of cobalt imports to Japan, in order of abundance. However, 1992 imports from Zaire decreased 60% from the previous year, imports from Zambia decreased 20%, and imports from Belgium decreased more than 30%.

New Caledonia.—In 1992, three New Caledonian mining companies were under contract to supply lateritic nickel ore to QNJV's Yabulu nickel-cobalt refinery in Queensland, Australia. J.C. Berton Mines was to supply 500,000 wet tons of ore from its Bienvenue Mine, Nickel Mining Corp. was to supply 800,000 wet tons from its Kouaoua Mine, and Société des Mines de la Tontouta was to supply 555,000 wet tons from its Moneo and Nakety Mines.

Inco completed its purchase of Compagnie des Mines de Xere from Le Bureau de Récherches Geologiques et Minières (BRGM) of France. Compagnie des Mines de Xere (formerly called Société de Promotion de Mines) held mining titles to lateritic nickel-cobalt resources in southern New Caledonia. Inco formed a new company, Goro Nickel S.A., to study the feasibility of mining and processing the laterites. Inco held 85% interest in Goro Nickel.

Norway.—The Falconbridge Nikkelverk refinery produced a record 2,293 tons of cobalt cathode in 1992, a 16% increase from the 1,983 tons produced in 1991. Feedstock for the refinery was in the form of matte from company operations in Sudbury, Canada; BCL Ltd. in Botswana; and Norilsk Nickel in Russia. The matte purchase contract with BCL was extended to the year 2006.

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.

Russia.—Most of the cobalt produced in the former U.S.S.R. was a byproduct of nickel mining and/or refining in Russia. Nickel and cobalt production in Russia involves a complex flow of ores, concentrates, and mattes between various production sites. Russian nickel-cobalt production is organized into two "Complexes" (also called Kombinats or Combinats). Norilsk Nickel Complex's production is from nickel sulfide ores mined, smelted, and refined at Norilsk in eastern Siberia and at various locations on the Kola Peninsula. Yuzhural Nickel Complex's smelters and refineries are in the Ural Mountains. Feedstock to Yuzhural Nickel's plants has included nickel laterites mined from the Ural region, cobalt-arsenide concentrates mined and beneficiated in the Tuva Autonomous Republic, and nickel-cobalt sulfides from Cuba. More recent reports[22] suggest that Yuzhural Nickel is also toll-refining white alloy from Zaire.

In 1992, significant quantities of Russian cobalt continued to enter Western markets. (See Markets and Prices section of this report.) Much of the cobalt leaving Russia was smuggled out of the country in spite of attempts by the Russian Government to control metal exports.

South Africa, Republic of.—Cobalt was produced as a byproduct of the Republic of South Africa's platinum industry. Two companies produced refined cobalt: 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 1982-91.[23] Cobalt production in 1991 decreased 16% from production in 1990, reportedly because of low recovery rates and labor disruptions at some of the mines. Production was expected to increase as a result of higher mill throughput at the platinum mines and improvements in recovery rates. Most of the cobalt produced in the Republic of South Africa was exported.

Taiwan.—Chempro, owned by Sassoon Metals & Chemicals AG of Switzerland, and the Uranus Chemical Co. of Taiwan formed a joint-venture company to produce metal-based specialty chemicals. Chempro Uranus planned to produce cobalt acetate crystals and solutions at a plant constructed in 1992 in Hsinchu, Taiwan. Cobalt acetates are used as catalysts in the manufacture of terephthalic acid and dimethyl terephthalate, which are used in the production of polyester textile fibers and polyethylene terephthalate films and bottles.

Tanzania.—Sutton Resources Ltd. continued exploration and development work in northwestern Tanzania. Sutton subsidiary Kabanga Nickel Co. investigated the Kabanga deposit. Preliminary engineering studies predicted an annual production of 24,000 tons of nickel, 3,000 tons of copper, and 1,400 tons of cobalt. A second subsidiary, Kagera Mining Co., signed an exploration and development agreement with the Government of Tanzania for nickel, cobalt, copper, and other metals in the Kagera region of Tanzania.

During the year, Sutton and BHP Minerals International Exploration Inc. agreed to form a joint venture to develop the Tanzanian properties. Under the agreement, BHP would fund exploration costs to earn a majority interest in the properties.

Uganda.—The Ugandan Government signed an agreement with the French Government's BRGM and United Kingdom-based Barclays Metals to develop cobaltiferous pyrites stockpiled at the Kilembe copper mines. The detailed feasibility study included plans to build a pilot plant in Uganda. Results from the pilot plant would be used to plan a full-scale plant at Kasese in Western Uganda. The partners planned to use bioleaching followed by solvent extraction and electrowinning to produce up to 1,000 tons per year of cobalt cathode.

Zaire.—The political stalemate in Zaire persisted through 1992, causing sporadic periods of political and social unrest, the postponement of much-needed foreign investment, rampant inflation, and continued shortages of consumables and spare parts at state-owned Gécamines. Gécamines maintained its status as the world's largest cobalt producer in spite of a 38% decrease in production of cobalt metal. In 1992, the company produced 2,629 tons of high-quality cobalt cathode at its Luilu refinery (as compared with 2,989 tons in 1991), 1,837 tons of lower grade cobalt cathode at its Shituru refinery (2,439 tons in 1991), and 583 tons of cobalt granules at Shituru (2,686 tons in 1991.) In late 1992 and early 1993, Gécamines' production was only 150 to 200 tons of cobalt per month.

The cobalt content of ore milled by Gécamines in 1992 decreased 36% to 13,300 tons, from 20,900 tons in 1991. The cobalt content of concentrates produced decreased 42% to 5,700 tons from 9,900 tons in 1991. In addition to cobalt in concentrates, 1992 input to Gécamines' refineries included 4,106 tons of cobalt in hydrates (down from 5,483 tons in 1991) and 1,113 tons of cobalt in scrap (up from 517 tons in 1991.) Ore feed to the concentrators remained an important concern for Gécamines, particularly as the stocks of cobalt hydrates are drawn down. The following mining projects were in progress to increase mine output: the rehabilitation of the Kamoto Mine, increasing overburden removal activities at the Kolwezi open pit, and the installation of two in-pit mobile crusher and conveyor-belt systems to transport ore from the KOV open pit mine. However, because of the lack of financing and shortages of spare parts and consumables it is unlikely Gécamines will be able to increase production from current levels in the near term.

Gécamines recently began selling cobalt-iron-copper "white alloy," cobalt-nickel matte, spillings, and cobalt-bearing slag, partially to offset the loss of income from lower sales of cobalt metal. In 1992, production of cobalt in white alloy and cobalt-nickel matte increased to 1,579 tons as compared with 506 tons in 1991. These materials require further refining before they can be used by cobalt consumers.

Zambia.—ZCCM produced 4,610 tons of refined cobalt metal between January and December 1992, a 4% decrease from the 4,817 tons produced in calendar year 1991.[24]

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 12 and 13.)*

Current Research

The USBM researched the feasibility of upgrading NDS cobalt. The process under development involved three steps: direct electrodissolution of cobalt metal, solution purification using conventional hydrometallurgical techniques, then electrodeposition of high-purity cobalt. The dissolution and deposition steps used double membrane electrolytic cell (DMEC) technology previously developed by the Bureau to recover high-purity cobalt and nickel from superalloy scrap. Research focused on solution purification procedures and electrolytic cell operating conditions to generate cobalt cathodes of high purity and good physical qualities, respectively.

The Bureau studied cobalt-manganese deposits in the Ouachita Mountains of west-central Arkansas. The study included field investigations, mineralogical characterization, beneficiation, and hydrometallurgical tests. Magnetic separation was determined to be the most effective method for concentrating the cobalt-bearing manganese oxides. Preliminary results gave recoveries in excess of 90% manganese and cobalt at grades of 41% manganese and 0.22% cobalt. Hydrometallurgical studies using an ammonia-reduction leach process were initiated. Further research is necessary to evaluate the cobalt and manganese resource potential of the district.[25]

The Idaho National Engineering Laboratory (INEL) studied the bioextraction of cobalt from pyritic ores under contract from the USBM. INEL used Thiobacillus ferrooxidans to leach a flotation concentrate from the Blackbird Mine in Idaho. INEL determined that nearly 100% extraction of both cobalt and arsenic occurred at low pulp densities, but that dissolved metal extraction did not increase proportionally with increasing pulp density. Results of the study indicated that the leaching of cobaltite was by an indirect process. The bacteria oxidized pyrite in the concentrate to produce ferric iron; the ferric iron then oxidized the cobaltite. It was concluded that further research would be necessary to optimize conditions for bioleaching cobaltite concentrates.[26]

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

In 1992, weak demand, continued supplies of Russian cobalt, and increases in production by several Western refiners helped to compensate for a significant

decrease in production by Gécamines, the world's largest cobalt producer. However, political and economic conditions in Zaire were not resolved and production levels are not anticipated to improve in the near term.

In terms of supply, both total cobalt supply and the supply of high-quality cobalt must be considered. Continued imports of Russian ingot to Western markets and steady offers of cobalt granules and rondelles from the NDS have the potential to contribute to total cobalt supply. However, these cobalt products are not of high quality. In the case of the Russian ingot, where possible consumers are adapting their processes to take advantage of its lower price. Future availability of Russian cobalt depends on export licenses and the success of the Russian Government to control illegal exports. In the case of NDS cobalt, actual quantities of cobalt sold will depend on the prices bid and market conditions at the time of the bids. Bids accepted by the DLA in March through July 1993 were at prices close to the market price of the Russian ingot. Chemical processors and trading firms showed the most interest in NDS cobalt.

Gradually declining prices into the summer of 1993 imply that there were ample supplies of all cobalt grades to meet demand. However, overall cobalt demand is expected to increase when the economies of the major consuming countries improve. Of particular importance to the cobalt market is the outlook for the aerospace industry because of the quantities and quality of cobalt required to make superalloy jet engine parts. Although there may be adequate quantities of cobalt available when demand improves, the question remains whether there will be a shortage of high-quality cobalt. Producer stocks that accumulated during 1992 will provide some security in the short-term.

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TABLE 1
WORLD PRODUCERS OF REFINED COBALT[1]

Country	Company	Cobalt products
Brazil	Companhia Niquel Tocantins	Cathode.
Canada	Inco Ltd.	Cathode, oxide.
Do.	Sherritt Gordon Ltd.	Metal powder, briquettes.
China	China National Nonferrous Metals Industry Corp.	Cathode,[2] oxide, salts.
Finland	OM Group, Inc.	Metal powder, oxide, salts.
France	Eramet-SLN	Chloride.
Japan	Sumitomo Metal Mining Co. Ltd.	Cathode, oxide, salts.
Norway	Falconbridge Ltd.	Cathode.
Russia	Norilsk Nickel Complex	Ingot, cathode, oxide, salts.
Do.	Yuzhural Nickel Complex	
South Africa, Republic of	Impala Platinum Ltd.	Metal powder.
Do.	Rustenberg Base Metal Refiners Pty. Ltd.	Sulfate.
Zaire	La Générale des Carrieres et des Mines.	Cathode, granules.
Zambia	Zambia Consolidated Copper Mines Ltd.	Cathode, crushed bar.

[1]Companies with production during 1992.
[2]Other metal forms possible.

TABLE 2
WORLD PRODUCERS OF INTERMEDIATE COBALT PRODUCTS[1]

Country	Company	Cobalt-containing products
Australia	Queensland Nickel Joint Venture	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.

[1]Companies with production during 1992; excludes companies producing refined cobalt.
[2]Cobalt may not be recovered.

TABLE 3
SALIENT COBALT STATISTICS

(Metric tons cobalt content unless otherwise specified)

	1988	1989	1990	1991	1992
United States:					
Consumption:					
Reported	7,308	7,172	7,512	r7,240	6,473
Apparent	7,824	7,164	7,635	7,786	6,526
Imports for consumption	7,051	5,793	6,529	6,924	5,757
Stocks, December 31[1]	1,766	1,456	1,853	1,622	897
Price: Metal, per pound[2]	$7.09	$7.64	$10.09	$16.92	$22.93
World: Production					
Mine	43,819	r36,200	r35,934	r26,803	e21,924
Refinery	26,407	r25,222	r25,497	r24,243	e19,991

eEstimated. rRevised.
[1]Stocks held by consumers and chemical processors.
[2]Market 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	1989	1990	1991	1992
Steel:				
Full-alloy	W	W	W	W
Stainless and heat-resisting	74	41	51	26
Tool	219	123	W	47
Superalloys	2,860	3,345	3,066	2,697
Alloys (excluding alloy steels and superalloys):				
Cutting and wear-resistant materials[2]	538	541	r525	522
Magnetic alloys	870	710	713	670
Nonferrous alloys	27	31	32	W
Welding materials (structural and hard-facing)[3]	136	180	135	130
Other alloys	52	74	62	45
Mill products made from metal powder	W	W	W	W
Chemical amd ceramic uses:				
Catalysts	W	W	W	949
Drier in paint or related usage	718	e751	e781	e745
Ground coat frit	366	357	W	257
Pigments	W	W	W	197
Miscellaneous and unspecified[5]	r1,313	r1,361	1,876	187
Total[6]	7,172	7,512	r7,240	6,473

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1]Includes estimates.
[2]Includes diamond bit matrices, cemented and sintered carbides, and cast carbide dies or parts.
[3]Includes wear-resistant alloys.
[4]Data not comparable with 1989 because of a change in reporting method.
[5]Includes feed or nutritive additive, glass decolorizer, and data indicated by symbol "W."
[6]Data do not add to totals shown because of independent rounding.

TABLE 5
U.S. REPORTED CONSUMPTION OF COBALT,[1] BY FORM

(Metric tons, cobalt content)

	1988	1989	1990	1991	1992
Chemical compounds (organic and inorganic)[2]	r2,033	2,081	2,192	2,137	2,105
Metal	4,256	3,907	4,095	r3,525	2,755
Purchased scrap	1,018	1,184	1,225	1,578	1,613
Total	[3]7,308	7,172	7,512	r7,240	6,473

rRevised.
[1]Includes estimates.
[2]Includes oxides.
[3]Data do not add to total shown because of independent rounding.

TABLE 6
U.S. REPORTED STOCKS OF COBALT MATERIALS,[1] DECEMBER 31

(Metric tons, cobalt content)

	1988	1989	1990	1991	1992
Chemical compounds (organic and inorganic) other than oxide	249	[2]394	[2]379	[2]362	[2]344
Metal	1,278	860	1,342	1,072	400
Oxide	76	[3]	[3]	[3]	[3]
Scrap	162	202	132	189	153
Total[4]	1,766	1,456	1,853	1,622	897

[1]Stocks reported by cobalt processors and consumers; includes estimates.
[2]Includes oxide.
[3]Included with "Chemical compounds."
[4]Data may not add to totals shown because of independent rounding.

TABLE 7
YEAREND PRICES OF COBALT MATERIALS[1]

(Dollars per pound)

Material	1988	1989	1990	1991	1992
Cobalt metal:					
Cathode or granules (shot)[2 3]	8.40	8.40	8.40	11.00	[4]18.00
Fine powder (less than 1.6 micrometers)[5]	17.75	17.75	22.11	31.67	32.11
Powder (300-mesh, 400-mesh, 100-mesh)	14.74	14.71	18.63	29.46	29.10
S-grade powder (minus 48-mesh)	8.65	[6]8.65	[6]8.65	[7]11.90	XX
Cobalt oxide:					
Ceramic-grade (70% to 71% cobalt)	9.70	9.42	11.14	18.94	18.00
Ceramic-grade (72% to 73% cobalt)	9.94	9.67	11.44	19.44	18.50
Metallurgical-grade (76% cobalt)	10.31	10.06	11.67	19.69	NA

NA Not available. XX Not applicable.
[1]Prices for 1988 are from Metals Week; 1989-92 prices are list prices from African Metals Corp., unless otherwise noted.
[2]See table 3 for cathode market price.
[3]250-kilogram drums.
[4]Cathode price. Yearend price for granules was $17.00 per pound.
[5]50-kilogram drums.
[6]Sherritt Gordon Ltd. list price.
[7]Metals Week.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY FORM

(Metric tons unless otherwise specified)

Form		1990	1991	1992
Metal:[1]				
Gross weight		[2]6,027	6,375	5,274
Cobalt content[3]		[2]6,027	6,375	5,274
Value	thousands	[2]$106,902	$157,711	$246,393
Oxides and hydroxides:				
Gross weight		488	583	431
Cobalt content[3]		351	420	310
Value	thousands	$8,539	$12,941	$18,651
Other forms:				
Acetates:				
Gross weight		120	33	92
Cobalt content[3]		29	8	22
Value	thousands	$866	$309	$646
Carbonates:				
Gross weight		36	53	34
Cobalt content[3]		16	24	16
Value	thousands	$594	$776	$934
Chlorides:				
Gross weight		19	12	42
Cobalt content[3]		5	3	11
Value	thousands	$103	$101	$651
Sulfates:				
Gross weight		372	350	461
Cobalt content[3]		101	95	125
Value	thousands	$1,664	$2,295	$5,548
Total:[4]				
Gross weight		[2]7,062	7,406	6,334
Cobalt content[3]		[2]6,529	6,924	5,757
Value	thousands	[2]$118,668	$174,134	$272,822

[1]Unwrought cobalt, excluding alloys and waste and scrap.
[2]Includes 108 metric tons, valued at $1,747,104, shipped to the National Defense Stockpile.
[3]Estimated from gross weights.
[4]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

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)
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	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
U.S.S.R.[6]	285	285	7,128	—	—	—	—	—	—	285	285	7,128
United Kingdom	39	39	988	117	84	2,471	—	—	—	157	124	3,459
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]	6,375	6,375	157,711	583	420	12,941	448	130	3,482	7,406	6,924	174,134
1992:												
Belgium	345	345	19,108	150	108	6,857	50	13	735	545	465	26,701
Brazil	8	8	385	—	—	—	2	1	30	10	9	415
Canada	875	875	40,461	2	1	72	16	7	479	892	883	41,013
China	50	50	1,727	11	8	434	—	—	—	61	57	2,161
Finland	223	223	14,141	145	104	5,970	385	104	5,091	753	431	25,202
France	24	24	1,666	7	5	615	—	—	—	31	29	2,281
Germany	86	86	6,200	6	4	238	—	—	—	91	90	6,438
Japan	7	7	382	6	4	145	(5)	(5)	4	13	11	532
Norway	933	933	44,660	—	—	—	—	—	—	933	933	44,660
Russia[7]	431	431	14,698	11	8	444	—	—	—	443	439	15,142
South Africa, Republic of	93	93	4,523	—	—	—	170	46	1,296	263	139	5,819
United Kingdom	44	44	1,871	94	68	3,861	6	2	142	144	114	5,873
Zaire	592	592	27,932	—	—	—	—	—	—	592	592	27,932
Zambia	1,560	1,560	68,421	—	—	—	—	—	—	1,560	1,560	68,421
Other	3	3	216	(5)	(5)	14	—	—	—	4	4	230
Total[4]	5,274	5,274	246,393	431	310	18,651	629	172	7,778	6,334	5,757	272,822

[1]Unwrought cobalt, excluding alloys and waste and scrap.
[2]Estimated from gross weights.
[3]Cobalt sulfates, cobalt chlorides, cobalt carbonates, and cobalt acetates.
[4]Data may not add to totals shown because of independent rounding.
[5]Less than 1/2 unit.
[6]Dissolved in Dec. 1991.
[7]Formerly part of the U.S.S.R. Includes materials imported during 1992 under the country code for the U.S.S.R.

Source: Bureau of the Census.

TABLE 10

U.S. EXPORTS OF COBALT IN 1992, BY COUNTRY[1]

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)	Gross weight (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Value[3] (thousands)		
Australia	11	$220	13	$350	—	—	—	—	20	$571
Brazil	22	816	112	1,270	42	$712	12	$191	116	2,988
Canada	115	5,820	52	1,395	12	181	376	1,884	249	9,281
Costa Rica	—	—	32	95	—	—	—	—	23	95
Germany	35	1,191	2	112	—	—	—	—	37	1,302
Guinea	—	—	241	64	—	—	—	—	173	64
Hong Kong	61	3,321	13	165	—	—	—	—	71	3,486
Indonesia	15	562	—	—	—	—	—	—	15	562
Italy	1	54	65	2,190	—	—	—	—	47	2,244
Japan	55	2,714	14	424	(5)	9	—	—	66	3,147
Korea, Republic of	(5)	3	10	206	53	716	—	—	20	925
Mexico	13	583	309	2,804	195	1,352	2	55	282	4,794
Netherlands	30	1,528	1	4	(5)	4	—	—	30	1,536
Taiwan	2	39	18	501	175	2,285	8	110	58	2,935
United Arab Emirates	35	270	—	—	—	—	—	—	35	270
United Kingdom	54	1,423	28	33	14	105	—	—	78	1,561
Other	36	1,636	89	2,185	3	64	5	61	101	3,946
Total[6]	485	20,180	999	11,797	494	5,428	403	2,301	1,424	39,707

[1]In addition to the materials listed, the United States exported cobalt ores and concentrates and wrought cobalt and cobalt articles.
[2]Includes unwrought cobalt, powders, waste and scrap, and mattes and other intermediate products of cobalt metallurgy.
[3]Customs value.
[4]Estimated from gross weights.
[5]Less than 1/2 unit.
[6]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11
WORLD ANNUAL COBALT PRODUCTION CAPACITY, DECEMBER 31, 1992

(Metric tons, cobalt content)

Country	Refinery capacity
Brazil	300
Canada	3,200
China[e]	500
Finland[e 1]	2,500
France[2]	600
Japan[1 3]	2,800
Norway	2,400
Russia[e]	6,600
South Africa, Republic of [1]	750
United States[4]	900
Zaire	18,000
Zambia	5,000
Total	43,550

[e]Estimated.
[1]Includes salts.
[2]Cobalt chloride.
[3]Includes an estimated standby capacity of 1,900 metric tons.
[4]Standby capacity.

TABLE 12
COBALT: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons, cobalt content)

Country[2]	1988	1989	1990	1991	1992[e]
Albania[e 3]	600	600	600	600	300
Australia[e 4]	1,200	r1,100	r1,100	r1,200	1,350
Botswana[5]	291	215	205	r208	200
Brazil[e]	150	r300	r400	r400	400
Canada[6]	2,398	2,344	2,184	2,171	7 2,219
Cuba[8]	1,783	1,825	e1,600	e1,600	1,500
Morocco[9]	253	121	194	r325	300
New Caledonia[e 10]	800	800	800	800	800
Russia[11 12]	—	—	—	—	1,700
South Africa, Republic of [e]	300	300	350	300	350
U.S.S.R.[e 12 13]	2,850	2,850	2,400	2,200	—
Zaire[9 14]	26,000	18,400	19,000	9,900	5,700
Zambia[9 15]	7,090	7,255	r6,999	r6,994	7,000
Zimbabwe[16]	104	90	r e102	r105	105
Total	43,819	r36,200	r35,934	r26,803	21,924

[e]Estimated. [r]Revised.
[1]Table includes data available through June 1, 1993. 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.
[2]In addition to the countries listed, Bulgaria, China, 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.
[3]Calculated from reported and estimated weight of nickeliferous ore.
[4]Figures represent quantities of cobalt contained in intermediate metallurgical products (cobalt oxide, cobalt sulfide and nickel-cobalt sulfide). Cobalt content of lateritic nickel ore, nickel concentrate, and zinc concentrate was estimated as follows, in metric tons: 1988—2,574; 1989—2,270 (revised); 1990—1,770 (revised); 1991—1,470 (revised); and 1992—1,070.
[5]Reported cobalt content of pelletized nickel-copper matte.
[6]Figures 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, defined as the assay content of cobalt in concentrates of Canadian origin, was reported as follows, in metric tons: 1988—6,234; 1989—6,167; 1990—5,470; 1991—5,274 (revised); and 1992—5,087 (preliminary).
[7]Reported figure.
[8]Determined from reported nickel-cobalt content of granular and powder oxide, oxide sinter, and sulfide production.
[9]Cobalt content of concentrates.
[10]Series represents estimated recoverable content of ores and intermediate metallurgical products exported from New Caledonia to France. The estimated cobalt content of total ores mined is as follows, in metric tons: 1988—6,000; 1989—6,000; 1990—6,000; 1991—6,000; and 1992—6,000.
[11]Formerly part of the U.S.S.R.
[12]All production in the U.S.S.R. from 1988-91 came from Russia.
[13]Dissolved in Dec. 1991.
[14]In 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: 1988—0; 1989—0; 1990—3,194; 1991—5,483; and 1992—4,106. Scrap: 1988—31; 1989—27; 1990—49; 1991—517 (revised); and 1992—1,113.
[15]Fiscal years beginning Apr. 1 of that stated. Cobalt content of ore milled was as follows, in metric tons: 1988—10,687; 1989—10,590; 1990—10,870; 1991—10,976 (revised); and 1992—10,800 (estimated).
[16]Estimated cobalt content of ore.

TABLE 13

COBALT: WORLD REFINERY PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Metric tons, cobalt content)

Country[2]	1988	1989	1990	1991	1992[e]
Albania: Oxide[e]	10	10	20	20	10
Brazil: Metal[e]	—	r70	r240	r240	240
Canada: Metal (including metal powder and oxide)	2,356	r2,110	r2,063	2,248	3,2210
China: Metal[e]	270	270	3325	350	400
Finland:					
Metal (including metal powder)	229	292	330	r270	300
Salts[e]	903	1,003	970	r1,233	1,800
Total	1,132	1,295	1,300	1,503	3,2100
France: Chloride (solution)	176	165	150	e150	150
Japan: Metal	109	99	199	185	105
Norway: Metal	1,951	1,946	1,830	1,983	3,2293
Russia: Unspecified[4 5]	—	—	—	—	2,500
South Africa, Republic of:					
Metal (powder)[e]	60	60	70	60	65
Sulfate[e]	146	139	179	149	169
Total	206	199	249	209	3234
U.S.S.R.: Unspecified[e 5 6]	5,300	5,300	4,500	4,500	—
Zaire: Metal[7]	10,026	9,311	9,947	8,114	3,5049
Zambia: Metal[8]	4,871	4,447	4,674	r4,741	4,700
Total	26,407	r25,222	r25,497	r24,243	19,991
Of which:					
Metal	19,872	r18,605	r19,678	r18,191	15,362
Salts[9]	1,235	1,317	1,319	r1,552	2,129
Unspecified	5,300	5,300	4,500	4,500	2,500

[e]Estimated. [r]Revised.

[1]Table includes data available through June 1, 1993. Figures represent cobalt refined from ores, concentrates, or intermediate products and do not include production of downstream products from refined cobalt.

[2]In addition to the countries listed, Belgium, Czechoslovakia, and Germany may recover cobalt from imported materials, but production is not reported, and information is inadequate to make reliable estimates of production.

[3]Reported figure.

[4]Formerly part of the U.S.S.R.

[5]All production in the U.S.S.R. from 1988-91 came from Russia.

[6]Dissolved in Dec. 1991.

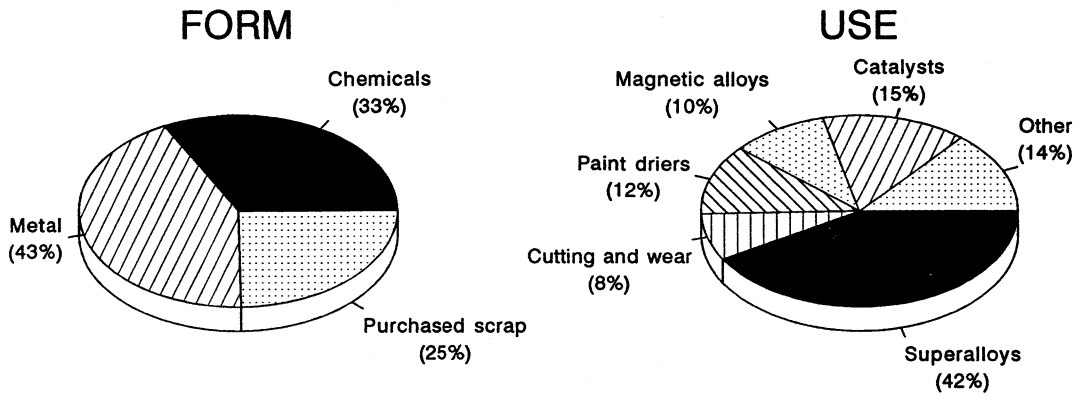
[7]Excludes production of cobalt in white alloy and cobalt matte that would require further refining.

[8]Fiscal years beginning Apr. 1 of that stated.

[9]Includes oxide.

FIGURE 1

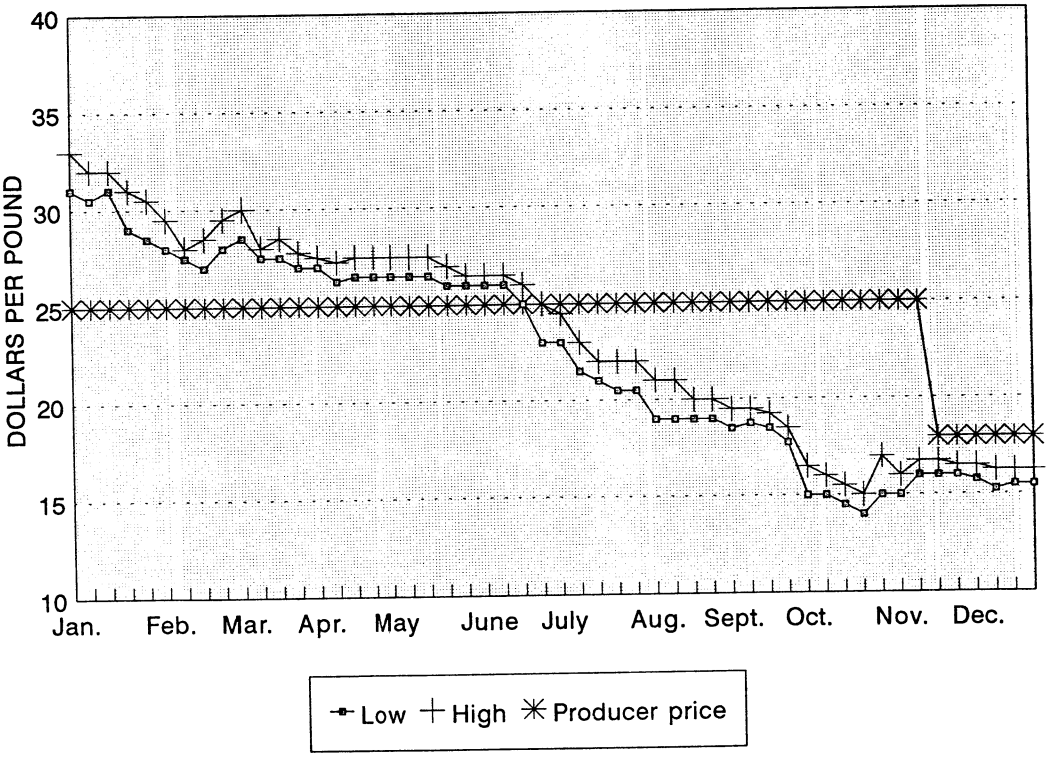
U.S. COBALT CONSUMPTION IN 1992, BY FORM AND USE



6,473 METRIC TONS

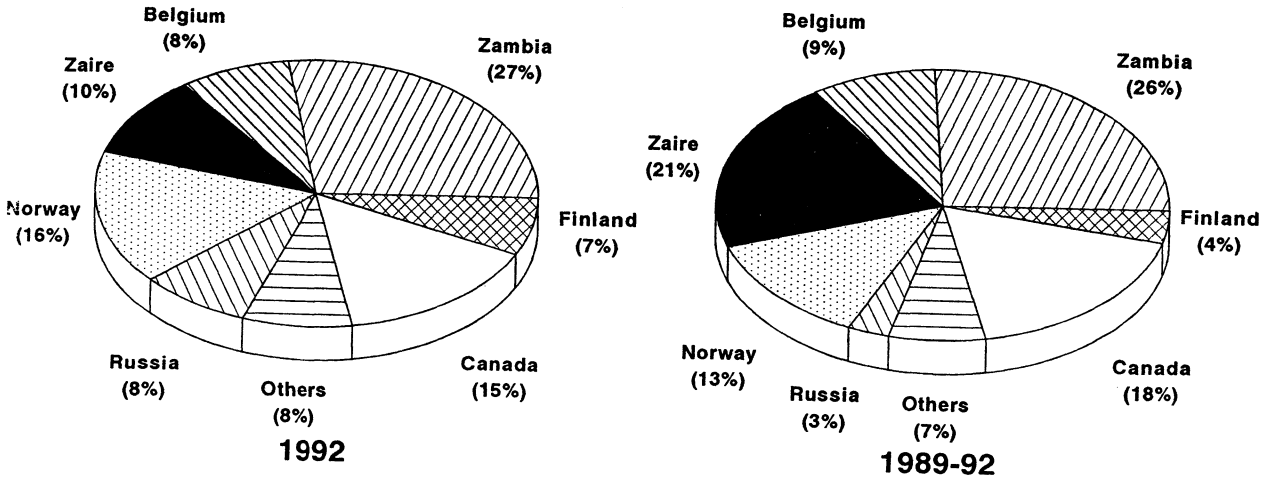
FIGURE 2

TIME-PRICE RELATIONSHIPS FOR COBALT IN 1992



Source: Metals Week.

FIGURE 3
U.S. COBALT IMPORTS, BY SOURCE



SOURCE: Bureau of the Census

COLUMBIUM (NIOBIUM) AND TANTALUM

By Larry D. Cunningham

Mr. Cunningham, a physical scientist with 13 years of 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 Mr. Dwayne Penn, statistical assistant; and columbium and tantalum world production data, by country, were prepared by Ms. 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 United States continued to be dependent on imports of columbium and tantalum materials, with Brazil being the major source for columbium imports and Australia the major source for tantalum imports. Columbium and tantalum price quotations remained relatively stable.

National Defense Stockpile (NDS) inventoried stocks for columbium and tantalum remained the same. However, the Defense Logistics Agency (DLA) awarded contracts for the conversion/upgrade of Government-owned columbium-tantalum concentrates (minerals) and columbium and tantalum metal powders into vacuum-grade columbium and tantalum metal ingot pieces. The DLA also awarded contracts for the purchase of superalloy-grade ferrocolumbium and vacuum-grade tantalum metal ingot pieces for the NDS.

There was an overall increase in reported consumption of columbium in the form of ferrocolumbium and nickel columbium. However, demand for columbium in superalloys was down, owing to a decline in demand from the military sector. Demand for tantalum was flat, with the consumption of capacitor-grade powder continuing to 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 1992 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 the 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 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 or 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 also can 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 is the process most widely being used for making steelmaking-grade ferrocolumbium from pyrochlore concentrates. Processes also 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 aluminothermically reduced batchwise to produce high-purity ferrocolumbium, nickel columbium, and columbium metal. Aluminothermically 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 also can 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 6.8 million tons 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-base materials. This event resulted in the lowering of prices for columbium oxide and high-purity columbium products. Columbium prices were lowered during 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% for 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 shelf-life. 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 also is 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 fluotantalic 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 also can 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 also can 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 with 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 1992 average price quote was about $28 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% for 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 1991 (table 7). As of October 23, 1992, the overall goal for the columbium group was 5.047 million kilograms, and the overall goal for the tantalum group was 3.959 million kilograms.

In September, the DLA contracted with two companies to provide columbium and tantalum materials for the NDS.

Cabot Performance Materials, Boyertown, PA, will convert Government-owned columbium-tantalum concentrates (minerals) into vacuum-grade columbium and tantalum metal ingot pieces for $10.7 million and upgrade Government-owned columbium metal powder to vacuum-grade columbium metal ingot pieces for $462,483. Cabot also will provide 113,400 kilograms of contained columbium in superalloy-grade (high-purity) ferrocolumbium for $4.4 million.

NRC Inc., Newton, MA, will provide 28,600 kilograms of vacuum-grade tantalum metal ingot pieces for $4.62 million and upgrade Government-owned tantalum metal powder to vacuum-grade tantalum metal ingot pieces for $2.2 million.

DLA planned to make payment with excess stockpile material (commodities). Cabot and NRC appointed Sogem-Afrimet Inc., New York, NY, as their agent for receiving payment commodities from DLA.

During the year, the United States officially entered into agreements on trade relations with 5 of the 12 independent states that succeeded the former U.S.S.R. Most-favored-nation (MFN) status was extended to the Republic of Armenia, April 7; the Russian Federation, June 17; Ukraine, June 23; the Republic of Moldova, July 2; and the Republic of Kyrgyzstan, August 21. In addition, the United States officially extended nondiscriminatory treatment to products of the Republic of Albania, effective November 2. MFN status means significantly lower U.S. import duties for columbium and tantalum products from these states. MFN tariffs for columbium and tantalum products range from duty free to 5.5% ad valorem, whereas non-MFN tariffs for columbium and tantalum products range from duty free to 45% ad valorem.

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, and 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 1992, 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.

Consumption and Uses

Overall reported consumption of columbium as ferrocolumbium and nickel columbium rose by 6% compared with that of 1991 (see table 8). Consumption of columbium by the steelmaking industry increased by 10%, in line with a 6% increase in raw steel production and a 4% increase in the percentage of columbium usage per ton of steel produced. Columbium consumption in carbon steel increased by almost 40%, while columbium consumption in HSLA steel was down by 4%. Demand for columbium in superalloys was down 11%, owing to a decline in demand for superalloys from the military sector.

That portion used in the form of nickel columbium decreased to about 148,000 kilograms.

Overall consumption of tantalum remained flat. Factory sales of tantalum capacitors were up by 23% to an alltime high, as reported by the Electronic Industries Association. However, the impact on tantalum demand by the record sales was offset by the continuing decline in the amount of tantalum capacitor-grade powder consumed per capacitor.

Markets and Prices

A published price for pyrochlore concentrates produced in Brazil and Canada was not available. A price for Brazilian pyrochlore has not been available since 1981, and the published price for Canadian pyrochlore was suspended in early 1989. The Metals Week published price for regular-grade ferrocolumbium, produced from pyrochlore concentrates, was unchanged throughout the year at $6.58 per pound of contained columbium, f.o.b. shipping port.

The Metal Bulletin published price for columbite ore, on the basis of a minimum 65% contained Cb_2O_5 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 columbium oxide was quoted at $8.17 per pound of oxide; the 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. The Metals Week published price for columbium metal was at a range of $30 to $50.

The Metals Week published spot price for tantalite ore, on the basis of contained Cb_2O_5 and Ta_2O_5, c.i.f. U.S. ports, rose from a range of $27.50 to $29.00 to a range of $28.00 to $30.00 in early August, where it remained through December. The Metal Bulletin published price for tantalite quoted since July 1990 at a range of $34 to $37 per pound of contained Ta_2O_5 fell to a range of $30 to $33 in mid-June where it remained through December. The Metal Bulletin published price for tantalite produced by Greenbushes Ltd. of Australia, on the basis of 40% contained Ta_2O_5, remained unchanged at $40 per pound. 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 and was more than double the level in 1991. Overall trade value for exports was down by 10%, with total volume up by 7%. For imports, trade value was up by more than 20%, with total volume up by 12%, owing in part to a significant increase in imports of tantalum concentrates from Australia. Data for exports and imports are summarized in table 9.

Imports for consumption of columbium mineral concentrates were down slightly from those of 1991 (see table 10). Canada continued as the leading supplier, providing more than 90% of total quantity and 86% of total value. Imports at an average grade of approximately 60% Cb_2O_5 and 1% Ta_2O_5 were estimated to contain 1.01 million kilograms of columbium and 25,000 kilograms of tantalum.

Imports for consumption of tantalum mineral concentrates increased substantially, with the average unit value for overall imports increasing by more than 20% (see table 11). Imports from Australia increased threefold and accounted for 35% of total quantity and 50% of total value. Imports at an average grade of approximately 35% Ta_2O_5 and 23% Cb_2O_5 were estimated to contain 395,000 kilograms of tantalum and 220,000 kilograms of columbium.

There were no imports for consumption of synthetic tantalum-columbium concentrates, compared with 63,000 kilograms valued at $741,000 in 1991. These figures are not included in the salient statistics data.

Brazil continued as the major source for U.S. columbium imports, accounting for about 70% of the total, and Australia was the major source for U.S. tantalum imports, accounting for more than 30% of the total (see figures 3 and 4). The schedule of applied tariffs during 1992 to U.S. imports of selected columbium and tantalum materials is given in table 12.

World Review

Industry Structure.—Principal world columbium and tantalum raw material and product producers are shown in tables 13 and 14, respectively. Brazil and Canada remained the major producers of columbium raw materials feedstock, while tantalum raw materials continued to be produced mainly in Australia, Brazil, and 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 15. World tantalum supply in 1981-92 is shown in figure 5.

Australia.—For its fiscal year ending June 30, 1992, Gwalia Consolidated Ltd. reported that ore treated at its Greenbushes Mine, southwest Western Australia, was about 2 million tons, with tantalum oxide production in tantalum concentrates (tantalite) about 197 tons compared with 146 tons the previous year.[1] During 1992, construction of the new $24 million tantalum processing plant at the Greenbushes Mine was completed on schedule and within budget. Commissioning of the plant had commenced using hard-rock ore from the new tantalum open pit where prestripping and preliminary development had been completed. The plant had an initial annual ore throughput capacity of about 850,000 tons with provision for expansion to 1 million tons. The plant's initial

annual tantalum capacity was to be about 180 tons of Ta_2O_5 contained in tantalum concentrates.

As reported by Pancontinental Mining Ltd. for its fiscal year ending June 30, 1992, tantalum production at the Wodgina Mine was about 107 tons of Ta_2O_5 contained in concentrate compared with 127 tons the previous year. A total of 89,049 tons of ore grading 0.1536% Ta_2O_5 was processed in the treatment plant yielding 234.8 tons of concentrate grading 45% Ta_2O_5, with a metallurgical recovery of 77%. Wodgina 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. In February, a 200-ton parcel of ore from the joint venture's Tabba Tabba tantalum deposit, 50 kilometers southeast of Port Hedland, was reported to be successfully processed through the Wodgina plant yielding 400 kilograms of concentrate grading 47.4% Ta_2O_5. The ore was trucked 65 kilometers to the Wodgina treatment plant.[2]

Canada.—As reported by Teck Corp., production of Cb_2O_5 at the Niobec Mine at St. Honoré, Quebec, decreased to about 3.28 million kilograms. Niobec is a 50-50 joint venture between Teck, operator, and Cambior Inc., product marketing. Ore milled increased to 815,000 tons, as the mill operated on the average of 2,234 tons of ore per day. Average recovery was down to 59.3% with Cb_2O_5 grade of concentrate at 68%. For the year, operating changes at the mine included installation of a computerized ventilation control system, replacement of flotation components in the carbonate circuit, and construction of a tailing water settling pond. Teck reported that ore reserve life, at the current rate of production, is 13 years.[3]

Japan.—According to the Tex Report, Japan's production of ferrocolumbium was 1,002 tons, up significantly from the 767 tons produced in 1991. Columbium ore imported for ferrocolumbium production declined by 13% to 1,169 tons, with Canada accounting for 68% of the total. Ferrocolumbium imports fell to 4,187 tons from the 4,526 tons reported in 1991. Brazil accounted for more than 90% of ferrocolumbium imports. Japan's demand for ferrocolumbium for steelmaking totaled 4,412 tons compared with 4,398 tons in 1991.

Roskill's Letter from Japan reported that Japan's demand for tantalum powder and compounds was 164 tons compared with 209 tons in 1991.

OUTLOOK

Columbium

Columbium is used principally as an additive in steelmaking, which annually accounts for about 80% of U.S. reported consumption. No significant change to this trend is expected in the near term because there are few other significant 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 1987-92, 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. Reported domestic consumption of columbium in the production of superalloys continues to be no more than 20% of total demand. Future growth for this end use will be affected mainly by the demand for columbium-containing superalloys by the aircraft industry. However, 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 1982-92 are given in table 16.

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 downsizing of components. Thus, annual U.S. apparent consumption of tantalum is anticipated to be less than 400 tons through most of the 1990's. The major components of U.S. supply-demand relationships for tantalum in 1982-92 are given in table 17.

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[1]Gwalia Consolidated Ltd. 1992 Annual Report. 55 pp.

[2]Pancontinental Mining Ltd. 1992 Annual Report. 88 pp.

[3]Teck Corp. 1992 Annual Report. 56 pp.

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TABLE 1
WORLD COLUMBIUM RESERVES AND RESERVE BASE, 1992

(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

[1]The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).
[2]Negligible.

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
1960	1.73	6.65
1961	1.43	5.44
1962	1.36	5.06
1963	1.36	5.00
1964	1.36	4.91
1965	1.34	4.72
1966	1.43	4.86
1967	1.42	4.69
1968	1.42	4.47
1969	1.42	4.25
1970	1.65	4.69
1971	1.65	4.45
1972	1.87	4.82
1973	1.97	4.77
1974	2.23	4.97
1975	2.23	4.53
1976	2.73	5.22
1977	5.53	9.89
1978	3.69	6.12
1979	3.79	5.79
1980	4.55	6.35
1981	4.87	6.17
1982	4.83	5.76
1983	4.73	5.42
1984	4.71	5.18
1985	4.63	4.90
1986	3.78	3.90
1987	3.71	3.71
1988	3.71	3.57
1989e	3.93	3.62
1990e	3.93	3.47
1991e	3.93	3.34
1992e	3.93	3.25

eEstimated.

TABLE 3
WORLD TANTALUM RESERVES AND RESERVE BASE, 1992

(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

[1]The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).
[2]Negligible.

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
1960	7.28	28.00
1961	11.11	42.24
1962	7.29	27.10
1963	7.93	29.15
1964	7.31	26.39
1965	10.26	36.13
1966	14.72	50.07
1967	12.24	40.40
1968	9.13	28.71
1969	9.15	27.40
1970	9.15	25.99
1971	8.26	22.26
1972	8.09	20.85
1973	8.00	19.37
1974	14.13	31.47
1975	18.32	37.24
1976	20.31	38.83
1977	25.64	45.87
1978	34.19	56.70
1979	80.00	122.14
1980	126.37	176.25
1981	99.51	126.12
1982	49.95	59.61
1983	30.60	35.09
1984	37.44	41.14
1985	33.68	35.68
1986	23.74	24.50
1987	27.08	27.08
1988	47.37	45.59
1989	44.93	41.41
1990	38.06	33.62
1991	36.70	31.15
1992	34.42	28.47

[1]60% basis, combined tantalum and columbium pentoxides.

TABLE 5
SALIENT COLUMBIUM STATISTICS

(Thousand kilograms of columbium content unless otherwise specified)

	1988	1989	1990	1991	1992
United States:					
Mine production of columbium-tantalum concentrates	—	(1)	(1)	(1)	(1)
Releases from Government excesses	—	—	—	—	—
Consumption of raw materials	NA	NA	NA	NA	NA
Production of ferrocolumbium	NA	NA	NA	NA	NA
Consumption of primary products:					
Ferrocolumbium and nickel columbium[e]	2,665	2,439	2,586	r2,412	2,555
Exports: Columbium metal, compounds, alloys (gross weight)[e]	54	NA	NA	NA	NA
Imports for consumption:					
Mineral concentrates[e]	794	1,216	1,125	1,160	1,230
Columbium metal and columbium-bearing alloys[e]	15	12	2	1	1
Ferrocolumbium[e]	1,922	2,411	1,897	2,133	2,449
Tin slag	NA	NA	NA	NA	NA
World: Production of columbium-tantalum concentrates[e]	r16,879	r14,059	r15,343	r15,846	14,646

[e]Estimated. [r]Revised. NA Not available.
[1]A small unreported quantity was produced.

TABLE 6
SALIENT TANTALUM STATISTICS

(Thousand kilograms of tantalum content unless otherwise specified)

	1988	1989	1990	1991	1992
United States:					
Mine production of columbium-tantalum concentrates	—	(1)	(1)	(1)	(1)
Releases from Government excesses	—	—	—	—	—
Consumption of raw materials	NA	NA	NA	NA	NA
Exports:					
Tantalum ores and concentrates (gross weight)[2]	97	4	1	11	17
Tantalum metal, compounds, alloys (gross weight)	221	162	161	219	136
Tantalum and tantalum alloy powder (gross weight)	126	96	82	66	61
Imports for consumption:					
Mineral concentrates[e]	181	499	299	340	420
Tantalum metal and tantalum-bearing alloys[3]	58	37	21	19	14
Tin slags	NA	NA	NA	NA	NA
World: Production of columbium-tantalum concentrates[e]	r292	r392	r400	r463	353

[e]Estimated. [r]Revised. NA Not available.
[1]A small unreported quantity was produced.
[2]Includes reexports.
[3]Exclusive of waste and scrap.

TABLE 7

COLUMBIUM AND TANTALUM MATERIALS IN GOVERNMENT INVENTORIES AS OF DECEMBER 31, 1992

(Thousand kilograms of columbium or tantalum content)

Material	Stockpile goals[2]	National Defense Stockpile inventory[1]		
		Stockpile-grade	Nonstockpile-grade	Total
Columbium:				
Concentrates[3]	—	522	394	916
Carbide powder	—	10	—	10
Ferrocolumbium	—	271	151	422
Metal	—	20	—	20
Total	[4]5,047	823	545	1,368
Tantalum:				
Minerals[3]	—	765	523	1,288
Carbide powder	—	13	—	13
Metal	—	91	([5])	91
Total	[4]3,959	869	523	1,392

[1]Overall inventory, on a recoverable basis, totals 1,253,000 kilograms for the columbium metal group and 1,233,000 kilograms for the tantalum metal group.
[2]As of October 23, 1992.
[3]The stockpile also contained inventories of 26,000 kilograms in columbium concentrates and 37,000 kilograms in tantalum minerals with status (inventory) not yet determined.
[4]Overall goals for the columbium and tantalum groups.
[5]45 kilograms.

Source: Defense Logistics Agency, Defense National Stockpile Center.

TABLE 8

CONSUMPTION, BY END USE, AND INDUSTRY STOCKS OF FERROCOLUMBIUM AND NICKEL COLUMBIUM IN THE UNITED STATES

(Kilograms of contained columbium[1])

End use	1991	1992
Steel:		
Carbon	602,594	837,541
Stainless and heat-resisting	337,956	346,936
Full alloy	(2)	(2)
High-strength low-alloy	r974,812	931,096
Electric	—	—
Tool	(3)	(3)
Unspecified	16,070	8,044
Total	r1,931,432	2,123,617
Superalloys	462,519	411,620
Alloys (excluding alloy steels and superalloys)	(4)	(4)
Miscellaneous and unspecified	18,355	20,076
Total consumption	r2,412,306	2,555,313
Stocks:		
December 31:		
Consumer	NA	NA
Producer[5]	NA	NA
Total stocks	NA	NA

rRevised. NA Not available.
[1]Includes columbium and tantalum in ferrotantalum-columbium, if any.
[2]Included with "Steel: High-strength low alloy."
[3]Included with "Steel: Unspecified."
[4]Included with "Miscellaneous and unspecified."
[5]Ferrocolumbium only.

TABLE 9

U.S. FOREIGN TRADE IN COLUMBIUM AND TANTALUM METAL AND ALLOYS, BY CLASS

(Thousand kilograms, gross weight, and thousand dollars)

Class	1991		1992		Principal destinations and sources, 1992
	Quantity	Value	Quantity	Value	
EXPORTS[1]					
Columbium:					
Ores and concentrates	8	55	—	—	—
Ferrocolumbium	741	6,952	902	8,254	Canada 691, $6,229; Meico 201, $1,953; China 4, $41; Australia 2, $16; India 4, $12.
Tantalum:					
Synthetic concentrates	—	—	2	17	Taiwan 1, $14; Japan (2), $4.
Ores and concentrates	11	248	17	33	All to Thailand.
Unwrought and waste and scrap	121	3,651	62	2,918	Germany 20, $1,269; Canada 6, $495; Hong Kong 3, $334; China 14, $288; United Kingdom 3, $275.
Unwrought powders	66	19,659	61	18,741	United Kingdom 24, $7,877; France 16, $4,679; Germany 12, $4,089; Japan 7, $1,915.
Unwrought alloys and metal	21	4,336	8	2,670	Canada 7, $2,403; Barbados (2), $123; Netherlands (2), $64; Germany (2), $31;
Wrought	77	26,580	66	22,668	Japan 24, $9,226; United Kingdom 11, $4,285; Germany 6, $2,695; France 7, $2,554; Canada 11, $1,759.
Total	XX	61,481	XX	55,301	United Kingdom $12,400; Japan $11,200; Canada $10,900; Germany $8,100; France $7,200 (3).
IMPORTS FOR CONSUMPTION					
Columbium:					
Ores and concentrates	2,515	8,445	2,428	8,764	Canada 2,214, $7,558; Nigeria 134, $564; Zaire 24, $379; Germany 54, $239.
Oxide	603	10,210	792	13,473	Brazil 689, $10,293; Germany 103, $2,456; Takjikistan 1, $720.
Ferrocolumbium	3,282	27,415	3,767	31,075	All from Brazil.
Unwrought alloys, metal, and powders	1	103	1	101	Germany 1, $92; United Kingdom (2), $6; Canada (2), $3.
Tantalum:					
Synthetic concentrates	63	741	—	—	—
Ores and concentrates	937	19,868	1,367	35,600	Australia 476, $17,937; Canada 140, $3,650; Zaire 200, $3,359; Rwanda 120, $2,125; Burundi 70, $1,874.
Unwrought waste and scrap	120	8,558	91	3,551	Germany 21, $1,778; Mexico 42, $694; Hong Kong 3, $235; France 7, $229; China 2, $170; United Kingdom 2, $169.
Unwrought powders	16	2,645	8	1,571	China 4, $738; Germany 3, $719; France (2), $76; Japan 1, $38.
Unwrought alloys and metal	1	259	4	635	Germany 4, $504; Japan (2), $128; United Kingdom (2), $3.
Wrought	2	765	2	768	Germany 1, $619; Austria (2), $60; Switzerland (2), $42; Japan(2), $21.
Total	XX	79,009	XX	95,538	Brazil $42,000; Australia $18,000; Canada $11,300; Germany $7,600.(3)

XX Not applicable.

[1]For 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.

[2]Less than 1/2 unit.

[3]Rounded.

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

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF COLUMBIUM MINERAL CONCENTRATES, BY COUNTRY

(Thousand kilograms and thousand dollars)

Country	1991		1992	
	Gross weight	Value	Gross weight	Value
Belgium[1]	68	88	—	—
Brazil	(2)	2	2	25
Canada	2,241	7,598	2,214	7,558
Germany[1]	37	164	54	239
Netherlands[1]	51	167	—	—
Nigeria	64	253	134	564
United Kingdom[1]	32	87	—	—
Zaire	22	87	24	379
Total[3]	2,515	8,445	2,428	8,764

[1]Presumably country of transshipment rather than original source.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.

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

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF TANTALUM MINERAL CONCENTRATES, BY COUNTRY

(Thousand kilograms and thousand dollars)

Country	1991		1992	
	Gross weight	Value	Gross weight	Value
Australia	113	4,360	476	17,937
Austria[1]	2	248	—	—
Belgium[1]	—	—	32	618
Bolivia	8	240	6	110
Brazil	23	376	24	555
Burundi[1]	—	—	70	1,874
Canada	133	3,458	140	3,650
China	20	503	—	—
French Guiana	(2)	14	(2)	14
Germany[1]	296	5,653	64	1,157
Japan[1]	78	1,496	20	1,592
Mexico[1]	—	—	(2)	10
Namibia	13	79	2	84
Netherlands[1]	29	613	—	—
Nigeria	—	—	4	76
Rwanda	—	—	120	2,125
Singapore[1]	—	—	125	1,639
South Africa, Republic of	20	380	38	228
Spain	—	—	3	60
Thailand	40	861	37	458
Uganda	—	—	5	46
United Kingdom[1]	(2)	2	(2)	8
Zaire	48	901	200	3,359
Zimbabwe	113	685	—	—
Total[3]	937	19,868	1,367	35,600

[1]Presumably country of transshipment rather than original source.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.

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

TABLE 12

U.S. IMPORT DUTIES ON COLUMBIUM AND TANTALUM MATERIALS

Item	HTS No.	Rate of duty effective January 1, 1992	
		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.

[1]Free from certain beneficiary developing countries under the Generalized System of Preferences (GSP), from beneficiary countries under the Caribbean Basin Economic Recovery Act (CBERA), and for products of Israel.
[2]Not duty free for Brazil.
[3]0.7% ad valorem for products of Canada.
[4]Nonspecific tariff classification.
[5]0.6% ad valorem for products of Canada.
[6]Free from beneficiary countries under CBERA and for products of Israel.
[7]1% ad valorem for products of Canada.
[8]1.1% ad valorem for products of Canada.
[9]0.9% ad valorem for products of Canada.

TABLE 13

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)	Columbium-tantalum.
Do.	Pan West Tantalum Pty. Ltd. (Wodgina)	Tantalum.
Brazil	Cia. Brasileira de Metalurgia e Mineração (CBMM) (Araxa)	Columbium.
Do.	Cia. de Estanho Minas Brasil (MIBRA)[1]	Columbium-tantalum.
Do.	Paranapanema S.A. Mineração Indústria e Construção (Pitinga)	Columbium-tantalum.
Do.	Mineração Catalão de Goiás S.A. (Catalão)	Columbium.
Canada	Cambior/Teck Corp. (Niobec)	Columbium.
Do.	Tantalum Mining Corp. of Canada Ltd. (Tanco)	Tantalum.
China	Government-owned	Columbium-tantalum.
U.S.S.R.[2]	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]	
Do.	Mamoré Mineração e Metalurgia[3]	
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]	
Do.	Hermann C. Starck Berlin KG	

[1]A wholly owned subsidiary of Metallurg Inc., New York.
[2]Dissolved in Dec. 1991; 1992 production possibly Russia and Ukraine.
[3]A subsidiary of Paranapanema S.A. Mineração Indústria e Construção.

TABLE 14

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.
Do.	Cia. Industrial Fluminense[2]	Cb and Ta oxide.
Do.	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.
Do.	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.
Do.	Japan Metals & Chemicals Co. Ltd.	FeCb.
Do.	Mitsui Mining & Smelting Co.	Cb and Ta oxide/metal/ carbide.
Do.	Showa Cabot Supermetals[3]	Ta capacitor powder.
Do.	Taiyo Mining & Industrial Co. Ltd.	FeCb.
Do.	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.
Do.	Kennametal, Inc.	Cb and Ta carbide.
Do.	NRC, Inc.[5]	Cb and Ta metal, Ta capacitor powder.
Do.	Reading Alloys, Inc.	FeCb, NiCb.
Do.	Shieldalloy Metallurgical Corp.[2]	FeCb, NiCb.
Do.	Teledyne Wah Chang Albany	Cb oxide/metal, FeCb, NiCb.
Do.	Thai Tantalum Inc.	Ta metal.

[1]Cb, columbium; Ta, tantalum; FeCb, ferrocolumbium; NiCb, nickel columbium; K-salt, potassium fluotantalate; oxide, pentoxide.
[2]A wholly owned subsidiary of Metallurg Inc., New York.
[3]A joint venture between Showa Denko and Cabot Corp.
[4]A subsidiary of Hermann C. Starck Berlin KG.
[5]Jointly owned by Bayer U.S.A. Inc. and Hermann C. Starck Berlin KG.

TABLE 15

COLUMBIUM AND TANTALUM: WORLD PRODUCTION OF MINERAL CONCENTRATES, BY COUNTRY[1]

(Thousand kilograms)

Country[2]	Gross weight[3]					Columbium content[e 4]					Tantalum content[e 4]				
	1988	1989	1990	1991	1992[e]	1988	1989	1990	1991	1992	1988	1989	1990	1991	1992
Australia: Columbite-tantalite	226	555	e529	e703	600	32	64	69	r94	80	74	119	165	218	185
Brazil:															
Columbite-tantalite	403	436	310	e290	200	93	101	71	66	45	117	126	90	84	60
Pyrochlore	33,814	r26,290	r29,380	r30,450	27,830	14,202	r11,040	r12,340	r12,790	11,690	—	—	—	—	—
Canada:[e]															
Pyrochlore	5,230	5,443	5,272	5,230	5,100	2,354	2,449	2,372	2,354	2,295	—	—	—	—	—
Tantalite	91	295	331	399	180	4	9	10	11	5	27	73	82	95	45
Malaysia: Columbite-tantalite	—	—	4	—	—	—	—	1	—	—	—	—	(5)	—	—
Namibia: Tantalite	7	6	r4	(5)	(5)	1	1	r1	(5)	(5)	1	1	r1	(5)	(5)
Nigeria: Columbite	50	46	44	r36	40	21	19	18	r15	17	3	3	2	2	2
Rwanda: Columbite-tantalite	r7	r64	r151	r150	150	r2	r19	r45	r45	45	r2	r14	r33	r33	33
South Africa, Republic of:															
Columbite-tantalite	(5)	(5)	(5)	(5)	6(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)
Spain: Tantalite	11	e11	e10	e8	8	NA	NA	NA	NA	NA	3	3	3	3	2
Thailand: Columbite-tantalite	124	109	9	3	3	21	19	2	1	1	33	29	2	1	1
Zaire:															
Columbite-tantalite	34	48	36	r57	50	9	r13	9	r15	13	9	13	10	r16	14
Pyrochlore	287	711	900	e1,000	1,000	130	320	400	450	450	—	—	—	—	—
Zimbabwe: Columbite tantalite	66	32	r35	r e32	32	10	5	5	5	5	23	11	12	r11	11
Total	r40,350	r34,046	r37,015	r38,358	35,193	r16,879	r14,059	r15,343	r15,846	14,646	r292	r392	r400	r463	353

eEstimated. rRevised. NA Not available.

[1]Excludes columbium- and tantalum-bearing tin ores and slags. Production of tantalum contained in tin slags was, in thousand kilograms: 1988—519; 1989—362; 1990—343; 1991—244; and 1992—160 according to data from the Tantalum-Niobium International Study Center. Table includes data available through July 2, 1993.

[2]In addition to the countries listed, Bolivia, China, and the former U.S.S.R. also produce, or are believed to produce, columbium and tantalum mineral concentrates, but available information is inadequate to make reliable estimates of output levels.

[3]Data 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.

[4]Unless 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.

[5]Less than 1/2 unit.

[6]Reported in and/or by official country sources.

TABLE 16
COLUMBIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand kilograms columbium content)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992[p]
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mine production	[1]	—	—	—	—	—	—	[1]	[1]	[1]	[1]
Shipments of Government stockpile excesses	—	—	—	—	—	—	—	—	—	—	—
Imports[2]	[e]1,975	W	W	W	W	W	NA	NA	NA	NA	NA
Industry stocks, Jan. 1	3,779	W	W	W	W	W	NA	NA	NA	NA	NA
Total U.S. supply	5,754	W	W	W	W	W	NA	NA	NA	NA	NA
Distribution of U.S. supply:											
Industry stocks, Dec. 31	[e]2,708	W	W	W	W	W	NA	NA	NA	NA	NA
Exports[e]	40	35	36	35	33	39	45	104	227	270	350
Government accessions	12	—	—	97	—	—	—	—	—	—	—
Industrial demand	2,994	2,608	3,479	3,425	3,203	3,311	3,583	3,403	3,357	3,311	3,500
U.S. DEMAND PATTERN											
Construction	1,227	1,043	1,324	1,506	1,411	1,424	1,683	1,701	1,678	NA	NA
Machinery:											
Metalworking machinery	97	78	104	103	96	90	90	82	82	NA	NA
Special industry machinery	292	235	279	274	256	277	268	254	254	NA	NA
Total	389	313	383	377	352	367	358	336	336	NA	NA
Oil and gas industries	509	339	485	513	417	431	358	445	436	NA	NA
Transportation	689	678	903	857	767	694	789	649	635	NA	NA
Other	180	235	384	172	256	395	395	272	272	NA	NA
Total U.S. primary demand	2,994	2,608	3,479	3,425	3,203	3,311	3,583	3,403	3,357	3,311	3,500

[e]Estimated. [p]Preliminary. NA Not available. W Withheld to avoid disclosing company proprietary data.

[1]A small unreported quantity was produced.

[2]Includes concentrates, ferrocolumbium, tin slags, and other.

TABLE 17

TANTALUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand kilograms tantalum content)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992[p]
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mine production	(1)	—	—	—	—	—	—	(1)	(1)	(1)	(1)
Secondary[e]	40	18	59	41	34	57	59	54	54	50	55
Shipments of Government stockpile excesses	—	—	—	—	—	—	—	—	—	—	—
Imports[2]	[e]493	W	W	W	W	W	NA	NA	NA	NA	NA
Industry stocks, Jan. 1	1,566	W	W	W	W	W	NA	NA	NA	NA	NA
Total U.S. supply	2,099	W	W	W	W	W	NA	NA	NA	NA	NA
Distribution of U.S. supply:											
Industry stocks, Dec. 31	[e]1,449	W	W	W	W	W	NA	NA	NA	NA	NA
Exports[e]	154	119	174	145	142	171	256	195	200	180	150
Government accessions	15	—	—	115	—	—	—	—	—	—	—
Industrial demand	481	536	762	363	372	381	422	376	390	370	375
U.S. DEMAND PATTERN											
Electronic components	319	333	477	201	219	229	277	227	236	NA	NA
Transportation	55	75	99	60	56	57	32	54	59	NA	NA
Machinery:											
Chemical equipment	31	21	27	22	20	15	14	14	14	NA	NA
Metalworking machinery	63	86	120	46	51	27	27	27	27	NA	NA
Total	94	107	147	68	71	42	41	41	41	NA	NA
Other	13	21	39	34	26	53	72	54	54	NA	NA
Total demand	481	536	762	363	372	381	422	376	390	370	375
Total U.S. primary demand (industrial demand less secondary)	441	518	703	322	338	324	363	322	336	320	320

[e]Estimated. [p]Preliminary. NA Not available. W Withheld to avoid disclosing company proprietary data.

[1]A small unreported quantity was produced.

[2]Includes concentrates, tin slag, and other.

FIGURE 1
TIME-PRICE RELATIONSHIP FOR COLUMBIUM

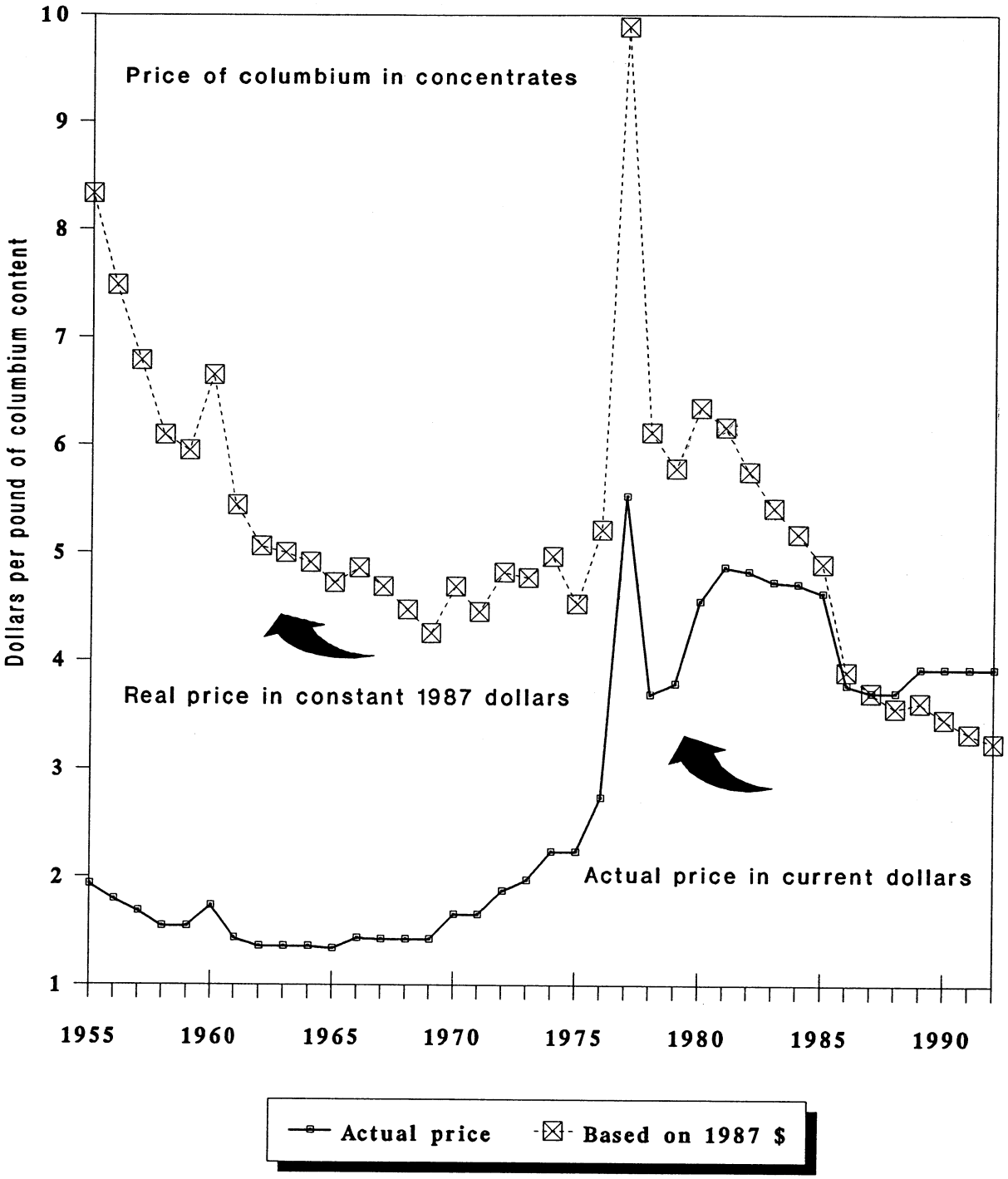


FIGURE 2

TIME-PRICE RELATIONSHIP FOR TANTALUM

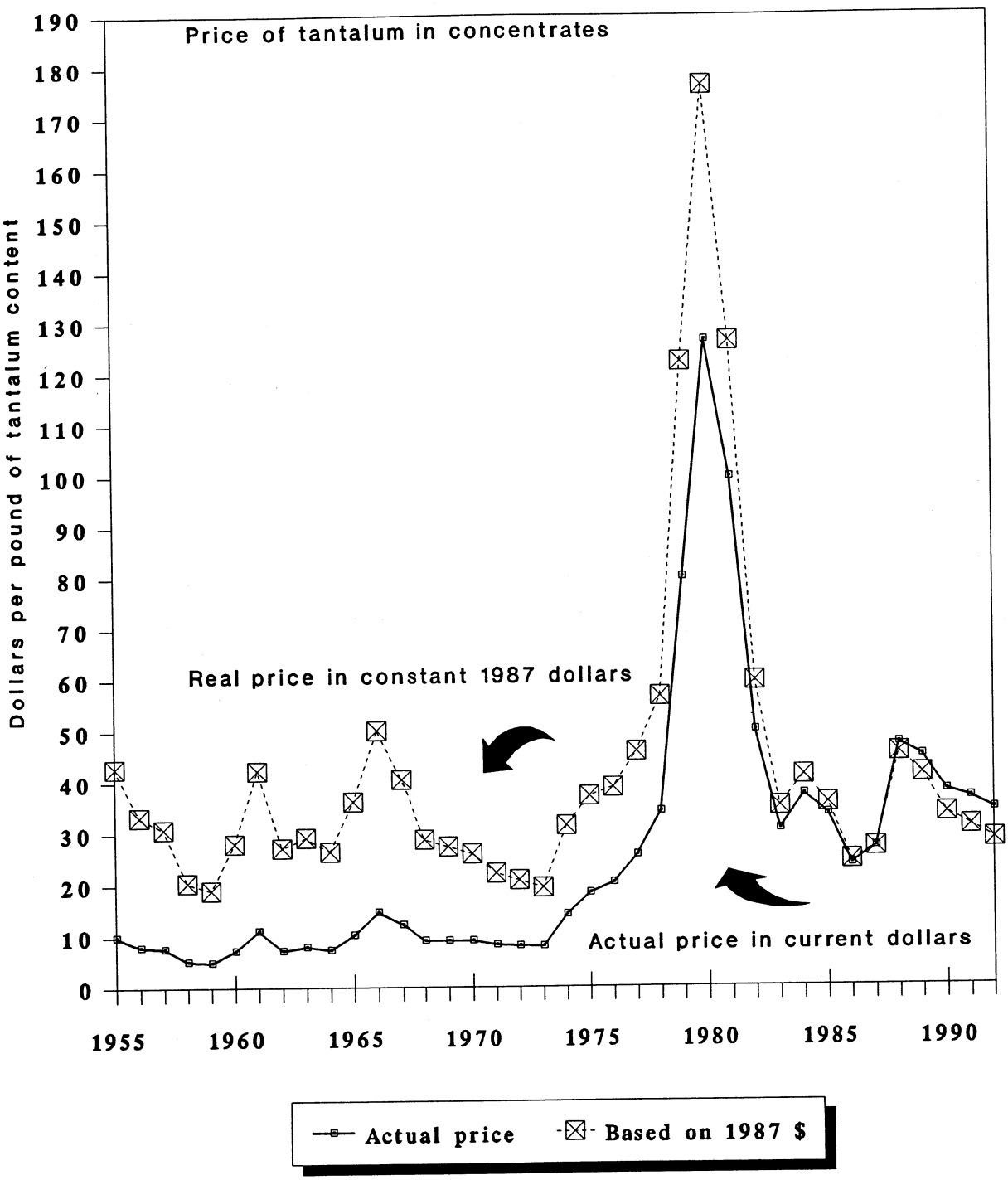


FIGURE 3
MAJOR SOURCES OF U.S. COLUMBIUM IMPORTS

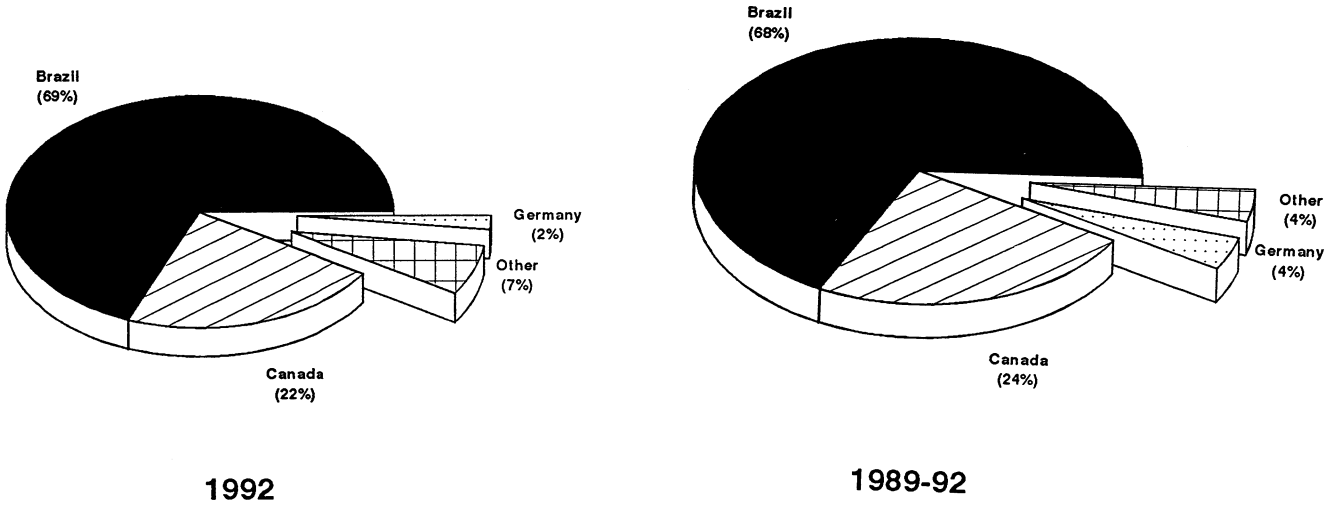


FIGURE 4
MAJOR SOURCES OF U.S. TANTALUM IMPORTS

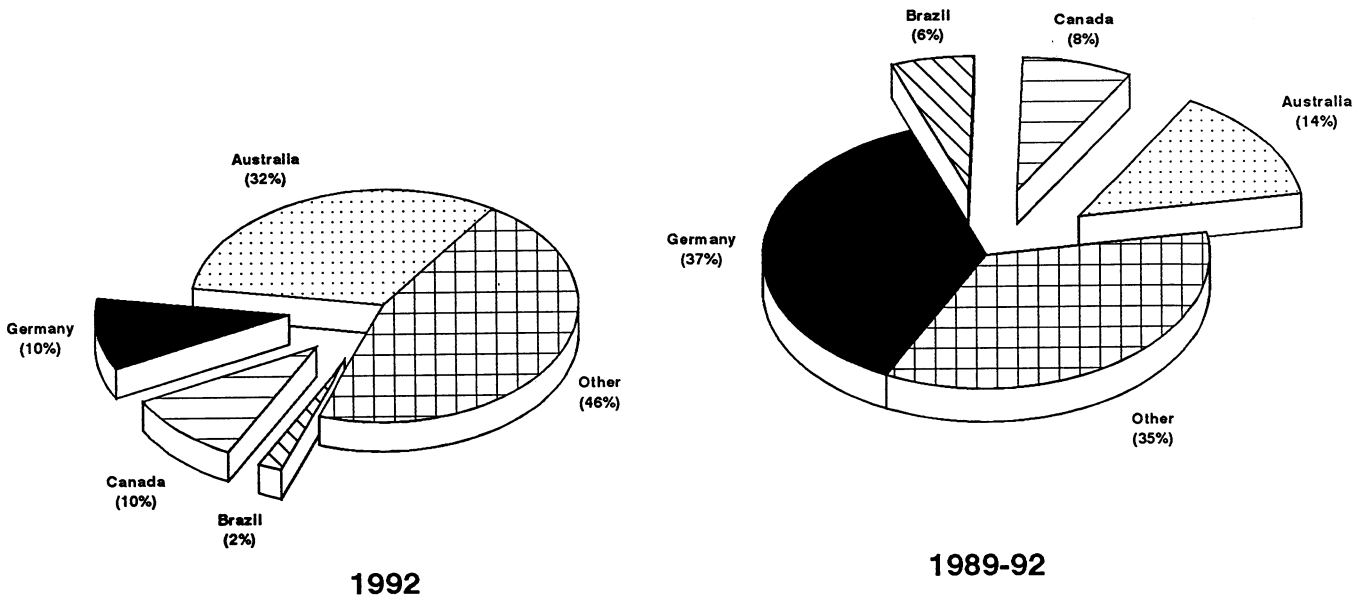
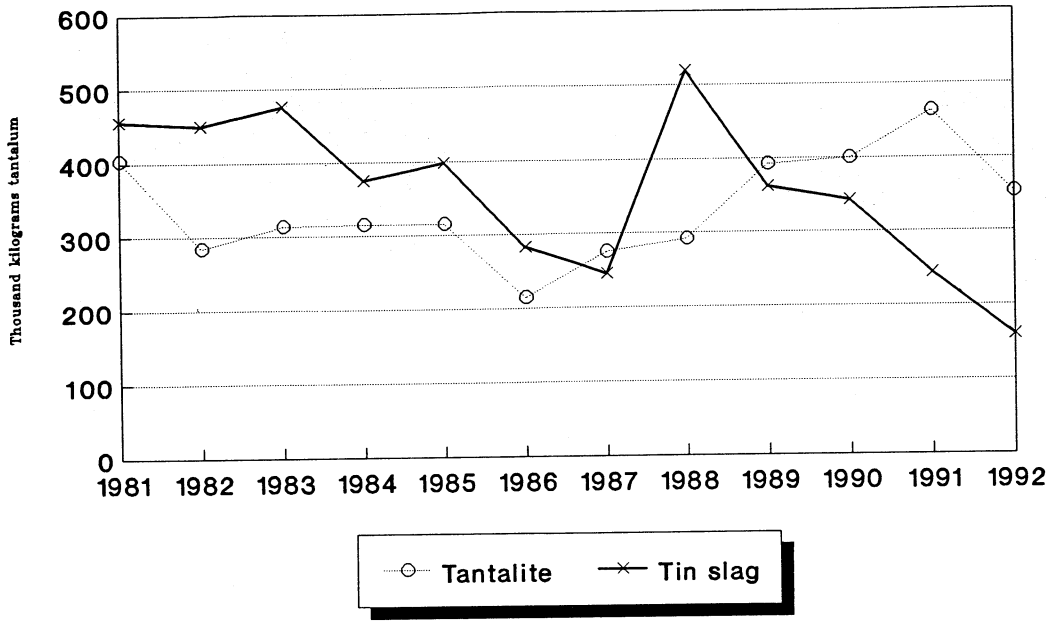


FIGURE 5
WORLD TANTALUM SUPPLY



COPPER

By Daniel L. Edelstein

Mr. Edelstein is a physical scientist with more than 18 years of combined experience working for the U.S. Bureau of Mines in mineral processing research, process evaluation, and mineral commodities. He has been a copper commodity specialist for 9 years as well as a specialist for the byproduct metals arsenic, selenium, and tellurium.

Nineteen ninety-two was a year of transition for the world copper industry. Despite record mine production in Chile, Indonesia, and the United States, world supplies of copper were tight and inventories declined during the first half of the year as a result of decreasing ore grades at some mines, strikes, political disruptions, and smelter bottlenecks. Prices, which had declined during the last quarter of 1991, rose steadily during the first half of 1992. The U.S. producer price peaked in July, averaging 118.65 cents per pound for the month, the highest level in more than 2 years. Coincidentally, stocks held on the world metal exchanges fell by about 75,000 metric tons during the first half of the year, to below 300,000 tons, after having risen almost continuously over a 2-year period. In the United States, both refined copper and scrap were reported to be in tight supply.

During the second half of the year the world copper balance turned from one of deficit to one of surplus. Copper inventories held on the world exchanges resumed the upward trend of the previous 2 years and by yearend had risen to more than 430,000 tons, the highest level since 1984. The bottleneck in smelting capacity began to ease as concentrates were shunted to underutilized smelters in Kazakhstan, Poland, Russia, and Zambia for processing. This redirection of concentrates led to lower smelting-refining charges and increased availability of copper at a time of weakening global demand.

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 lode mine production survey. Of the 117 operations to which this survey was sent in 1992, 91% responded and 67 reported copper production, representing an estimated 99.7% of the mine production shown in tables 1, 3, and 5. Production for the remainder was estimated using other surveys.

ANNUAL REVIEW

Production

Domestic mine production increased during 1992 as a result of incremental expansions of existing mines and startup of several leach operations. In 1992, 67 mines in 13 States produced copper in the United States; 14 mines and 5 States accounted for more than 95% and 91%, respectively, of the national total. Domestic copper mines employed 13,600 workers during 1992, down slightly from the number employed in the previous year. Productivity at domestic mines increased significantly, from 17.7 worker hours per ton of copper produced in 1991 to 15.9 worker hours in 1992. Most domestic companies reported significant reductions in operating costs through productivity gains. In response to the global tightness in smelting capacity, all domestic smelters were undergoing modification to increase or better utilize existing capacity.

Arimetco International Inc. began production from its Emerald Isle Mine in Arizona with the completion of an 8,000-pound-per-day solvent extraction-electrowinning (SX-EW) plant. Arimetco, which also operated the Johnson Camp, AZ, and Yerington, NV, SX-EW facilities, announced its 50% acquisition of the McArthur oxide copper property from Holcorp Mines Ltd., of Toronto, Canada. Located near its Yerington Mine, McArthur reportedly contains 40,000 tons of recoverable copper.

By the end of 1992, ASARCO Incorporated had nearly completed a 7-year, $1.3 billion program to become a fully integrated copper and lead mining company. Asarco's copper reserves were expanded eightfold during that period. According to the company's 1992 Annual Report, mine production of copper rose 24% in 1992, to 280,000 tons, owing to completion of expansion projects at its Mission complex late in 1991 and its Ray Mine early in 1992 that increased capacity to 100,000 tons and 165,000 tons, respectively. Costs for expansion of the Ray Mine, which included a new concentrator and in-pit crusher, and the Mission complex were estimated at $224 million and $100 million, respectively.

Asarco's smelter production rose by 9%, reflecting the second year of record production at the Hayden smelter. Construction of the new CONTOP furnace at its El Paso, TX, smelter began in May. Startup of the furnace was expected during the first half of 1993.

Arizona Copper Co. (AZCO) began development of its Sanchez Project, in Arizona, with construction of a 25,000-ton-per-year SX-EW plant expected to begin early in 1993 and production startup scheduled for 1994. Exploration by previous owners had established oxide reserves in excess of 110 million tons

grading 0.37% copper.

According to its 1992 Annual Report, Cyprus Minerals Co. produced 300,000 tons of copper (including 8,000 tons from its Selwyn Mine in Australia) at an average cost of 78 cents per pound, down from 80 cents the previous year. Using updated cost and geological information, Cyprus reported a 60% increase in its proved and probable reserves to 6.5 billion tons having an average grade of 0.35% copper.

According to its Annual Report, Cyprus set a goal to reduce production costs to about 60 cents per pound, 25% below 1992 costs, and to become a fully integrated producer. In 1992, Cyprus processed only 60% of its concentrates in its own facilities. To achieve these goals, Cyprus initiated an investment program in 1992 that could approach $350 million over 3 years. In 1992, it reported spending $14 million on truck fleet modernization and anticipated spending an additional $61 million in 1993. Other aspects of its cost reduction investment included $83 million for expansion of its Miami, AZ, refinery; $54 million for mill improvements and power cogeneration at its Bagdad Mine; and $21 million at Sierrita/Twin Buttes for mill and leach improvements. An additional $115 million expenditure was planned for incremental capacity expansion.

Installation of a new ISAMELT furnace at Cyprus' Miami smelter was completed during 1992. Capacity was expected to increase by 200,000 tons to 650,000 tons of concentrate per year by mid-1993. The smelter operated at reduced capacity during the year owing to shutdown for repair and maintenance.

Mine production at Kennecott's Bingham Canyon Mine rose to a record level in 1992 of 288,700 tons, up by more than 50,000 tons from the previous year (The RTZ Corp. PLC, Form 20-F, 1992). The increase was the result of having completed in January a $219 million expansion of mill facilities begun in 1990. This was the second major investment in mine modernization at Bingham Canyon undertaken since 1985. In March, Kennecott announced plans to invest $880 million to construct a new on-site smelter and to expand refining capacity. The new smelter, with a projected capacity of 272,000 tons of copper per year, would make Kennecott a fully integrated producer. As a result of required environmental curtailments, Kennecott had been exporting about one-half of its concentrate production.

After several years of delay, Kennecott received the necessary environmental clearances to begin development of its Flambeau high-grade copper-gold deposit in Wisconsin. Startup of the 28,000-ton-per-year mine was scheduled for June 1993. In April, Kennecott and the U.S. Environmental Protection Agency signed a nonbinding "Agreement in Principal" for the remediation of ground water contamination resulting from its Utah operations.

In its 1992 Annual Report, Magma Copper Co. reported producing 251,000 tons of copper from its own operations, up 13,000 tons from the previous year. Nearly all of the increase came from its SX-EW production. Magma reported a record year for production and earnings, having reduced net operating costs in 1992 by 5 cents per pound, to 66 cents per pound, and improved productivity by 12%. During the 5-year period 1988 through 1992, Magma reduced net operating costs by 12 cents per pound and increased productivity by 61%. Total cathode production rose by 9% in 1992 on the strength of increased electrowon production (70,000) tons, and a 7% increase in custom smelting and refining. In July, Magma began the engineering phase for development of its newly acquired (1991) Robinson project, which was expected to be producing about 57,000 tons of copper per year by the end of 1994. Capital costs for the mine and mill were projected at $250 million. In 1992, Magma increased its reserves with the acquisition of a major deposit near Florence, AZ, having combined oxide and sulfide reserves of more than 725 million tons. Early in 1993, Magma announced that it had approved the development of the Kalamazoo ore body, thus extending underground mining at San Manuel by 12 years to the year 2009. It also announced plans to expand smelting and refining capacity by 20% through the construction of a third acid plant. The $100 million project was slated for completion in 1994.

Copper production by Phelps Dodge Corp., according to its 1992 Annual Report, was at the same level as that in 1991 and amounted to 586,000 tons (including about 99,000 tons of its minority participant's share and 22,000 tons from its Ojos del Salbo Mine in Chile). Phelps Dodge was the largest U.S. and the world's second largest mine producer of copper. In January, Phelps Dodge ceased production of concentrate ore at its Tyrone Mine in New Mexico with the exhaustion of sulfide reserves. Production of copper in concentrate declined from 93,000 tons in 1990, to 57,000 and 8,000 tons, respectively, in 1991 and 1992. The loss of concentrate production was balanced by increases in SX-EW production at its Tyrone and Morenci Mines. In 1992, SX-EW accounted for 263,000 tons or 45% of Phelps Dodge's total production. In May, Phelps Dodge completed construction of its Northwest extension project at Morenci, raising SX-EW production capacity at Morenci by 64,000 tons per year to a total of 155,000 tons from the three adjacent pits at Morenci. Phelps Dodge's smelter production increased marginally despite a 60-day shutdown of its Hidalgo smelter for refurbishment. In October, Phelps Dodge began construction at its La Candaleria copper-gold project in Chile, which contained reserves in excess of 360 million tons grading 1.1% copper. In September, it sold a 20% interest in the project to Sumitomo Corp. of Japan for $40 million. Production of more than 100,000 tons of copper per year was slated to begin in 1995.

Copper Range Co. produced about 50,000 tons of copper at its White Pine Mine in Michigan, according to its 1992 Annual Report. The company took advantage of high treatment and refining charges and tightness in world smelter capacity to double its purchases of outside concentrates to almost 14,000 tons of recoverable copper. The increased purchases allowed the company to more

fully utilize capacity and reduce purchases of pyritic flux ores. The cash cost, excluding depreciation, at White Pine was reduced by 13% compared to 1991 and averaged 82 cents per pound of copper.

Consumption

As noted previously, domestic demand for refined copper rose by 6% from its depressed 1991 level. According to data supplied by the Copper Development Association, shipments of copper and copper alloy products to U.S. markets rose by 5.3% in 1992, to 2.98 million tons. Building and construction was the largest market segment, accounting for 42% of demand, followed by electric and electronic uses, 24%; industrial machinery, 13%; transportation equipment, 11%; and consumer and general products, 10%. According to U.S. Bureau of Mines estimates, electrical uses of copper in all market segments accounted for about 72% of apparent consumption, followed by nonelectrical use in construction, 14%; machinery, 5%, transportation, 5%; ordnance, 2%; and other 2%.

World Review

Despite the aforementioned constraints, increased mine production in Chile, Indonesia, and the United States led world copper mine production to a record-high level. World mine production capacity increased to 11.2 million tons. In the United States, mine capacity reached 2.04 million tons, an increase of about 100,000 tons, while increased capacity utilization resulted in a 134,000-ton increase in mine production. Capacity and production in Chile rose by 130,000 tons and 96,000 tons, respectively. Production at the Escondida Mine in Chile rose by 40,000 tons to 337,000 tons, making it the second largest copper mine in Chile and the world. A $440 million expansion of the Los Bronces Mine, owned by Exxon Minerals Chile, Inc., was completed in 1992, tripling capacity to 130,000 tons. An $18 million expansion project at Phelps Dodge's Ojos del Salado Mine, completed in November 1991, helped boost production by more than 4,000 tons. In Indonesia, mine production rose by almost 70,000 tons as a result of expansions at Freeport-McMoRan Inc.'s Grasberg Mine and mill. Significant increases also were noted in China (a new mill at the Dexing Mine was completed in 1991), Poland, and to a lesser extent in Australia. Production increases were partially offset by significant declines in the Philippines and Zaire and modest declines in other countries. In the Philippines, production at Atlas Mining, the largest producer continued to decline, falling by about 22,000 tons. Political turmoil in Zaire led to severe shortages of materials and fuel and a disruption of transportation routes.

Though U.S. demand for refined copper rose by 6% from its depressed 1991 level, spreading recession during the second half of the year in the rest of the world led to only a modest 2.8% growth in Western European demand and a marked 12.5% decline in Japanese consumption. Japanese consumption was partially offset by increases in Indonesia, North Korea, Taiwan, and other Asian countries. A large increase in western country exports of refined copper to China more than offset increased imports from Eastern European countries and helped to modify what would have been an even larger Western World surplus of refined copper.

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TABLE 1
SALIENT COPPER STATISTICS

(Metric tons unless otherwise specified)

		1988	1989	1990	1991	1992
United States:						
Ore produced	thousand metric tons	223,576	237,301	249,500	276,891	255,910
Average yield of copper	percent	.60	.61	.62	.57	.68
Primary (new) copper produced:						
From domestic ores, as reported by:						
Mines		1,416,928	1,497,818	1,587,742	1,631,078	1,765,102
Value	millions	$3,764	$4,324	$4,311	$3,931	$4,180
Percent of world total		r16	17	18	18	19
Smelters[1]		1,042,961	1,120,445	1,158,462	1,122,926	1,180,305
Refineries		1,282,370	1,351,747	1,502,014	1,500,544	1,614,509
From foreign ores, matte, etc., as reported by refineries		123,650	125,085	74,620	76,889	96,135
Total new refined, domestic and foreign[2]		1,406,020	r1,476,833	r1,576,633	1,577,433	1,710,644
Secondary (scrap) copper produced:						
Smelter from scrap (new and old)		331,612	359,066	304,860	364,331	393,609
Refined copper from scrap (new and old)		446,427	480,018	440,757	417,761	433,171
Secondary copper recovered from old scrap only		518,179	547,561	r536,732	r518,401	554,075
Exports:						
Refined		58,325	130,189	211,164	r263,217	176,913
Unmanufactured[3]		557,000	725,000	780,000	r806,000	679,000
Imports for consumption:						
Refined		331,671	300,110	261,672	288,586	289,077
Unmanufactured[3]		513,038	515,000	512,000	512,000	593,000
Stocks, Dec. 31: Total industry and COMEX:						
Refined		96,704	106,656	101,274	r132,050	204,618
Blister and materials in solution		121,442	131,650	118,924	135,099	166,154
Consumption:						
Refined copper (reported)		2,210,424	2,203,116	2,150,426	2,048,323	2,178,191
Apparent consumption, primary and old copper (old scrap only)		2,213,768	2,184,534	2,168,179	2,104,968	2,310,807
Price: Weighted average, cathode, cents per pound, producers		120.51	130.95	123.16	109.33	107.42
World:						
Production:						
Mine	thousand metric tons	r8,727	r9,058	r9,017	r9,187	9,294
Smelter	do.	r9,566	r9,821	r9,472	r9,216	9,328
Refineries	do.	r10,574	r10,918	r10,805	r10,637	10,907
Price: London, Grade A, average cents per pound		117.92	128.91	121.02	106.21	103.72

rRevised.

[1]Includes primary copper produced from foreign ores, matte, etc., to avoid disclosing company proprietary data.

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

[3]Includes copper content of alloy scrap. Copper content of alloy scrap imported and exported in 1989 and 1990 was estimated from gross weight.

TABLE 2

MAJOR U.S. COPPER-PRODUCING COMPANY RESERVES IN 1992

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	512,560	0.67	3,434	3,434	8.2
Ray, AZ	100.0	1,016,048	.63	6,401	6,401	15.3
Silver Bell, AZ	100.0	91,938	.47	432	432	1.0
Continental, MT	49.9	322,958	.30	969	483	1.2
Total copper deposits[2]	XX	1,943,504	.58	11,236	10,751	25.7
Byproduct deposits:						
Coeur, ID	50.0	363	.80	3	1	(3)
Galena, ID	37.5	907	.52	5	2	(3)
Troy, MT	75.0	10,886	.68	74	56	.1
Total byproduct deposits[2]	XX	12,156	.67	82	58	.1
Total reserves	XX	1,955,660	.58	11,318	10,809	25.8
Copper Range Co.:[4]						
White Pine, MI	100.0	167,830	1.12	1,875	1,875	4.5
Cyprus Minerals Co.:[5]						
Bagdad	100.0	1,116,473	.37	4,131	4,131	9.9
Sierrita/Twin Buttes	100.0	889,586	.29	2,579	2,579	6.2
Miami	100.0	290,299	.44	1,277	1,277	3.1
Casa Grande	100.0	14,061	.01	1	1	(3)
Pinos Altos	100.0	363	6.37	23	23	(3)
Mineral Park	100.0	13,063	.24	31	31	(3)
Total reserves[2]	XX	2,323,846	.35	8,043	8,043	19.2
Kennecott Corp.:[6]						
Bingham Canyon	100.0	1,059,000	.62	6,566	6,566	15.7
Flambeau	100.0	1,700	10.63	181	181	.4
Total reserves	XX	1,060,700	.64	6,747	6,747	16.1
Magma Copper Co.:[7]						
Magma Superior	100.0	1,222	5.00	61	61	.2
San Manuel:						
Oxide pit	100.0	20,088	.44	89	89	.2
Oxide pit (marginal)	100.0	2,583	.16	4	4	(3)
In situ leach ores	100.0	178,556	.35	625	625	1.5
Underground sulfide	100.0	57,040	.69	395	395	.9
Open pit sulfide	100.0	273	.96	3	3	(3)
Kalamazoo underground:						
Sulfide reserves	100.0	15,643	.72	113	113	.3
Lower Kalamazoo	100.0	148,492	.71	1,047	1,047	2.5
Pinto Valley:						
Dump leach (sulfide)	100.0	353,950	.11	400	400	1.0
Miami tailings leach	100.0	22,838	.36	82	82	.2
Open pit sulfide	100.0	140,168	.37	516	516	1.2
Leach ore (sulfide)	100.0	49,774	.20	99	99	.2
Robinson Nevada:						
Open pit sulfide	100.0	182,693	.61	1,105	1,105	2.6
Total reserves[2]	XX	1,173,320	.39	4,539	4,539	10.8

See footnotes at end of table.

TABLE 2—Continued

MAJOR U.S. COPPER-PRODUCING COMPANY RESERVES IN 1992

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
Phelps Dodge Corp.:[8]						
Morenci, AZ	85.0	528,889	0.76	4,020	3,417	8.2
Morenci, AZ (leach)	85.0	781,268	.34	2,656	2,258	5.4
Chino, NM (milling)	66.7	254,193	.69	1,754	1,169	2.8
Chino, (leach)	66.7	128.003	.30	384	256	.6
Burro Chief, NM (leach)[e]	100.0	153,677	.33	507	507	1.2
Total reserves	XX	1,846,032	.50	9,321	7,608	18.2
Grand total, major companies	XX	8,527,387	.49	41,842	39,621	94.7

[e]Estimated. XX Not applicable.
[1]Source: ASARCO Incorporated 1992 Annual Report.
[2]Data may not add to totals shown because of independent rounding.
[3]Less than 0.05%.
[4]Source: Metall Mining Corp. 1992 Annual Report.
[5]Source: Cyprus Minerals Co. Form 10-K, Dec. 31, 1992.
[6]Source: RTZ Corp. Form 20-F ending Dec. 31, 1992.
[7]Source: Magma Copper Co. 1992 Annual Report.
[8]Source: Phelps Dodge Corp. 1992 Annual Report.

TABLE 3

MINE PRODUCTION OF RECOVERABLE COPPER IN THE UNITED STATES, BY STATE

(Metric tons)

State:	1988	1989	1990	1991	1992
Arizona	842,728	898,466	978,767	1,024,066	1,153,225
Michigan, Montana, Utah	295,489	314,313	322,301	337,137	384,506
New Mexico	258,660	259,640	262,815	252,859	211,337
Other States[1]	20,051	25,399	23,859	17,016	16,034
Total	1,416,928	1,497,818	1,587,742	1,631,078	1,765,102

[1]Includes California, Colorado, Idaho, Illinois, Missouri, Nevada, and Tennessee; in addition, 1990 includes Kentucky; and 1991 and 1992 Oregon.

TABLE 4

TWENTY-FIVE LEADING COPPER-PRODUCING MINES IN THE UNITED STATES IN 1992, 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	405
2	Bingham Canyon	Salt Lake, UT	Kennecott, Utah Copper Corp.	do.	300
3	San Manuel	Pinal, AZ	Magma Copper Co.	do.	172
4	Ray	do.	ASARCO Incorporated	Copper ore, concentrated and leached	165
5	Chino	Grant, NM	Phelps Dodge Corp.	Copper-molybdenum ore, concentrated and leached	157
6	Sierrita	Pima, AZ	Cyprus Sierrita Corp.	do.	124
7	Bagdad	Yavapai, AZ	Cyprus Bagdad Copper Co.	do.	116
8	Pinto Valley	Gila, AZ	Pinto Valley Copper Corp.	do.	92
9	Mission Complex	Pima, AZ	ASARCO Incorporated	Copper ore, concentrated	90
10	Tyrone	Grant, NM	Phelps Dodge Corp. and Burro Chief Copper Co.	Copper ore, concentrated and leached	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	San Xavier	Pima, AZ	ASARCO Incorporated	Copper ore, concentrated	22
15	Twin Buttes	do.	Cyprus Sierrita Corp.	Copper ore, leached	20
16	Troy	Lincoln, MT	ASARCO Incorporated	Copper-silver ore, concentrated	18
17	Superior (Magma)	Pinal, AZ	Magma Copper Co.	Copper ore, concentrated	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	Yerington	Lyon, NV	Arimetco Incorporated	Copper ore, leached	5
21	Johnson	Cochise, AZ	do.	do.	5
22	Pinos Altos	Grant, NM	Cyprus Pincos Altos Corp.	Copper ore, concentrated	7
23	Silver Bell	Pima, AZ	ASARCO Incorporated	do.	5
24	Oracle Ridge	Pinal, AZ	South Atlantic Ventures Ltd.	do.	NA
25	Lakeshore	do.	Cyprus Case Grande Corp.	Copper ore, leached	10

NA Not available.

TABLE 5

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	1988		1989		1990		1991		1992	
	Gross weight	Recoverable copper	Gross weight	Recoverable copper	Gross weight	Recoverable copper	Gross weight	Recoverable copper	Gross weight	Recoverable copper
Mined copper ore:										
Concentrated	222,268,000	1,113,287	230,526,000	1,126,742	240,618,000	1,150,416	261,204,000	1,146,865	[1]222,680,000	1,218,921
Leached[2]	1,308,000	227,992	6,775,000	311,885	8,882,000	393,463	15,687,000	441,241	33,230,000	510,296
Total	223,576,000	1,341,279	237,301,000	1,438,627	249,500,000	1,543,879	276,891,000	1,588,106	255,910,000	1,729,217
Copper precipitates shipped; leached from tailings, dump, in-place material	69,683	49,299	47,388	34,485	31,344	22,997	41,370	27,684	27,402	23,492
Other copper-bearing ores[3]	10,685,000	26,351	15,285,000	24,707	10,111,000	20,866	8,999,000	15,288	7,713,000	12,394
Grand total[4]	XX	1,416,928	XX	1,497,818	XX	1,587,742	XX	1,631,078	XX	1,765,102

XX Not applicable.

[1]In 1992, 603,769 ounces of gold and 15,182,176 ounces of silver were recovered from concentrated ore. The average value of gold and silver per metric ton of ore concentrated was $1.01.

[2]Includes electrowon from concentrates roast-leached.

[3]Includes gold ore, gold-silver ore, lead ore, lead-copper ore, lead-zinc ore, molybdenum ore, silver ore, tungsten ore, zinc ore, fluorspar, flux ores, cleanup, ore shipped directly to smelters, and tailings.

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

TABLE 6

PRODUCTION OF REFINED COPPER, BY SOURCE AND METHOD OF RECOVERY

(Metric tons)

Period	Primary materials				Scrap			Total refined
	Electrolytically refined[1]		Electrowon	Total[2]	Electrolytically refined[1]	Fire refined	Total[2]	
	Domestic[3]	Foreign						
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	1,059,303	76,889	441,241	1,577,433	318,182	99,575	417,761	1,995,194
1992	1,104,213	96,135	510,296	1,710,644	331,057	102,114	433,171	2,143,815

[1]Based on source of material at smelter level.
[2]Data may not add to total shown because of independent rounding.
[3]Includes fire-refined copper.

TABLE 7

PRODUCTION, SHIPMENTS, STOCKS, IMPORTS, AND EXPORTS OF COPPER SULFATE IN THE UNITED STATES

(Metric tons)

Year	Production		Shipments[1]	Stocks, Dec. 31	Imports	Exports
	Quantity	Copper content				
1988	34,184	8,630	32,943	4,210	10,677	NA
1989	33,187	8,349	33,912	3,485	13,458	571
1990	34,286	8,627	36,357	1,414	12,251	559
1991	40,186	10,104	39,220	2,380	10,309	827
1992	46,777	11,782	46,296	2,860	8,290	1,049

NA Not available.
[1]Includes consumption by producing companies.

TABLE 8

BYPRODUCT SULFURIC ACID (100% BASIS) PRODUCED IN THE UNITED STATES[1]

Plant type	1988	1989	1990	1991	1992
Copper[2]	2,892,655	3,075,859	3,380,940	3,819,439	3,342,931
Lead[3]	133,672	155,899	165,283	127,121	108,475
Zinc[4]	416,617	409,564	412,682	418,927	364,384
Total	3,442,944	3,641,322	3,958,905	4,365,487	3,815,790

[1]Includes acid from foreign materials.
[2]Excludes acid made from pyrite concentrates.
[3]Includes acid produced at molybdenum plants to avoid disclosing company proprietary data.
[4]Excludes acid made from native sulfur.

TABLE 9

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
1991:					
Copper scrap	[2]695,199	W	[r]58,758	[r]802,046	[r]1,556,003
Refined copper[3]	414,327	[r]1,591,768	[r 4]42,228	([5])	2,048,323
Hardeners and master alloys	757	—	[r]2,725	—	[r]3,482
Brass ingots	—	—	[r]116,921	—	[r]116,921
Slab zinc	73,888	—	21,108	2,955	97,951
Miscellaneous	—	—	—	90	90
1992:					
Copper scrap	[2]748,953	W	64,800	854,771	1,668,524
Refined copper[3]	458,496	1,674,985	[4]44,710	([5])	2,178,191
Hardeners and master alloys	714	—	2,756	—	[6]3,469
Brass ingots	—	—	112,159	—	112,159
Slab zinc	93,049	—	16,346	3,593	112,988
Miscellaneous	—	—	—	47	47

[r]Revised. W Withheld to avoid disclosing company proprietary data; included in "Brass mills."
[1]Includes ingotmakers.
[2]Includes consumption of copper scrap at wire rod mills to avoid disclosing company proprietary data.
[3]Detailed information on consumption of refined copper can be found in table 10.
[4]Includes consumption of refined copper at secondary smelters-refiners to avoid disclosing company proprietary data.
[5]Withheld to avoid disclosing company proprietary data; included in "Foundries, chemicals plants, miscellaneous users."
[6]Data do not add to total shown because of independent rounding.

TABLE 10

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
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
1992:						
Wire rod mills	1,660,794	—	—	—	14,191	1,674,985
Brass mills	311,147	W	12,420	43,641	91,288	458,496
Chemical plants	W	W	—	—	870	870
Ingotmakers	W	—	W	W	3,035	3,035
Foundries	2,960	W	7,579	28	4,472	15,039
Miscellaneous[1]	W	W	W	W	25,766	25,766
Total	1,974,901	W	19,999	43,669	139,622	2,178,191

W Withheld to avoid disclosing company proprietary data; included with "Billets and other."
[1]Includes iron and steel plants, primary smelters producing alloys other than copper, consumers of copper powder and copper shot, and other manufacturers.

TABLE 11

STOCKS OF COPPER IN THE UNITED STATES, END OF PERIOD

(Metric tons)

Period	Blister and materials in process of refining[1]	Refined copper					
		Primary and Secondary refiners	Wire rod mills	Brass mills	Other[2]	New York Commodity Exchange	Total
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	135,099	38,334	29,578	10,724	r22,811	30,603	r132,050
1992	166,154	35,450	36,973	12,454	23,704	96,037	204,618

rRevised.
[1]Includes copper in transit from smelters in the United States to refineries therein.
[2]Includes chemical plants, foundries, and miscellaneous plants; includes 20,000 tons in the National Defense Stockpile.

TABLE 12

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[1]	
	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)
1991	252,630	$345,013	r11,218	r$16,228	r263,217	r$622,628	131,318	$181,833	21,294	$50,102	r679,674	r$1,215,804
1992:												
Australia	8,371	13,186	5	7	2	8	—	—	45	85	8,423	13,286
Belgium	—	—	—	—	159	238	99	111	—	—	258	349
Brazil	1,548	2,606	—	—	—	—	172	356	—	—	1,720	2,962
Bulgaria	5,172	8,752	—	—	—	—	—	—	—	—	5,172	8,752
Canada	53,628	76,728	10,314	7,099	8,529	21,657	26,864	26,119	15,990	38,489	115,325	170,092
China	13,848	23,523	134	83	32,990	74,161	23,870	19,054	—	—	70,842	116,821
Colombia	4	9	—	—	76	148	—	—	2	13	82	170
Costa Rica	—	—	—	—	284	736	—	—	—	—	284	736
Dominican Republic	3	4	—	—	185	441	—	—	14	51	202	496
Finland	—	—	687	56	—	—	—	—	—	—	687	56
France	6	15	—	—	870	2,067	—	—	5	8	881	2,090
Germany	137	210	919	5,951	1,039	2,594	216	232	—	—	2,311	8,987
Ghana	—	—	—	—	—	—	—	—	110	377	110	377
Hong Kong	17	19	19	14	9,329	20,349	8,464	7,664	79	118	17,908	28,164
India	—	—	157	112	21	57	97	124	19	24	294	317
Indonesia	—	—	—	—	398	228	31	19	—	—	429	247
Italy	276	266	—	—	960	2,309	138	216	—	—	1,374	2,791
Japan	96,117	121,083	573	1,163	53,636	121,029	25,469	39,259	328	367	176,123	282,901
Korea, Republic of	31,034	43,444	1	18	803	1,991	12,422	19,468	38	68	44,298	64,989
Mexico	30,854	16,241	31	68	4,468	9,062	300	318	23	50	35,676	25,739
Netherlands	10	17	—	—	1,723	3,040	47	32	—	—	1,780	3,089
Philippines	15,284	17,658	—	—	—	—	—	—	—	—	15,284	17,658
Russia[2]	2,703	5,158	—	—	10	15	—	—	—	—	2,713	5,173
Singapore	4	4	18	104	415	1,001	1,057	1,099	8	14	1,502	2,222
Spain	6,278	10,465	21	32	—	—	—	—	—	—	6,299	10,497
Switzerland	—	—	—	—	93	246	—	—	—	—	93	246
Taiwan	25	46	(3)	8	55,628	122,621	1,784	1,468	224	698	57,661	124,841
Thailand	—	—	—	—	4,697	10,833	36	65	—	—	4,733	10,898
United Kingdom	401	477	49	45	454	1,074	35	25	15	74	954	1,695
Venezuela	—	—	—	—	64	155	4	11	2	6	70	172
Other	51	62	34	131	84	236	91	191	25	97	282	717
Total[1]	265,769	339,972	12,963	14,891	176,913	396,296	101,195	115,830	16,926	40,538	573,766	907,527

rRevised.

[1]Data may add to totals shown because of independent rounding.

[2]Formerly part of the U.S.S.R.

[3]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 13
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)
1991	20,107	$69,789	19,294	$74,263	22,944	$92,628	7,853	$45,404	7,240	$24,789
1992:										
Argentina	81	351	91	302	1	11	4	42	20	3
Australia	279	1,228	60	282	3	87	26	319	447	1,175
Austria	1	18	200	737	—	—	(2)	5	7	25
Belgium	62	206	27	338	1	6	9	141	—	—
Brazil	50	221	30	93	2	8	14	75	14	47
Canada	5,108	19,783	14,878	44,497	8,216	26,200	3,096	12,105	294	880
Chile	85	374	17	60	10	34	22	361	92	123
China	267	1,002	12,177	27,739	198	439	57	169	253	752
Colombia	61	258	545	1,330	60	163	39	192	33	108
Costa Rica	90	301	529	1,548	4	25	25	103	38	104
Dominican Republic	25	78	1,342	3,834	566	1,832	1,338	5,899	1	3
Ecuador	53	214	117	345	60	239	11	90	20	55
Egypt	227	659	379	845	4	21	19	98	30	115
El Salvador	5	22	100	270	7	17	183	848	—	—
France	176	962	1	23	18	253	45	1,000	431	616
Germany	32	95	111	751	38	584	116	1,955	130	737
Greece	54	173	1	6	13	139	—	—	295	673
Hong Kong	78	294	519	4,613	467	1,823	48	1,222	17	49
Ireland	104	262	1	6	59	403	92	589	—	—
Israel	73	241	17	210	20	232	55	529	96	222
Italy	867	1,965	(2)	3	4	34	45	410	99	265
Jamaica	23	75	184	563	38	159	137	612	4	20
Japan	141	2,214	617	4,469	60	822	490	3,784	2,391	7,070
Korea, Republic of	9	54	278	2,673	4	39	28	716	1,703	4,929
Kuwait	330	1,277	1	8	1	31	6	76	—	—
Malaysia	57	248	5	28	3	55	9	64	6	20
Mexico	3,501	13,360	2,802	8,978	18,476	73,976	2,028	12,551	107	321
Netherlands	638	1,967	40	353	22	212	53	159	230	696
New Zealand	195	847	29	64	(2)	3	4	43	161	502
Philippines	76	225	8	23	60	274	17	138	110	331
Saudi Arabia	1,002	3,480	(2)	17	308	1,880	316	1,694	17	49

See footnotes at end of tables.

TABLE 13—Continued

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)
1992—Continued:										
Singapore	95	284	105	407	105	1,939	88	476	644	1,874
South Africa Republic of	39	149	1	16	(2)	10	4	45	111	289
Spain	1,394	4,469	91	361	8	98	5	109	75	236
Sweden	13	28	31	111	29	314	6	162	352	1,205
Twaiwan	898	3,398	1,492	9,371	198	1,154	389	2,442	183	492
Thailand	623	2,302	613	1,718	—	—	68	205	57	163
Trinidad and Tobago	18	19	528	1,529	38	91	3	27	6	20
United Arab Emirates	735	2,555	9	21	17	58	(2)	4	—	—
United Kingdom	425	1,694	135	390	1,209	5,455	524	4,682	325	1,012
Venezuela	605	$2,406	203	$527	17	$113	134	$556	1	$5
Other	1,069	3,755	219	952	640	3,040	656	2,965	554	1,478
Total	19,663	73,512	38,531	120,410	30,981	122,273	10,208	57,663	9,351	26,664

[1]Total exports of wire rod for 1991 were 2,041 tons, valued at $7,242,512 and 1992 were 1,312 tons, valued at $4,106,161.

[2]Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 14

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)
1991	60,766	$68,661	3,594	$5,468	60,329	$148,617	288,586	$684,694	28,751	$54,949	442,027	$962,387
1992:												
Brazil	—	—	—	—	—	—	8,836	20,991	—	—	8,836	20,991
Canada	19,177	28,415	1,653	1,921	19	43	224,094	513,163	29,616	57,876	274,559	601,418
Chile	—	—	843	1,392	23,235	50,413	41,929	93,743	2,506	5,542	68,513	151,090
Costa Rica	—	—	—	—	—	—	—	—	677	587	677	587
Dominican Republic	—	—	—	—	—	—	—	—	553	987	553	987
Estonia[2]	—	—	—	—	—	—	22	39	592	1,031	614	1,070
Germany	—	—	—	—	106	450	692	1,731	—	—	798	2,181
Indonesia	41,336	57,787	—	—	—	—	—	—	18	27	41,354	57,814
Jamaica	—	—	—	—	—	—	—	—	572	493	572	493
Japan	—	—	(3)	3	115	334	409	1,176	—	—	524	1,513
Mexico	34,132	30,770	743	1,100	14,593	32,316	2,010	4,585	10,206	18,460	61,684	87,231
Namibia	—	—	—	—	3,315	8,109	—	—	—	—	3,315	8,109
Netherlands	—	—	—	—	—	—	—	—	686	1,853	686	1,853
Panama	—	—	—	—	—	—	—	—	818	1,384	818	1,384
Peru	3,723	1,733	—	—	16,770	37,101	8,329	18,895	148	196	28,970	57,925
Philippines	—	—	4,520	4,747	—	—	—	—	—	—	4,520	4,747
Portugal	3,719	6,018	—	—	—	—	—	—	—	—	3,719	6,018
Russia[2]	—	—	89	433	—	—	20	39	526	1,058	635	1,530
Spain	—	—	—	—	—	—	—	—	1,133	1,776	1,133	1,776
Venezuela	—	—	—	—	—	—	—	—	2,019	1,980	2,019	1,980
Zaire	—	—	—	—	—	—	2,005	4,731	—	—	2,005	4,731
Other	35	106	27	155	6	112	733	1,265	2,324	2,942	3,125	4,580
Total[4]	102,122	124,829	7,876	9,751	58,158	128,877	289,077	660,358	52,398	96,193	509,631	1,020,008

[1]C.i.f. value at U.S. port.
[2]Formerly part of the U.S.S.R.
[3]Less than 1/2 unit.
[4]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 15

U.S. IMPORTS FOR CONSUMPTION 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[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)
1991	13,073	$52,072	47,350	$210,746	1,996	$10,861	2,358	$8,519	4,690	$12,627
1992:										
Australia	1	5	7	30	1	11	—	—	2,909	7,885
Belgium	—	—	113	1,167	(3)	9	—	—	—	—
Brazil	34	112	1,213	3,533	—	—	36	163	—	—
Canada	1,949	7,155	10,796	35,897	6,751	17,676	36	361	—	—
Chile	354	1,220	1,972	5,792	148	358	—	—	—	—
Finland	152	781	2,719	10,048	349	3,252	—	—	—	—
France	1,523	5,534	74	354	260	3,350	8	60	—	—
Germany	101	718	4,528	17,392	255	2,103	14	130	(3)	9
Italy	8	65	36	72	6	88	39	460	—	—
Japan	729	3,094	12,168	67,777	90	1,352	96	726	39	291
Luxembourg	—	—	987	10,323	—	—	—	—	—	—
Mexico	815	2,845	712	2,232	67	245	33	111	497	1,270
Netherlands	—	—	114	427	54	248	—	—	—	—
Norway	(3)	5	—	—	—	—	—	—	218	565
Peru	—	—	221	550	—	—	226	557	—	—
Poland	—	—	199	590	—	—	—	—	—	—
Sweden	11	42	10,881	40,674	—	—	—	—	18	46
Taiwan	4	45	87	633	6	131	1	18	—	—
Turkey	—	—	21	66	30	140	301	1,311	—	—
United Kingdom	37	336	765	6,885	2	253	6	48	269	719
Other	362	1,350	703	1,800	271	1,708	72	298	—	—
Total[4]	6,080	23,306	48,314	206,244	8,293	30,926	869	4,243	3,951	10,785

[1]Total imports of wire rod for 1991 were 516 tons, valued at $1,826,755 and 1992 were 6,644 tons, valued at $17,562,325.

[2]C.i.f. value at U.S. port.

[3]Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 16

COPPER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992[e]
Albania[e]	r14.9	r16.7	r13.2	r8.0	3.6
Argentina	.5	.7	.3	e.4	.4
Armenia[2]	—	—	—	—	1.0
Australia	238.3	296.0	330.0	311.0	3326.0
Bolivia	.2	.3	.2	e(4)	(4)
Botswana[5]	24.4	21.7	20.6	r20.6	21.0
Brazil	44.8	47.4	36.4	r37.9	339.8
Bulgaria[e]	r50.0	r38.8	r32.9	r47.2	45.0
Burma	4.7	5.1	4.4	5.7	34.8
Canada:					
By concentration or cementation	772.5	r719.1	r790.0	r e807.6	761.1
Leaching (electrowon)	4.0	4.0	3.7	e3.5	3.1
Chile[6]	1,451.0	1,609.3	1,588.4	1,814.3	1,910.0
China[e]	282.0	276.0	300.0	300.0	375.0
Congo	1.0	—	—	—	—
Cuba	3.0	1.8	e2.8	e3.0	2.5
Cyprus[7]	.3	.5	.5	r.2	3.2
Czechoslovakia[8]	r4.8	4.9	3.3	r2.6	2.5
Ecuador[e]	.1	.1	.1	.1	.1
Finland	20.2	14.5	12.6	11.7	310.2
France	.5	1.0	.5	.3	.3
Georgia[2]	—	—	—	—	6.0
Germany:					
Eastern states	r9.0	r7.9	r3.6	—	—
Western states[8]	.7	.1	(4)	—	—
Total	r9.7	r8.0	r3.6	—	—
Honduras	r.5	2.4	1.4	e1.0	1.0
India	55.4	57.4	e61.0	r55.4	49.0
Indonesia[8]	121.5	144.0	r164.1	r211.7	3280.8
Iran[e]	51.0	68.0	60.3	80.7	391.6
Japan	16.7	14.7	12.9	12.4	312.1
Kazakhstan[2]	—	—	—	—	350.0
Korea, North[e]	15.0	15.0	15.0	15.0	16.0
Korea, Republic of	(4)	(4)	.1	(4)	(4)
Macedonia[9]	—	—	—	—	70.0
Malaysia	22.1	23.8	24.3	25.6	328.6
Mexico:					
By concentration or cementation	273.5	253.9	293.6	r292.5	280.0
Leaching (electrowon)	11.4	10.3	26.9	32.1	40.0
Mongolia	r121.7	123.6	123.9	r90.1	3105.1
Morocco	15.4	16.0	16.4	r15.8	15.0
Mozambique[e]	.1	.1	(4)	—	—
Namibia	40.9	r e32.8	r e32.5	r33.9	334.6
Nepal	(4)	(4)	(4)	(4)	(4)
Norway	15.9	16.5	19.7	17.4	312.7
Oman[e]	317.1	16.6	14.0	r14.0	315.0
Papua New Guinea	218.6	204.0	170.2	204.5	3193.4

See footnotes at end of table.

TABLE 16—Continued

COPPER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992[e]
Peru:[10]					
By concentration or cementation	r316.4	r368.2	317.7	r382.0	350.0
Leaching (electrowon)	21.1	19.7	16.3	17.9	3 18.1
Philippines	218.1	193.0	182.1	r148.3	3 123.3
Poland	437.0	384.0	r329.3	r320.3	387.0
Portugal[10]	3.7	103.7	162.9	r164.8	150.5
Romania[e 8]	26.0	25.0	25.0	20.0	20.0
Russia[2]	—	—	—	—	375.0
Saudi Arabia	e.3	.8	.9	.9	.9
Serbia and Montenegro[9]	—	—	—	—	5.0
South Africa, Republic of[8]	168.5	181.9	178.7	r184.6	3 167.1
Spain	r14.2	r28.5	r10.9	r e10.0	10.0
Sweden	r74.5	69.5	r74.3	r81.6	86.0
Turkey[e 11]	3 30.5	r32.7	r35.8	r35.7	27.5
U.S.S.R.[e 12]	r1,000.0	r1,000.0	r950.0	r900.0	—
United Kingdom	.7	.5	1.0	r.3	—
United States:[6]					
By concentration or cementation	1,191.7	1,185.6	1,194.3	1,189.8	1,254.8
Leaching (electrowon)	228.0	13 311.9	13 393.5	13 441.2	13 510.3
Uzbekistan[2]	—	—	—	—	80.0
Yugoslavia[14 15]	103.5	138.9	140.1	e138.0	—
Zaire:[8]					
By concentration or cementation	r188.7	r185.4	r143.7	r e70.5	30.9
Leaching (electrowon)	r307.1	r280.8	r229.1	r e180.0	140.0
Zambia:[16]					
By concentration or cementation (smelted)	r308.9	r345.5	r331.7	r300.3	320.0
Leaching (electrowon)	147.7	120.8	104.6	r109.9	120.0
Zimbabwe[e 8]	r16.9	r16.4	3 14.7	r14.4	10.5
Total[17]	r8,727.3	r9,057.5	r9,016.6	r9,186.7	9,294.2

[e]Estimated. [r]Revised.

[1]Data represent copper content by analysis of concentrates produced except where otherwise noted. Table includes data available through June 30, 1993.

[2]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[3]Reported figure.

[4]Less than 50 tons.

[5]Copper content of pelletized nickel-copper matte produced in smelter.

[6]Reported 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 Mineria (SERNAGEOMIN) were as follows, in thousand metric tons: 1988—1,472.0; 1989—1,628.3; 1990—1,616.3; 1991—1,840.0 (estimated); and 1992—1,935.0 (estimated).

[7]Copper content of cement copper. Includes copper content of pyrite for 1989.

[8]Recoverable content.

[9]Formerly part of Yugoslavia; data were not reported separately until 1992.

[10]Recoverable 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.

[11]Includes copper content of pyrite.

[12]Dissolved in Dec. 1991.

[13]Includes electrowon from concentrates roast-leached.

[14]Dissolved in Apr. 1992.

[15]Copper content by analysis of ore mined.

[16]Data are for fiscal years beginning Apr. 1 of year stated. Zambian-mined copper reported recovered during smelting and electrowinning.

[17]Data may not add to totals shown because of independent rounding.

TABLE 17

COPPER: WORLD SMELTER PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Albania, primary	14.8	15.3	r1.6	r4.8	0.2
Australia:					
Primary	177.8	204.0	192.0	197.0	200.0
Secondary[e]	3 10.5	10.0	10.0	10.0	10.0
Total[e]	3 188.3	214.0	202.0	207.0	210.0
Austria, secondary	34.5	39.1	41.0	e 44.8	49.5
Belgium:[e]					
Primary	.2	.2	.2	.2	.2
Secondary	93.2	r102.8	r87.6	r105.0	87.4
Total	93.4	r103.0	r87.8	r105.2	87.6
Brazil, primary	147.9	153.4	r152.1	r141.4	145.0
Bulgaria:[e]					
Primary	r54.4	r57.2	r29.3	r26.8	24.0
Secondary	3.0	2.0	1.0	1.0	1.0
Total	r57.4	r59.2	r30.3	r27.8	25.0
Canada:					
Primary	478.3	462.3	r475.6	r512.0	3 519.2
Secondary	46.6	37.8	r47.4	r34.5	3 31.1
Total	524.9	500.2	r523.0	546.5	550.4
Chile, primary[4]	1,189.4	1,226.6	1,328.5	1,296.1	1,300.0
China, primary[e]	320.0	340.0	350.0	360.0	370.0
Czechoslovakia:					
Primary[e]	5.0	r5.0	r5.0	r5.0	5.0
Secondary[e]	r4.7	r3.0	r3.2	r3.0	3.0
Total	r9.7	r8.0	r8.2	r8.0	8.0
Finland:					
Primary	79.0	79.5	90.2	90.1	3 110.5
Secondary[e]	12.0	12.0	12.0	12.0	12.0
Total[e]	91.0	91.5	102.2	102.1	122.5
France, secondary	8.5	e 8.4	r e 6.6	r e 5.8	6.0
Germany:					
Primary:					
Eastern states	r22.7	r20.1	r14.0	—	—
Western states	r162.5	r176.9	r183.6	—	—
Total primary	r185.2	r197.0	r197.6	r171.9	210.0
Secondary:					
Eastern states[e]	36.0	37.0	19.9	—	—
Western states	50.0	75.9	75.9	—	—
Total secondary	86.0	112.9	95.8	r e 70.0	70.0
Total	r271.2	r309.9	r293.4	r e 241.9	280.0
Hungary, secondary[e]	.1	.1	.1	.1	.1
India, primary	44.3	42.5	40.7	r e 47.0	50.0
Iran:[e 5]					
Primary	49.4	72.2	52.1	52.4	57.0
Secondary	2.6	3.8	2.7	2.8	3.0
Total	52.0	76.0	54.8	55.2	60.0

See footnotes at end of table.

TABLE 17—Continued

COPPER: WORLD SMELTER PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Japan:					
Primary	854.6	882.3	893.2	967.7	[3]1,046.2
Secondary	139.4	123.2	147.4	[r]117.7	[3]128.7
Total	994.0	1,005.5	1,040.6	[r]1,085.4	[3]1,174.9
Kazakhstan:[6]					
Primary	—	—	—	—	325.0
Secondary	—	—	—	—	40.0
Total	—	—	—	—	365.0
Korea, North:[e]					
Primary	15.0	15.0	15.0	20.0	21.0
Secondary	3.0	3.0	3.0	5.0	5.0
Total	18.0	18.0	18.0	25.0	26.0
Korea, Republic of, primary	123.5	123.6	[e]124.0	[3]125.0	130.0
Mexico, primary	150.3	174.3	175.4	[r]182.6	180.0
Namibia, primary	42.2	38.0	[r]33.2	32.9	[3]34.4
Norway, primary	31.7	35.0	36.5	38.4	[3]39.3
Oman, primary	[r]16.5	15.2	12.1	[r]12.2	[3]15.0
Peru, primary	246.9	241.2	195.5	268.8	[3]253.9
Philippines, primary	159.2	[r]156.3	[r]153.5	[r]167.5	168.0
Poland:[e]					
Primary	385.0	380.0	326.0	360.0	360.0
Secondary	25.0	20.0	20.0	20.0	20.0
Total	410.0	400.0	346.0	380.0	380.0
Portugal:[e]					
Primary	2.5	.7	1.0	1.0	1.0
Secondary	2.0	2.0	2.0	2.0	2.0
Total	4.5	2.7	3.0	3.0	3.0
Romania:					
Primary[e]	[r]30.7	[r]31.4	[r]27.3	[r]27.0	24.0
Secondary[e]	8.0	8.0	1.0	1.0	1.0
Total	[r]38.7	[r]39.4	[r]28.3	[r]28.0	25.0
Russia:[6]					
Primary	—	—	—	—	425.0
Secondary	—	—		—	50.0
Total	—	—	—	—	475.0
Serbia and Montenegro:[7]					
Primary	—	—	—	—	90.0
Secondary	—	—	—	—	40.0
Total	—	—	—	—	130.0
South Africa, Republic of, primary	180.6	184.8	176.0	[e]170.4	165.0
Spain:					
Primary	111.0	120.0	110.0	[r]111.1	110.0
Secondary	34.6	32.3	32.0	[r]38.0	40.0
Total	145.6	152.3	142.0	[r]149.1	150.0
Sweden:					
Primary	93.7	[r]70.0	[r]76.4	[r]68.1	[3]77.8
Secondary	22.2	24.6	[r]31.6	[r]29.4	[3]20.6
Total	115.9	[r]94.6	108.0	[r]97.6	98.4

See footnotes at end of table.

TABLE 17—Continued

COPPER: WORLD SMELTER PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Taiwan, primary	43.3	43.2	16.1	—	—
Turkey:[e]					
Primary	12.8	20.9	r20.7	r28.2	25.8
Secondary	.1	.2	.2	.2	.2
Total	12.9	21.1	r20.9	r28.4	26.0
U.S.S.R.:[e 8]					
Primary	r1,200.0	r1,200.0	r1,100.0	r950.0	—
Secondary	150.0	150.0	130.0	120.0	—
Total	r1,350.0	r1,350.0	r1,230.0	r1,070.0	—
United States:					
Primary[9]	1,043.0	1,120.4	1,158.5	1,123.0	3,1,180.3
Secondary	331.6	359.1	304.8	364.3	3393.6
Total	1,374.6	1,479.5	1,463.3	1,487.3	3,1,573.9
Uzbekistan:[6]					
Primary	—	—	—	—	75.0
Secondary	—	—	—	—	10.0
Total	—	—	—	—	85.0
Yugoslavia:[10]					
Primary	106.5	101.6	105.9	r e105.0	—
Secondary	65.5	71.4	68.3	r e50.0	—
Total	172.0	173.0	174.3	r e155.0	—
Zaire, primary:					
Electrowon	r307.1	r280.8	r229.1	r e180.0	140.0
Other	r159.7	r168.4	r126.7	r57.5	21.9
Total	r466.8	r449.2	r355.8	r e237.5	161.9
Zambia, primary:[11]					
Electrowon	95.9	75.4	51.9	r64.5	70.0
Other	308.9	r345.5	r331.7	r300.3	320.0
Total	404.8	420.8	r383.7	r264.9	3390.0
Zimbabwe, primary[12]	r16.3	r15.8	r14.1	r13.8	314.0
Grand total[13]	r9,565.6	r9,820.6	r9,472.4	r9,216.5	9,327.9
Of which:					
Primary:					
Electrowon	r403.0	r356.2	r281.0	r244.5	210.0
Other	r8,079.5	r8,338.7	r8,143.6	r8,035.3	8,093.7
Secondary	r1,083.1	r1,125.7	r1,047.8	r1,036.7	1,024.2

[e]Estimated. [r]Revised.

[1]This 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, 1993.

[2]Argentina 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.

[3]Reported figure.

[4]Data 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.

[5]Data 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.

[6]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[7]Formerly part of Yugoslavia; data were not reported separately until 1992.

[8]Dissolved in Dec. 1991.

[9]Figures 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: 1988—49,299; 1989—34,485; 1990—22,997 (revised); 1991—27,684 (revised); and 1992—27,402.

[10]Dissolved in Apr. 1992.

[11]For 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 18).

[12]Includes impure cathodes produced by electrowinning in nickel processing.

[13]Totals may not add to detail shown because of independent rounding.

TABLE 18

COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1988	1989	1990	1991	1992e
Albania, primary	14.1	14.5	r10.9	r4.4	0.1
Argentina, secondary	12.5	11.0	15.0	15.0	14.0
Australia:					
Primary	196.0	210.0	247.0	252.0	2295.0
Secondary	26.7	r35.0	r24.0	r35.0	232.0
Total	222.7	r245.0	r271.0	r287.0	2327.0
Austria:					
Primary	r3.4	7.2	8.7	r8.1	5.4
Secondary	38.4	39.1	41.0	r44.8	49.4
Total[3]	r41.8	46.3	49.7	r52.8	54.8
Belgium:[4]					
Primary	299.9	256.0	259.0	r191.0	190.0
Secondary	93.0	88.0	102.0	r106.0	105.0
Total	392.9	344.0	361.0	r297.0	295.0
Brazil:					
Primary	147.9	153.4	r152.1	r141.4	145.0
Secondary	38.1	r54.4	r49.6	r37.0	40.0
Total[3]	185.9	r207.8	r201.7	r178.5	185.0
Bulgaria:e					
Primary	45.5	45.8	214.3	r7.6	8.0
Secondary	10.0	10.0	10.0	r5.0	5.0
Total	55.5	255.8	24.3	r12.6	13.0
Canada:					
Primary	482.1	r477.4	r468.4	r503.8	2508.2
Secondary	46.6	37.8	r47.4	r34.5	231.1
Total	528.7	r515.2	515.8	r538.3	2539.3
Chile, primary	1,012.7	1,071.0	1,191.6	r1,228.3	21,243.0
China:e					
Primary	r390.0	r400.0	r400.0	r400.0	420.0
Secondary	r120.0	r140.0	r160.0	r160.0	160.0
Total	r510.0	r540.0	r560.0	r560.0	580.0
Czechoslovakia:					
Primarye	10.0	10.0	8.0	r10.0	8.0
Secondarye	17.1	16.9	16.6	r15.3	16.0
Total	27.1	26.9	24.6	r25.3	24.0
Egypt, secondarye	r 28.4	3.6	3.6	3.6	3.6
Finland:					
Primary	47.9	49.7	57.1	r56.5	61.9
Secondarye	6.0	6.0	8.0	8.0	9.0
Totale	53.9	55.7	65.1	r64.5	270.9
France:					
Primary	7.2	20.3	22.9	r19.6	30.1
Secondary	36.0	29.0	29.0	e30.0	29.0
Total	43.2	49.3	51.9	r49.6	59.1
Germany:					
Primary:					
Eastern statese	61.0	62.0	39.9	—	—

See footnotes at end of table.

TABLE 18—Continued

COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1988	1989	1990	1991	1992e
Germany—Continued:					
Primary—Continued:					
Western states	192.2	196.1	204.0	—	—
Subtotal	253.2	258.1	243.9	r318.3	366.0
Secondary:					
Eastern states[e]	34.1	31.6	16.8	—	—
Western states	234.2	279.1	272.0	—	—
Subtotal	268.3	310.7	289.0	r203.4	216.0
Total:					
Eastern states[e]	95.1	93.6	56.7	—	—
Western states	426.4	475.2	476.2	—	—
Grand total[e]	521.5	568.8	532.9	r521.7	582.0
Hungary, primary and secondary[e]	r19.2	19,000.0	19.0	r15.0	15.0
India, primary:					
Electrolytic	38.9	41.0	40.6	45.0	45.0
Fire refined	1.2	.8	e1.0	e1.0	1.0
Total	40.1	41.8	e41.6	e46.0	46.0
Iran, primary[e 5]	32.0	40.0	243.3	277.9	80.0
Italy:					
Primary[e]	16.3	—	—	—	—
Secondary	59.1	83.3	83.0	r84.4	76.0
Total	75.4	83.3	83.0	r83.4	76.0
Japan:					
Primary	854.6	882.3	893.1	967.7	21,046.2
Secondary	100.5	107.3	114.8	108.6	2114.7
Total[3]	955.1	989.6	1,008.0	1,076.3	21,160.9
Kazakhstan:[6]					
Primary	—	—	—	—	325.0
Secondary	—	—	—	—	40.0
Total	—	—	—	—	365.0
Korea, North:[e]					
Primary	18.0	18.0	18.0	20.0	20.0
Secondary	4.0	4.0	4.0	4.0	5.0
Total	22.0	22.0	22.0	24.0	25.0
Korea, Republic of:					
Primary	168.3	178.7	e183.0	r201.9	205.0
Secondary	.7	1.2	e2.6	r e1.0	2.0
Total	169.0	179.9	185.6	r e202.9	207.0
Mexico:					
Primary:					
Electrowon	11.4	10.3	26.9	32.1	30.0
Other[e]	107.7	113.8	2104.7	r107.0	110.0
Secondary[e]	21.8	23.0	r31.0	r 253.0	80.0
Total[3]	140.8	147.0	r162.7	r192.1	220.0
Norway, primary[5]	31.7	35.0	36.5	38.4	239.3
Oman, primary	16.5	15.1	12.0	r11.1	211.4
Peru, primary	179.6	r224.3	r181.8	e246.1	2250.2

See footnotes at end of table.

TABLE 18—Continued

COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1988	1989	1990	1991	1992[e]
Philippines, primary	132.2	132.2	r125.9	r116.7	122.0
Poland, primary[5]	400.6	390.3	352.0	378.0	2387.0
Portugal, primary[e 5]	5.4	6.0	r.1	r.3	.3
Romania:[e]					
Primary	40.0	42.9	24.7	r10.0	10.0
Secondary	3.0	5.1	3.0	r5.0	3.0
Total	43.0	48.0	27.7	r15.0	13.0
Russia:[6]					
Primary	—	—	—	—	425.0
Secondary	—	—	—	—	50.0
Total	—	—	—	—	475.0
Serbia and Montenegro:[7]					
Primary	—	—	—	—	100.0
Secondary	—	—	—	—	30.0
Total	—	—	—	—	130.0
South Africa, Republic of, primary[5]	136.7	144.2	133.0	138.8	130.0
Spain:					
Primary	108.8	e115.7	e116.0	r111.1	129.0
Secondary	50.0	e50.0	e50.0	r38.0	50.0
Total	158.8	e165.7	e166.0	r149.1	179.0
Sweden:					
Primary	68.3	70.0	66.3	r67.6	71.3
Secondary	22.0	24.6	31.0	r29.0	30.0
Total	90.3	94.6	97.3	r96.6	2101.3
Taiwan:					
Primary	43.3	43.2	16.1	—	—
Secondary[e]	10.0	10.0	6.0	12.0	12.0
Total[e]	53.3	53.2	22.1	12.0	12.0
Turkey, primary[e]	90.0	86.4	84.2	r80.0	80.0
U.S.S.R.:[e 8]					
Primary	r1,200.0	r1,200.0	r1,100.0	r950.0	—
Secondary	150.0	150.0	130.0	120.0	—
Total	r1,350.0	r1,350.0	r1,230.0	r1,070.0	—
United Kingdom:					
Primary	49.3	48.6	47.0	r16.6	10.4
Secondary	74.7	70.4	74.6	r53.5	31.7
Total	124.0	119.0	121.6	r70.1	42.1
United States:					
Primary:					
Electrowon	228.0	311.9	393.5	441.2	2510.3
Other	1,178.0	1,164.9	1,183.2	1,136.2	21,200.3
Secondary	446.0	480.0	440.8	417.8	2433.2
Total[3]	1,852.0	1,956.8	2,017.4	1,995.2	22,143.8
Uzbekistan:[6]					
Primary	—	—	—	—	75.0
Secondary	—	—	—	—	10.0
Total	—	—	—	—	85.0

See footnotes at end of table.

TABLE 18—Continued

COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1988	1989	1990	1991	1992e
Yugoslavia:[9]					
Primary	105.6	101.9	102.2	r107.2	—
Secondary	39.8	49.2	49.2	r e27.0	—
Total[3]	145.4	151.0	151.4	r134.2	—
Zaire, primary[10]	r202.8	r181.6	r140.9	r104.0	247.5
Zambia, primary:[11]					
Electrowon	51.8	45.4	52.7	r45.4	50.0
Other	397.7	418.1	385.4	r357.1	400.0
Total[3]	449.6	463.6	438.1	r402.5	450.0
Zimbabwe:[12]					
Primary	16.1	15.7	14.1	r13.8	14.0
Secondary[e]	11.4	8.3	8.4	8.2	8.2
Total[e]	27.5	24.0	22.5	r22.0	22.2
Grand total[3]	r10,573.8	r10,918.4	r10,804.7	r10,637.2	10,906.7
Of which:					
Primary[3]	r8,840.7	r9,051.5	r8,962.1	r8,963.2	9,205.8
Secondary[3]	r1,713.9	r1,847.9	r1,823.6	r1,659.0	1,685.9
Primary and secondary, undifferentiated	r19.2	r19.0	r19.0	r15.0	15.0

eEstimated. rRevised.

[1]This 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, 1993.

[2]Reported figure.

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

[4]Includes leach cathode from Zaire, which is processed.

[5]May include secondary.

[6]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[7]Formerly part of Yugoslavia; data were not reported separately until 1992.

[8]Dissolved in Dec. 1991.

[9]Dissolved in Apr. 1992.

[10]Excludes leach cathode exported for reprocessing in Belgium.

[11]Data 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.

[12]May not include copper-nickel matte (copper content more than 6,000 tons per year) imported from Botswana for toll refining.

FLUORSPAR

By M. Michael Miller

Mr. Miller, a physical scientist with 15 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 coordinator. All units are in metric tons, unless otherwise noted.

In the United States, one major producer supplied about 11% of the Nation's fluorspar requirements. Supplementing fluorspar as a domestic source of fluorine was byproduct fluorosilicic acid production from some phosphoric acid producers. According to the Bureau of the Census, imports of fluorspar decreased by about 7% compared with the 1991 revised figures. 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 fluorosilicic acid production. The latter was formerly termed fluosilicic acid, but as a result of an international effort to standardize nomenclature, its name has been changed to fluorosilicic acid. Of the four fluorspar mining operations to which a survey request was sent, three responded, representing 100% of known domestic shipments. Production statistics in table 1 are withheld to protect company proprietary data. Of the eight fluorosilicic acid producers surveyed, seven 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, 74% responded. Of the operations surveyed on an annual basis, 80% responded. *(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 barite, calcite, galena, quartz, and sphalerite. 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 of 3.18, 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 in excess of 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 arsenic, beryllium, calcium carbonate, lead, phosphates, silica, sulfide or free sulfur, 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.

Traditionally, metallurgical-grade fluorspar (metspar) has contained a minimum of 60% effective CaF_2, with effective CaF_2 units calculated by subtracting 2.5 times the silica content of the metspar from its total CaF_2 content. More recently, there has been much less emphasis on effective CaF_2 units and more emphasis simply on total CaF_2 content. Today, the term "metspar" is usually used to refer to material with a minimum content of 85%, but is sometimes used for material as high as 96%, which includes what is technically ceramic grade. Metspar is often traded as lump or gravel that must meet physical requirements similar to those of the following National Defense Stockpile

(NDS) purchase specifications.

According to the current NDS purchase specifications (P-69b-R3), which were determined by the Federal Interagency Committee for Stockpile Purchase Specifications and Special Instructions in consultation with U.S. steel producers, metallurgical-grade fluorspar must contain a minimum of 70% by weight effective CaF_2. Specifications for maximum allowable impurities are as follows: sulfur = 0.10%, lead = 0.25%, arsenic = 0.01%, barium = 0.01%, zinc = 0.01%, phosphorus = 0.25%, tin = 0.02%, antimony = 0.02%, and copper = 0.10%. Physical requirements are that all metallurgical-grade fluorspar shall be in the form of gravel and, after washing, shall pass a 75-millimeter sieve (3-inch sieve), and not more than 10% by weight shall pass a 9.5-millimeter sieve (3/8-inch sieve).

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% CaF_2 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-Resources[1]

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.

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% CaF_2 can be preconcentrated to yield a flotation feed of 40% CaF_2 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 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.

Economic Factors

Depletion allowances against Federal taxes of 22% and 14%, respectively, remained in effect for domestic and foreign production by U.S. companies.

Operating Factors

The United States is import dependent for the majority of its fluorspar supplies. Fluorspar products are transported to customers by truck, rail, barge, and ship. Most acid-grade fluorspar is shipped in the form of damp filter cake containing 7% to 10% moisture to facilitate handling and reduce dust.

Most acid-grade imports come from China, the Republic of South Africa, and occasionally other overseas suppliers. Fluorspar is shipped by ocean freight utilizing the "Tramp" market for ships. Bulk carriers of 10,000 to 50,000 tons deadweight normally are utilized. Participants negotiate freight level, terms, and conditions. The main participants are *charterers*—generally the buyers or sellers, *ship owners*—who either own vessels or have them time chartered, *operators*—traders normally taking positions on either cargo or ships, and *brokers*—generally represent ship owners or charterers and act as go-betweens. Ships are primarily owned by the following: privately held shipping companies, publicly held shipping companies, Government-controlled companies, and groups of professionally managed fleets under varying ownership. The total number of ships in the 10,000- to 50,000-ton range is about 2,000, of which more than 60% is at least 15 years old. The rate of new ship construction is very low; less than 2% of the total fleet is on order. Factors or concerns currently affecting the shipping market are the age of the fleet, environmental safety and quality assurance, insurance rates, rising operating costs due to inflation, increasing port expenses, increased tax or tariffs relating to ship costs, and anticipated volatility due to changing world conditions.[3]

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 1992, it was authorized to sell 20,000 sdt (18,144 metric tons) of metallurgical-grade fluorspar during fiscal year 1992 (October 1, 1991 to September 30, 1992). The DLA-DNSC sold 4,000 short wet tons (3,629 metric tons) in fiscal year 1992 from the stockpile in Marietta, PA. According to the fiscal year 1993 annual materials plan of the 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 were initiated. Based on revised national security needs dictated by new post-cold war planning assumptions, the Department of Defense has been authorized to dispose of the entire fluorspar stockpile. The overall mechanism for this disposal would be the National Defense Authorization Act for Fiscal Year 1993 (Public Law 102-484), which authorized the disposal of obsolete and excess materials contained in the NDS. To prevent undue disruption of markets, advisory and impact committees were to be established. Both committees were to have representatives from the Departments of Commerce, Energy, Interior, State, and Treasury. In addition, the advisory committee was required to have representatives from the mining and processing industries and their customers. The impact committee is required to "consult from time to time" with industry to determine how disposals could affect domestic and foreign markets.[4]

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 608 of title VI required the Environmental Protection Agency (EPA) to establish a comprehensive program to limit emissions of ozone depleting substances during their use and disposal. As a result, in December 1992, EPA proposed regulations to establish a recycling program for ozone depleting refrigerants

recovered during the servicing and disposal of air-conditioning or refrigeration equipment. The proposed regulations would require persons servicing air-conditioning or refrigeration equipment to observe certain service practices that reduce refrigerant emissions and would establish equipment and offsite reclaimer certification programs. In addition, EPA would require that ozone-depleting compounds contained "in bulk" in appliances be removed prior to disposal of the appliances, and that all air-conditioning and refrigeration equipment, except for small appliances and room air conditioners, be provided with a servicing aperture that would facilitate recovery of the refrigerant.[5] The CFC's recycled in this program are exempt from the excise tax on ozone-depleting chemicals.

As part of energy legislation passed by Congress in 1992, the tax on those CFC's with the highest ozone depletion potential will rise to $3.35 per pound (about $7.39 per kilogram) in 1993, to $4.35 per pound ($9.59 per kilogram) in 1994, to $5.35 per pound (about $11.79 per kilogram) in 1995, and will increase by $0.45 per pound (about $0.99 per kilogram) each year thereafter. The new excise taxes are higher than those in the previous tax schedule, which was included as part of a deficit reduction bill in 1989.

Delegates representing signatories to the Montreal Protocol met in Copenhagen, Denmark, and agreed to speed up the phaseout of CFC's. The adjustments bring the worldwide production phaseout in line with European and U.S. plans announced earlier in the year. Under the new timetable, CFC-11, -12, -113, -114, and -115 production will be reduced 75% from 1986 production levels by January 1, 1994. It also calls for a complete production phaseout as of January 1, 1996. Amendments, which must be ratified, included a phaseout schedule for HCFC's and control of hydrobromofluorocarbons. Essentially, the HCFC schedule would begin in 1996 by freezing HCFC production at 1989 levels, then reduce that allowance by 35% in 2004, 65% in 2010, 90% in 2015, and 99.5% in 2020.

As part of a project initiated in 1991, the U.S. Bureau of Mines is continuing to collect information on the fluorspar and HF industries for the purpose of addressing impacts on production costs and supply and demand resulting from regulatory requirements on the industries or new technologies to produce replacements for banned CFC's. A Network Flow Model and Supply Analysis Model will be developed for the fluorspar and HF industries to address material flow from the production of acid-grade fluorspar to HF plants and on to CFC consumers. Operating costs and transportation costs for each stage will be incorporated. During 1992, information on U.S. HF plants was collected and detailed engineering cost studies for the two types of HF plants currently in operation in the United States were obtained. During 1993, economic analysis of fluorspar operations and North American HF operations will be completed. During 1994, data will be collected on European HF industries and a final project report completed. If funding becomes available, data on HF industries in South America and Asia will be added to the models in the future.

Issues

As required by Section 612 of Title VI of the CAAA, EPA is required to publish a list of safe alternative CFC's for specific uses. The list had not been published by the end of 1992. This delay is causing uncertainty in the consumer markets, in particular the foam blowing, refrigeration, and air conditioning markets. Equipment manufacturers and consumers are faced with the very real uncertainty of redesigning equipment and selecting replacement compounds without knowing if the replacement compounds will be on the "approved list" or not. This uncertainty is further complicated by the alternatives offered by the CFC producers. Each CFC producer is offering different products, usually blends designed to replace traditional products such as R-502. Because the pace of research and development of replacements has been dictated by the phaseout schedule, there is a resulting lack of product standardization in the industry. Thus the consumer is being forced to choose a single supplier of replacement compounds, because the other CFC producers' products are likely to be incompatible with the consumers new equipment.

Production

Illinois was the only State reporting production in 1992 and accounted for nearly 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 and processed some material from the NDS 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 shipped a small amount of fluorspar from stocks, but the Crowell-Daisy Mine in Nye County, NV, remained closed.

Two Canadian firms have been active in the exploration and acquisition of fluorspar properties in North America. Silverspar Minerals Inc. has explored prospects in Arizona and has negotiated the acquisition of fluorspar properties in Kentucky, New Mexico, and Tennessee. In Arizona, its property is called the Silver District Property, which is on the Arizona-California border north of Martinez Lake, AZ. In New Mexico, there is the Salado Property, west of Truth or Consequences, NM, and the Hidalgo Property, in southern New Mexico. In Tennessee, there is the Sweetwater Property, in south-central Tennessee. In Kentucky, Silverspar Minerals has been negotiating an option to purchase the fluorspar mining assets of

USX Corp., which are in the Kentucky fluorspar district of western Kentucky. Verdstone Gold Corp. announced the acquisition of two fluorspar properties in British Columbia, Canada, and two properties in Nevada. The properties in Nevada were the Blazer fluorspar deposit in Lander County and the Baxter (Kaiser) Mine in Mineral County.

Nine plants processing phosphate rock for the production of phosphoric acid sold a reported 64,408 tons of byproduct fluorosilicic acid at a value of about $8.6 million. This was equal to 111,600 tons of 92% fluorspar equivalent. The fertilizer industry is operating at a relatively high rate, and the supply and demand of fluorosilicic acid is at present reasonably balanced. Because fluorosilicic acid is a byproduct and not manufactured for itself alone, shortages can occur when fertilizer demand goes down.

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 1992 increased by about 5%. Reported consumption by the steel industry decreased by about 7%, despite a 4% increase in U.S. raw steel production.

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 also was 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 137,792 tons for 1992 compared with the 1991 quantity of 146,643 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) increased slightly to 45,451 tons and dichlorodifluoromethane (CFC-12) increased by 4.5% to 72,428 tons compared with 1991 figures. Data on production of chlorodifluoromethane (HCFC-22) was unavailable. No information is currently collected on production of the HCFC and HFC replacement compounds.

The chemical industry continued construction on commercial plants to manufacture replacement HCFC's and HFC's. Eight new plants went on-line worldwide during 1992, four in the United States, two in Japan, and two in France. A reported 11 additional plants are under construction or are in the planning stage.

Some of the new plants will be producing HCFC's 22, 123, 124, 141b, and 142b. These HCFC substitutes have ozone-depletion potentials much lower than 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, because of the recently agreed upon phaseout schedule for HCFC's and the likelihood that the schedule will be accelerated, the market for HCFC's will exist for only a finite amount of time. Industry expects HCFC's to be produced and utilized at least through the end of this decade.

The HFC replacements 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, 141b, 143a, and 152a. The latter five HFC's hold potential for use by themselves or more likely as blends in mid- to low-temperature refrigeration and automobile air conditioners. In addition, some interim replacements may be mixtures of these compounds and HCFC's. Inhalation and toxicity tests continued on the various replacements. EPA has proposed additional HFC compounds for additional study, such as HFC's 227ca, 227ea, 236cb, 236ea, 236fa, 245cb, and 245fa.

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 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 also was 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.

Fluorosilicic 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 2.)*

Stocks

Consumer stocks at yearend were 47,699 tons, a decrease of nearly 31% from the level reported in 1991. At yearend, the NDS fluorspar inventory was essentially unchanged from yearend 1991 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 about 112,777 sdt (105,938 metric tons) of nonstockpile, metallurgical-grade material. The latter category was reduced by a sale of 4,000 short wet tons (3,629 metric tons) in September. 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 Large, PA; Warren, OH; and Pine Bluff, AR.

Prices

According to prices published by Industrial Minerals (Metal Bulletin PLC), the price of domestic acid-grade fluorspar was unchanged compared with 1991 prices. Published yearend producer prices for Mexico were unchanged. South African and Chinese prices decreased compared with 1991 prices.

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). The price quotation for synthetic cryolite also remained unchanged at $510 to $550 per short ton (about $562 to $606 per metric ton). *(See table 3.)*

Foreign Trade

According to the Bureau of the Census, U.S. exports of fluorspar decreased by about 82%. Because Ozark-Mahoning reported no foreign sales, all U.S. exports were reexports of material imported into the United States. *(See table 4.)*

Imports for consumption of fluorspar decreased by about 7% compared with those of the previous year, according to Bureau of the Census data and revisions made to 1991 data. It is believed that there were some Chinese shipments unreported in the official 1991 trade data, and an estimate of this tonnage was included in Chinese acid-grade imports. In 1992, China was the largest supplier of fluorspar to the United States, followed by, in descending order, the Republic of South Africa, Mexico, and Namibia. The average c.i.f. unit value, in dollars per metric ton, was about $112 for acid grade and about $85 for subacid grade. *(See table 5.)*

The suspension of the 13.5% ad valorem tariff on subacid-grade fluorspar imports expired December 31, 1992. The temporary suspension was part of the Customs and Trade Act of 1990, signed into law on August 20, 1990. The 13.5% ad valorem tariff went back into effect on January 1, 1993, and applies to both most-favored-nation (MFN) and non-MFN countries. The tariff on acid grade for MFN countries is $2.10 per long ton ($2.07 per metric ton) and for non-MFN countries $5.60 per long ton ($5.51 per metric ton).

Imports for consumption of HF decreased 19% to a quantity equivalent to approximately 101,000 tons of fluorspar. Imports of synthetic and natural cryolite increased 21% to a quantity equivalent to approximately 4,880 tons of fluorspar. Imports of aluminum fluoride decreased by 3% to a quantity equivalent to approximately 48,400 tons of fluorspar. *(See tables 6, 7, and 8.)*

World Review

World fluorspar consumption and production decreased compared with 1991 levels. In order of rank, China, Mexico, the former U.S.S.R., Mongolia, 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. World production has decreased by 25% in the past 2 years, despite major revisions downward of world production totals for prior years. China's pricing practices continued to cause difficulties for other fluorspar producers. As a result, the European Community proposed an import duty on Chinese acidspar of 10.9 ecu per ton (about $13 per ton) with a floor price under consideration. The Mexican Government also was considering an import duty on Chinese imports.

Brazil.—The Brazilian fluorspar industry continued to be adversely impacted by low international fluorspar prices. Brazilian producers have abandoned the export market, relying strictly on domestic markets. Production comes from the mines and operations of the following companies: Mineracao del Rey Ltda., Mineracao Nossa Senhora do Carmo Ltda., Mineracao Floral Ltda., and Companhia Brasiliera Alumina.

In 1992, Mineracao Santa Catarina was acquired by Companhia Brasiliera Alumina, which already owned a fluorspar mining operation in Santa Catarina State to supply its aluminum production operations. Mineracao del Rey Ltda. and Mineracao Nossa Senhora

do Carmo Ltda., in cooperation, started the country's first fluorspar briquetting plant. The plant has a capacity of 66,000 tons per year.[6]

The Brazilian mining company Paranapanema announced plans to develop a cryolite deposit in the State of Amazonas. The cryolite deposit was discovered in 1991 in the company's Pitinga tin mine, near the town of Joao Figueiredo. The cryolite occurs below the cassiterite ore body at a total depth of about 150 meters. The mine will produce about 25,000 to 30,000 tons per year and has total estimated reserves of 3 million tons. Development costs are estimated at $15 to $17 million with startup projected in 30 to 36 months. A company representative stated that the mine will be developed with a Danish partner.

China.[7]—Although fluorspar exports from China continued at high levels, the number of operating mines probably decreased in 1992. The central Government changed its method of funding fluorspar operations to emphasize actual sales rather than simply production. As a result, many of the smaller and more remote mines apparently ceased production. Large producer stocks, reportedly built up in recent years, have been sold. Whether these two factor will generate any upward pressure on international prices is uncertain.

Italy.[8]—Nuova Mineraria Silius S.p.A. was formed in early 1992 to take over the assets and operations of the country's major acid-grade producer, Mineraria Silius, S.p.A. Nuova Mineraria was being run by an executive committee, with the Sardinian Regional Autonomous Government maintaining majority equity in the company. The takeover has resulted in a substantial work force reduction. Serious planning was underway for a new flotation mill to be located at the mine, with startup anticipated in 1994.

Mexico.—In 1991, Sesa Fluorspar Inc. purchased the Reynolds Metals processing plant in Eagle Pass, TX, and had moved it to Mexico. This new operational phase was short lived, because in 1992, Sesa Fluorspar was forced to shut down operations. Fluorita de Rio Verde also shut down operations in 1992. The small producer, Silsea, ceased production and was attempting to sell off its stockpile. Cia Minera La Valenciana S.A. de C.V. started production in 1992 after a hiatus of some years. Output was intended for the company's new HF plant.[9]

The Mexican Chamber of Mines presented a request to the Secretary of Commerce and Industrial Development for a compensatory tax on imports of Chinese acidspar into Mexico. The Secretary issued a statement that investigations had been initiated to confirm the dumping of acidspar, to collect price data, and to determine impacts on the domestic fluorspar industry. No results had been announced by the end of 1992.

Mongolia.—Mongolia's fluorspar mining industry is dominated by two joint-venture companies—Mongolsovtsvetmet (Mongolia and Russia) and Mongolczechoslovakmetal (Mongolia and Czechoslovakia). The latter operated the Chulut Cagan Del Mine, which sold all of its production to Czechoslovakia. Sales were terminated in early 1992 and the mine shut down. The company is seeking new markets, so far unsuccessfully.[10] Mongolsovtsvetmet operated Mongolia's largest fluorspar mine and only flotation mill at Bor-Ondor. The mine was closed temporarily in 1992 as a result of a dam failure that flooded the mine.[11]

Turkey.—Taneks Foreign Trade Inc. announced plans in late fall of 1992 to start production of fluorspar from a deposit at Malatya in central Anatolia. The deposit has fluorspar reserves of 0.5 million tons. The company's plans included construction of a mill with an annual capacity of 24,000 tons, divided between metallurgical grade and acid grade. The majority of its output was expected to be metallurgical grade intended for export to European iron and steel markets.[12]

Turkey's state-owned mining, metallurgy, and banking company, Etibank, announced the opening of a thorium-bearing barite-fluorspar-rare earths deposit to foreign participation. Etibank sought foreign technical expertise in the evaluation, development, and marketing of the mineral deposit, which is near the city of Eskisehir in the Sivrihisar district of midwestern Turkey. The deposit is characterized by lens and layer occurrences, and carbonitic dikes and veins. Reserves are estimated at 30 million tons at an average grade of 37.44% CaF_2. Run-of-mine samples tested at 37.3% CaF_2, with a product grade of 90% with 60% recovery.[13]

United Kingdom.[14]—The United Kingdom's fluorspar production is concentrated in Derbyshire. In 1992, Swan Industrial Minerals Ltd. acquired the Derbyshire mineral rights of fluorspar producer Deepwood Mining Co. Ltd. and its wholly owned subsidiary Matlock Barytes Co. Ltd. At the same time, they acquired Horace Taylor Minerals Ltd., which will process fluorspar from Swan's fluorspar deposits at a new fluorspar and barite processing facility scheduled for startup in February 1993. The facility, in Matlock, will be producing high-quality metspar for domestic markets and export and preconcentrates for acidspar production. *(See table 9.)*

Current Research

Phosphate Engineering and Construction Co. of Lakeland, FL, applied for a patent whereby byproduct fluorosilicic acid is reacted with phosphate rock to produce phosphoric acid and calcium silicon hexafluoride ($CaSiF_6$). In the process the $CaSiF_6$ is hydrolyzed to produce silica and calcium fluoride, which are separated by centrifuging and settling. The calcium fluoride is then reacted with sulfuric acid to produce HF. The company is negotiating with phosphate producers to construct a demonstration plant.

The U.S. Bureau of Mines initiated a cooperative testing effort with private industry to demonstrate and evaluate Bureau column flotation and rapid flotation technology integrating advanced electrochemical sensors and intelligent process control strategies. Column flotation technology has proven to be more efficient than conventional froth flotation for the development of lower grade ores. Commercial application of column flotation has resulted in economic improvements that enhance industry's position in mineral production and allow it to remain competitive in the international marketplace.

The U.S. Bureau of Mines is assisting EPA in development of treatment methods to decontaminate lead wastes at several Superfund sites. The cleaning process utilizes fluorosilicic acid and consists of the following: (1) carbonating the lead waste to convert lead sulfate into acid soluble lead carbonate; (2) leaching the carbonated material with fluorosilicic acid and hydrogen peroxide to dissolve lead carbonate, lead oxide, and lead metal; and (3) electrowinning the lead-loaded leachate to recover metallic lead and recycle the leachate.

OUTLOOK

Consumption of metallurgical-grade fluorspar by the U.S. steel industry decreased again in 1992, despite a small gain in raw steel production. The closure of the last open-hearth furnaces, which required significant quantities of fluorspar, eliminated a traditional market for fluorspar. The decreasing level of consumption is mainly a result of continuing changes in technology, improvements in efficiencies, and tighter raw material specifications. These factors indicate that U.S. consumption of metallurgical-grade fluorspar will continue to decrease through the 1990's.

The international market for metspar is still huge. Worldwide, the steel industry is still the largest consumer of fluorspar. However, with the spread of more efficient steelmaking processes, the unit consumption of fluorspar is expected to fall. This will probably offset overall gains in steel production.

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 fluorosilicic 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.

Consumption by the primary aluminum producers in the Western World is expected to increase at a gradual rate through most of this decade. Demand is subject to a number of industry changes in operating performance, environmental performance, and technology, plus capacity increases.

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.

Although U.S. reported consumption of fluorspar for HF production increased in 1992, it is not known if this reflected an upturn in the replacement fluorocarbon (HCFC's and HFC's) market or increased consumption necessitated by the mothballing of the Allied-Signal HF plant in Amherstburg, Ontario, Canada. The fluorocarbon producers continue to build new HCFC and HFC facilities. Allied-Signal expanded HF capacity at its plant in Geismar, LA, but the capacity increase from 104,000 tons per year to 120,000 tons per year is not sufficient to offset the lost capacity from the mothballed Amherstburg plant (52,000 tons per year).

There is some indication that demand by the fluorochemical industry is increasing, but in 1992 it was insufficient to make up for decreases reported by the steel and aluminum industries. With capture and recycling now required by EPA, ongoing development of not-in-kind replacements for CFC's, and the continued decrease in demand by the steel industry, it is difficult to forecast when demand will increase. With the final phaseout of CFC's in 1995 and expected production increases by the aluminum industry, demand for acidspar should increase in the mid-1990's.

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[1]Kilgore, C. C., S. R. Kramer, and J. A. Bekkala. Fluorspar Availability—Market Economy Countries and China. BuMines IC 9060, 1985, pp. 16 and 17.

[2]Work cited in footnote 1.

[3]Diamond, R. C. Ocean Freight—An Important Link Within the Supply Chain. Pres. at International Fluorspar Conference, Hamilton, Bermuda, May 17-18, 1993, 10 pp.; available from R. C. Diamond, Mid-Ship Marine, Inc., New York, NY.

[4]Department of Defense. Strategic and Critical Materials Report to the Congress. Mar. 1993.

[5]Federal Register. U.S. Environmental Protection Agency. Protection of Stratospheric Ozone; Refrigerant Recycling. V. 57, No. 238, Dec. 10, 1992, pp. 58644-58674.

[6]Skillen, A. Fluorspar Producers—Cracks in the Chinese Wall? Ind. Miner. (London). No. 307, Apr. 1993, pp. 41-42.

[7]Pages 36-37 of work cited in footnote 6.

[8]Loughbrough, R. Italy's Industrial Minerals—A Fistful of Feldspar. Ind. Miner. (London). No. 301, Oct. 1992, p. 49.

[9]Pages 37-38 of work cited in footnote 6.

[10]Bulgan, G. The Mongolian Fluorspar Industry. Pres. at Industrial Mineral's Fluorspar's Future Fortunes Conference, Casablanca, Morocco, Apr. 25-27, 1993, 5 pp.; available from Industrial Minerals, London, United Kingdom.

[11]Fulton, R. B. Mongolian Fluorspar. Pres. at International Fluorspar Conference, Hamilton, Bermuda, May 17-18, 1993, 5 pp.; available from R. B. Fulton, Kennett Square, PA.

[12]Industrial Minerals (London). World of Minerals. No. 301, Oct. 1992, pp. 12-13.

[13]Mining Engineering. Industry Newswatch. V. 44, No. 9, Sept. 1992, p. 1079.

[14]Pages 46-47 of work cited in footnote 6.

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SRI International—Chemical Economics Handbook, Fluorine.
U.S. Department of Commerce reports, Inorganic Chemicals, M28A.
U.S. International Trade Commission reports, Synthetic Organic Chemicals.

TABLE 1
SALIENT FLUORSPAR STATISTICS[1]

		1988	1989	1990	1991	1992
United States:						
Production:						
Finished (shipments)e	metric tons	63,500	66,000	63,500	58,000	[2]51,000
Value f.o.b. mine	thousands	W	W	W	W	W
Exports	metric tons	3,136	5,134	14,921	73,943	13,646
Value	thousands	$346	$694	$1,891	$16,424	$1,983
Imports for consumption	metric tons	689,139	655,590	513,921	r437,027	407,169
Value[3]	thousands	$62,748	$79,897	$65,938	r$54,549	$42,502
Consumption (reported)	metric tons	651,055	641,882	564,545	483,589	485,442
Consumption (apparent)[4 5]	do.	r726,940	r698,255	r581,806	r500,720	[6]480,376
Stocks, December 31:						
Domestic mines:						
Finished	do.	W	W	W	W	W
Consumer	do.	56,012	79,347	74,692	68,999	47,699
World: Production	do.	r5,282,172	r5,695,735	r5,131,035	r4,077,268	e3,846,443

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.
[1]Does not include fluorosilicic acid (H_2SiF_6) or imports of hydrofluoric acid (HF) and cryolite.
[2]Includes 2,700 tons of nonstockpile-grade metspar from the National Defense Stockpile beneficiated by Ozark Mahoning Co.
[3]C.i.f. value at U.S. port.
[4]U.S. primary and secondary production plus imports plus adjustments for Government and industry stock changes.
[5]Apparent consumption figures were revised by deleting "minus exports" from the apparent consumption equation. All fluorspar exports are general imports that have been reexported. They do not show up in the imports for consumption, but when included in apparent consumption distort the resulting consumption figure.
[6]Includes 907 tons of nonstockpile-grade metspar from the National Defense Stockpile.

TABLE 2
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	
	1991	1992	1991	1992	1991	1992
Hydrofluoric acid (HF)	328,696	347,367	—	—	328,696	347,367
Iron and steel (foundries)	—	—	W	W	W	W
Open-hearth furnaces	—	—	W	W	W	W
Basic oxygen furnaces	—	—	33,276	33,204	33,276	33,204
Electric furnaces	1,788	2,229	25,532	20,733	27,320	22,962
Other[1]	W	W	W	W	94,297	81,909
Total	W	W	W	W	483,589	485,442
Stocks, December 31 (consumer)	67,371	45,704	1,628	1,995	68,999	47,699

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Includes aluminum fluoride, enamel, glass and fiberglass, iron and steel (foundries), open-hearth furnaces, primary aluminum, primary magnesium, and welding rod coatings.

TABLE 3
PRICES OF DOMESTIC AND IMPORTED FLUORSPAR

(Dollars per metric ton)

	1991	1992
Domestic, f.o.b., Illinois district, bulk, acid grade	190-195	190-195
Chinese, dry bulk, c.i.f., Rotterdam, acid grade	106-110	100-110
Mexican, f.o.b., Tampico:		
Acid grade, filtercake	122-127	122-127
Metallurgical grade	90- 95	90- 95
South African, f.o.b., Durban, acid grade, dry basis	120-125	110-115

Source: Industrial Minerals (Metal Bulletin PLC), No. 303, Dec. 1992, p 86.

TABLE 4
U.S. EXPORTS OF FLUORSPAR, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Australia	56	$7,966	38	$5,483
Canada	11,082	1,582,452	10,745	1,638,883
Colombia	25	2,820	—	—
Dominican Republic	3,427	524,577	—	—
Honduras	—	—	24	3,528
Korea, Republic of	—	—	241	26,943
Mexico	58,960	14,225,959	2,509	288,891
United Kingdom	102	11,421	—	—
Venezuela	291	68,337	89	19,612
Total	73,943	16,423,532	13,646	1,983,340

Source: Bureau of the Census.

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF FLUORSPAR, BY COUNTRY AND CUSTOMS DISTRICT

Country and customs district	1991		1992	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
CONTAINING MORE THAN 97% CALCIUM FLUORIDE (CaF_2)				
China:				
Houston	26,191	$3,490	32,075	$3,631
New Orleans	48,662	5,470	106,642	10,057
Unknown[2]	e61,000	e7,300	—	—
Total	r135,853	r16,260	138,717	13,688
France: Philadelphia	54	24	54	26
Japan: New Orleans	4,627	416	—	—
Mexico:				
El Paso	787	88	—	—
Houston	6,824	751	—	—
Laredo	55,254	7,027	29,277	3,619
New Orleans	7,457	857	6,434	796
Total	70,322	8,723	35,711	4,415
Morocco: New Orleans	9,828	1,382	—	—
Namibia: New Orleans	—	—	4,614	467
South Africa, Republic of: New Orleans	r122,391	r17,221	117,218	14,514
Spain: New Orleans	11,278	1,545	—	—
Grand total	r354,353	r45,571	296,314	33,110
CONTAINING NOT MORE THAN 97% CALCIUM FLUORIDE (CaF_2)				
Canada: Seattle	285	22	—	—
China:				
Baltimore	—	—	6,000	440
New Orleans	28,228	2,437	53,130	4,093
Total	28,228	2,437	59,130	4,533
Japan: New Orleans	4,674	387	—	—
Mexico:				
Buffalo	50	6	499	50
El Paso	3,789	209	3,366	235
Houston	40	9	—	—
Laredo	1,914	295	308	29
New Orleans	42,484	4,460	47,552	4,545
Seattle	1,264	88	—	—
Total	49,541	5,067	51,725	4,859
South Africa, Republic of: New Orleans	(3)	(3)	—	—
Grand total[4]	r82,728	r7,912	110,855	9,392

eEstimated. rRevised.

[1]C.i.f. value at U.S. port.

[2]Includes an estimated 61,000 tons of imports believed missing from the 1991 trade statistics.

[3]The 1991 imports of 17,360 tons have been reclassified as acid grade.

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

Source: Bureau of the Census.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF HYDROFLUORIC ACID (HF), BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Canada	16,985	$23,240	6,302	$8,596
Germany	57	117	61	166
Israel	—	—	4	64
Japan	624	967	263	537
Mexico	64,464	64,471	60,147	57,246
Panama[2]	18	18	—	—
United Kingdom	240	272	358	442
Total	r82,388	r89,085	67,135	67,051

rRevised.
[1]C.i.f. value at U.S. port.
[2]Panama erroneously omitted in 1991.

Source: Bureau of the Census.

TABLE 7
U.S. IMPORTS FOR CONSUMPTION OF CRYOLITE, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Canada	483	$381	608	$347
China	58	41	214	154
Denmark	1,328	1,588	1,846	2,043
Germany	742	728	887	820
Japan	511	521	474	501
Other	237	189	38	32
Total	3,359	3,448	4,067	3,897

[1]C.i.f. value at U.S. port.

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM FLUORIDE, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Canada	5,913	$5,963	5,270	$4,547
China	1,183	951	1,485	1,187
Italy	—	—	42	35
Japan	7,056	7,969	7,331	6,995
Mexico	15,546	15,513	15,900	14,503
Norway	2,674	2,506	1,656	1,559
United Kingdom	594	244	558	291
Other	360	278	33	152
Total[2]	33,326	33,424	32,274	29,268

[1]C.i.f. value at U.S. port.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9

FLUORSPAR: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2] and grade[3]	1988	1989	1990	1991	1992[e]
Argentina	18,052	23,317	e20,000	e20,000	19,000
Brazil (marketable):					
Acid grade	54,920	56,973	47,724	r52,415	52,000
Metallurgical grade	35,078	r38,550	22,659	r28,898	29,000
Total	89,998	r95,523	70,383	r81,313	81,000
Canada: Acid grade[e]	40,000	50,000	25,000	—	—
China:[e]					
Acid grade	950,000	1,200,000	1,150,000	1,000,000	1,000,000
Metallurgical grade	450,000	500,000	550,000	600,000	600,000
Total	1,400,000	1,700,000	1,700,000	1,600,000	1,600,000
Czechoslovakia	e95,000	68,910	46,966	e40,000	40,000
Egypt	1,849	1,721	1,249	r1,790	1,700
France:					
Acid and ceramic grades	153,000	159,000	e145,000	r e145,000	135,000
Metallurgical grade	e50,000	62,000	56,000	r e25,000	25,000
Total[e]	203,000	r221,000	201,000	r170,000	160,000
Germany:					
Eastern states[e]	r280,100	r244,900	r120,000	—	—
Western states (marketable)	77,710	r74,500	e85,300	—	—
Total[e]	r357,810	r319,400	r e205,300	r e61,000	60,000
Greece[e]	r604	r450	e200	e200	200
India:					
Acid grade	8,823	10,300	r10,399	e9,700	10,000
Metallurgical grade	6,772	12,589	r13,042	r14,439	15,000
Total	15,595	22,889	r23,441	r24,139	25,000
Iran[5]	6,483	e6,000	4,767	r12,260	12,000
Italy:					
Acid grade	81,700	66,600	81,822	r60,650	55,000
Metallurgical grade	58,157	59,679	40,681	r37,868	25,000
Total	139,857	126,279	122,503	r98,518	80,000
Kenya: Acid grade	r67,351	95,181	112,295	r77,402	r80,630
Korea, North: Metallurgical grade[e]	40,000	40,000	40,000	41,000	41,000
Korea, Republic of: Metallurgical grade	261	856	560	r290	300
Mexico:[6]					
Acid grade	338,000	359,000	268,000	r132,000	219,000
Ceramic grade	27,000	27,000	11,000	r—	—
Metallurgical grade	253,000	225,000	192,000	r90,000	145,000
Submetallurgical grade	138,000	168,000	163,000	r148,000	—
Total	756,000	779,000	634,000	r370,000	364,000
Mongolia:					
Acid grade	115,000	115,000	119,000	e120,000	97,100
Other grades[7]	584,000	586,000	495,000	r250,000	180,000
Total	699,000	701,000	614,000	r e370,000	277,100

See footnotes at end of table.

TABLE 9—Continued

FLUORSPAR: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2] and grade[3]	1988	1989	1990	1991	1992e
Morocco: Acid grade	100,500	105,000	86,500	r74,600	80,000
Namibia: Acid grade	r38,533	r25,679	r27,107	r34,565	4,40,408
Pakistan	284	4,741	5,312	e5,300	5,000
Romania: Metallurgical grade[e]	18,000	16,000	15,000	14,000	15,000
South Africa, Republic of:[8]					
Acid grade[e]	r283,000	310,000	262,000	240,000	230,000
Ceramic grade[e]	8,000	9,000	7,500	6,000	5,500
Metallurgical grade[e]	r37,420	49,340	r41,530	24,340	22,600
Total	328,421	368,340	311,032	r270,341	4258,105
Spain:					
Acid grade	137,140	154,493	r144,010	r e107,000	85,000
Metallurgical grade	5,435	6,799	r9,681	r e5,000	5,000
Total	142,575	161,292	r153,691	r e112,000	90,000
Sweden[e]	4225	150	r—	r—	—
Thailand: Metallurgical grade	76,321	98,375	94,757	r62,067	52,000
Tunisia: Acid grade	55,416	53,575	40,974	r37,580	15,000
Turkey: Metallurgical grade[e]	413,240	13,000	13,000	13,000	13,000
U.S.S.R.[e 9]	410,500	410,000	380,000	350,000	300,000
United Kingdom	103,797	122,057	118,498	r77,903	85,000
United States (shipments)[e]	63,500	66,000	63,500	58,000	51,000
Grand total	r5,282,172	r5,695,735	r5,131,035	r4,077,268	3,846,443

[e]Estimated. [r]Revised.

[1]Table includes data available through June 1, 1993.

[2]In addition to the countries listed, Bulgaria is believed to have produced fluorspar in the past, but production is not officially reported, and available information is inadequate for the formulation of reliable estimates of output levels.

[3]An 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.

[4]Reported figure.

[5]Year beginning Mar. 21 of that stated.

[6]Data are reported by Consejo de Recursos Minerales.

[7]Principally submetallurgical-grade material.

[8]Data show estimated proportions of acid-grade, ceramic-grade, and metallurgical-grade fluorspar within the reported totals. Data may not add to totals shown because of rounded estimates.

[9]Dissolved in Dec. 1991. This commodity is believed to be produced in Kazakhstan, Kyrgyzstan, Russia, Uzbekistan, and possibly other former republics of the U.S.S.R.; however information is inadequate to formulate reliable estimates of individual country production.

GEMSTONES

By Gordon T. Austin

Mr. Austin, a physical scientist with more than 30 years of industry and Government experience, has been the gemstones commodity specialist since 1986. Ms. Kelly Dorney of the Branch of Data Collection and Coordination prepared the domestic production survey data.

Webster's dictionary 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 1992, the value of natural gemstones from deposits in the United States was $66.2 million, a decrease of 22% compared with that of 1991. Production of gemstones included faceting rough, lapidary rough, carving material, specimen material, natural and cultured freshwater pearls, mother of pearl, fossil ivory, amber, 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 gem stones, would be classed as simulants. Colored and colorless varieties of cubic zirconia are the major simulants produced. In 1992, the reported combined production value of U.S. synthetic and simulant materials was $18.9 million, about a 6% increase from that of 1991.

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 380 operations surveyed, 94% responded, accounting for about 96% of the total production, 93% of the natural production, and 99% of the synthetic and simulant production.

The number of operations surveyed in 1992 was essentially the same as the number surveyed in 1991. The response rate was slightly better. 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.

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 25000 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 is extensive in the United States but not as large-scale operations. More than 60 different gemstones have been produced commercially from relatively small domestic sources. 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, emeralds, 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. 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 primarily 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.

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: faceted, cabochons, and baroque.

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. *(See figure 1.)*

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 abrasives bonded to cloth, 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.

Industry Structure

The world market for rough diamonds is controlled to a high 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% 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 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, contract 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. A new agreement was reached between De Beers Consolidated Mines

Ltd., its customer, and the Government of South Africa on the method of domestic rough diamond distribution. In the past, all categories of rough diamonds that could be processed economically in South Africa must first be offered to local manufacturers. Rough could be exported duty free only if it had first been offered to the local market, otherwise a 15% duty is charged. Now, all rough will be shipped to London and mixed with diamonds from the other producers. Rough for South African cutters is then drawn from the world rough supply.

The CSO has been extremely successful at maintaining the rough diamond market for more than 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 44 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. 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 pavè effect (set close together to conceal the metal base) is but one example.

It is estimated that the Russian'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 and 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 Russian 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.

Cutting and polishing of colored, synthetic, and simulant gemstones is centered in, listed according to importance, Thailand, India, Hong Kong, Republic of Korea, China, and Brazil, where cheap labor and favorable export laws ensure the lowest total costs for finished gems.

Geology-Resources

Gemstones are found in a large variety of igneous, metamorphic, and sedimentary 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 reserves are estimated to be about 300 million carats, including near-gem and cheap-gem qualities. Nearly all of the reserves are in, listed in order of size, Australia, Africa, and Russia (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, a boule 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-Stockbarge solidification method, named for an American, P.W. Bridgman, and a German, D.C. Stockbarge, 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-Stockbarge 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 diameter and weighing more than 1 metric ton have been grown. The crystals have the same shape as the crucible.

The Czochralshi pulled-growth method is used for ruby, sapphire, spinel, yttrium-aluminum-garnet (YAG), gadolinium-gallium-garnet (GGG), and alexandrite. Czochralshi developed his method about 1917 while working with crystals of metallic nutrients.

In the Czochralshi 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, Czochralshi, and skull 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 I_1 improved to SI_2. Yehuda also has 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 Russia 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 Russia.

Processing.—Most gemstone ores 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 1992, all 50 States produced at least $1,000 worth of gem materials. Ten States accounted for 83% of the total value of production of natural gemstones. The States, in order of declining value of production, were Tennessee, California, Arizona, Louisiana, Texas, Oregon, Oklahoma, Iowa, Arkansas, and North Carolina. 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 $34.9 million per year, with a high of $84.4 million in 1991 and a low of $7.4 million in 1983. 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 $45.7 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 $18.9 million in 1992, an increase of 6% over that of 1991. The average value of production of these gem materials for the past 7 years was $16.9 million, with a high of $20.5 million in 1990 and a low of $10.3 million in 1986. Fourteen firms, four in California, four in Arizona, and one each in Massachusetts, Michigan, New Jersey, North Carolina, Ohio, and Washington, produced synthetic and simulant gem material. The eight States, in order of declining value of production, were California, Massachusetts, Arizona, New Jersey, Washington, North Carolina, Michigan, and Ohio.

Arizona is well known for the widest variety of gemstones produced by any State. In 1992, these 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 $1.8 million worth of material.

Arkansas is famous for the production of quartz crystals, but it appears that the fads that have supported the production of quartz crystals for the past few years has ended. It 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. A four phased program to evaluate the diamond deposit was halted by legal actions after completing three exploratory drill holes in 1990. After a Federal appellate court cleared the way for the program to continue, phase 1, the drilling of 26 core holes totaling 2,600 meters, was completed during 1992.

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.

The State also has a freshwater culture pearl farm at Marysville. The farm uses animals imported from Tennessee and other southeastern States. Production 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 largest of any State for synthetics and simulants.

Colorado is not known as a gemstone-producing State, but it does hold some gemstone honors. 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. It also produced the United States' 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 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 1992, 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.

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) also are 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.

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.

Historically, Oregon has been known for the production of various picture and scenic jaspers, agates, thundereggs, 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. There has been an established U.S. freshwater mussel fishing industry since the mid-1850's. The mussels are from the family Unioidae, of which about 20 different species are commercially harvested. During 1992 the value of U.S. mussel shell exports was more than $43 million.

To date, freshwater pearls from the United States have been a byproduct of the shell industry. 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. 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 and heart of the U.S. pearl industry.

In Wisconsin and Michigan, 12 kimberlite pipes have been identified on exploration holdings, 7 have yielded microdiamonds, and 3 have not been tested.

Utah 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 and 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. 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 is variscite, first produced in about 1893 near Fairfield. The latest recorded commercial production was from near Lucin during the summer of 1992. 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 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 in the normally black obsidian. During 1992, two different firms produced this material commercially.

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, 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 carats 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 that produce a single gem material of note 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 1992 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

pyroeletric 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, indicating 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 an 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 has 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 1992, estimated value of U.S. apparent consumption was $3,226 million, down about 13% from 1989's record high. The average annual estimated consumption for the past 10 years was $3,148 million, with a high of $3,705 in 1988 and a low of $2,132 in 1983. The trend for estimated consumption for the past 10 years was one of continued growth with some downward adjustments related to economic conditions.

In 1992, the value of U.S. estimated apparent consumption of diamonds increased about 8% to $2.8 billion. The average annual value of apparent consumption of diamonds for the past 10 years was $2.6 billion, with a high of $3.1 billion in 1989 and a low of $2.1 billion in 1983.

The 1992 estimated apparent consumption of colored stones, led by emerald, ruby, and sapphire, was valued at $392.0 million, a decrease of 3%. The estimated apparent consumption of pearls—natural, cultured, and imitations—was $19.1 million, a slight decrease. The average annual consumption for the past 10 years was $155.3 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 increased about 464% to $117.9 million. Average apparent consumption of these materials for the past 10 years was $62.6 million per year, with a high of $117.9 million in 1992 and a low of $17.2 million in 1983. During 1992, sales in retail jewelry stores increased about 4% to $14.4 billion, according to the U.S. Department of Commerce.

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 of diamond rough 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 $7,208 and $7,256, and was $7,208 at yearend. The average value per carat of all grades, sizes, and types of gem-quality diamond imports was $443, a 14% decrease compared to that of 1991. The average value of diamond imports for the past 10 years was $408 per carat, with a high of $525 in 1990 and a low of $353 in 1984.

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 $3,900, the same as that of 1991. The average value of ruby imports decreased slightly to $29.53 per carat. The average annual value of ruby imports for the past 10 years was $36.67 per carat, with a high

of $48.71 in 1990 and a low of $16.42 in 1984.

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 $1,400, the same as that of 1991. The average value of sapphire imports decreased 30% to $16.29 per carat. The average annual value of sapphire imports for the past 10 years was $22.40 per carat, with a high of $27.97 in 1987 and a low of $16.29 in 1992.

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 1991. The average value of emerald imports increased 72% to $72.23 per carat. The average annual value of emerald imports for the past 10 years was $57.30 per carat, with a high of $78.79 in 1988 and a low of $35.06 in 1984. *(See tables 6 and 7).*

Foreign Trade

The value of diamond exports plus reexports decreased 5% to $1.45 billion. The quantity of cut diamonds exported and reexported decreased 10% to 911,419 carats, and the value of diamond exported and reexported decreased slightly to $1.32 billion.

The value of other precious stones, cut but unset or rough other than diamonds, pearls, and synthetics, exported and reexported increased from $105.5 million to $241.2 million. The value of synthetic gemstone exports plus reexports decreased slightly to $21.2 million.

The value of natural, cultured, and imitation pearls, not set or strung, exports and reexports of pearls increased 62% to more than $6.7 million.

The value of gems and gemstones imported increased 4% to $4,839.4 million compared to those of 1991, but was 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 $4,272 million, with a high of $5,115 million in 1989 and a low of $2,856 million in 1983.

The value of imported gem diamonds increased 4% to $4,143.6 million, but was below the 1989 record high of $4,358 million. The imports of cut diamonds increased 15% in quantity and 5% in value to 7.7 million carats and $3,648.6 million, respectively. The average annual quantity of cut diamonds imported for the past 10 years was 7.3 million carats, with a high of 8.9 million in 1989 and a low of 5.2 million carats in 1983. The average annual value of cut diamond imports was $3,130.0 million, with a high of $3,805.5 in 1989 and a low of $1,982.7 million in 1983.

The value of imports of other gem and gemstones, led by emerald, ruby, and sapphire, was $668.2 million, a decrease of about 26% compared to that of 1991. Emerald imports increased 29% to $213.5 million. The average annual value of emerald imports for the past 10 years was $164.6 million, with a high of $213.5 million in 1992 and a low of $134.1 million in 1983.

The value of ruby imports increased 10% to $77.8 million, but was less than the record-high value for the past 10 years of $98.4 million in 1990. The average annual value of imports for the past 10 years was $76.1 million, with a high of $98.4 in 1990 and a low of $58.7 in 1987. The value of sapphire imports was $75.1, a decrease of 8% compared to those of 1991. The average annual value of sapphire imports for the past 10 years was $82.9 million, with a high of $100.0 million in 1989 and a low of $70.8 million in 1985.

The value of imported gem materials other than diamond, emerald, ruby, and sapphire increased 35% to $327.7 million. The average annual value of imports was $338.9 million, with a high of $429.5 in 1988 and a low of $210.3 in 1990. *(See tables 8, 9, 10, 11, and 12).*

World Review

Diamond sales by De Beers Centenary AG was $3.4 billion in 1992, a decrease of 13% compared with 1991 sales of $3.94 billion. Sales during the second half of 1992 were only $1.63 billion, 12% less than the $1.84 billion sales for the second half of 1991. A De Beers official stated that the reduction in sales was the result of the world economic conditions. De Beers controls about 80% of the rough, uncut diamonds sold in the world. Sales of colored stones remained strong.

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—Russia (northeastern Siberia and in the Yakutia); in Australia; and in South America—Venezuela and Brazil.

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.—Odebrecht, a Brazilian company, purchased modular diamond recovery plants from Van Eck & Lurie for use on its diamond projects in Angola. Odebrecht is undertaking projects in Quango Province on behalf of Endiama, the Angolan state mining corporation.

Armenia.—The diamond cutting and polishing factory at Nur Adjen produced about $60 million of income during the year, despite cutbacks of rough diamonds from Yakutia. The factory worked at full capacity even in the winter because of its priority for electricity and heat. The factory's 1,800 workers are not allowed to drink at lunch (unlike Russian and Ukrainian diamond factory workers), have high moral, and comparatively high

salaries; these factors resulted in high-quality production.

Australia.—Argyle's diamond production of 39.0 million carats was a record for the mine. The Argyle partners stated that the installation of a new heavy-media separation circuit in the alluvial plant and the 2-million-ton expansion in the AK-1 treatment plant would increase production and efficiency. The largest gem-quality diamond recovered from the Argyle mine to date, a 41.7-carat elongated octahedron, was discovered in May. The peanut shell-sized diamond has not been evaluated to establish a price. However, it is not as valuable as the highly prized Argyle pink diamonds. Since the start of mining in 1983, more than 265 million carats of diamonds has been recovered from the AK 1 pipe and alluvial operations.

Ashton Mining Ltd. reported that the Australian Diamond Exploration Joint Venture had discovered 20 commercial-sized stones in the Northern Territory. The stones were from work on the Merlin anomaly.

Redfire Resources NL announced it appeared its opal mining would start in early 1993 on their Coocoran opal project in New South Wales 20 kilometers west of Lighting Ridge. Initial company estimations are that the deposit has potential for a bonanza of economic-grade opals from two separate zones.

Centenary International Mining is spending $373,000 to earn a 70% interest in the Lila Springs Claims, a boulder opal deposit in New South Wales. The company plans to raise funds for the purchase of equipment to start recovering opal to quickly establish a cash-flow. Additionally, Centenary has claims that cover about 200 kilometers of strike length along the Giralia Fault. These claims cover a fossil beach sand deposit suspected to contain diamonds.

Canada.—Sudbury Contact Mines announced the discovery of six more microdiamonds from its Diamond Lake property east of Kirkland Lake, Ontario. This brings to 14 the number of diamonds recovered from cores from 3 holes drilled during the winter of 1991-92. Sudbury drilled eight additional targets during the summer. The targets were drilled to an average depth of 150 meters.

Dia Met Minerals announced additional results from the testing of its kimberlite discovery in the Lac De Gras area of the Northwest Territories. The most recent information disclosed the recovery of 101 carats of diamonds from a 160-ton bulk sample from core drilling. About 25% of the diamonds was gem quality, and some of the stones were in the 1- to 3-carat size range.

Thermal Exploration Co. of California acquired a 70% interest in about 390,000 hectares in the Lac de Gras area of the Northwest Territories. The claims are on the same trend as Dia Met Minerals' and BHP-Utah's holdings. Kennecott Canada Ltd. can earn a 70% interest in Thermal's holding by providing 100% of the exploration costs.

Sudbury Contact Mines, which continued to explore in the Kirkland Lake mining district of northern Ontario, they sampled a second kimberlite pipe and commenced drilling late in the year.

Celtic Gold and Claude Resources secured funding to continued exploration of their joint-venture diamond project at Sturgeon Lake in Saskatchewan. Drilling is underway to examine a ring structure.

China.—Everay Jewellery Ltd. opened its sixth diamond cutting factory in Guangdong Province. The new factory is the company's largest in China and has a capacity for 1,000 workers. The factory produced round brilliants of five points and less. Everay's production of finished goods from China is just over 100,000 pieces per month.

Russia.—The Siberian Republic of Sakha (formerly Yakutia), an autonomous republic with the Russian Federation, signed an agreement with De Beers Centenary AG to exclusively market diamonds through the CSO. Under the agreement, the Republic has the right to retain up to 10% of its rough diamonds for cutting or independent sales. Sakha is responsible for 99.8% of the rough diamond production from the Commonwealth of Independent States. Additionally, De Beers agreed to furnish equipment and training to establish a cutting factory in Sakha. Called Polar Star, the plant will cut about 100,000 carats per year and produce jewelry for the domestic market.

Sakha also signed an agreement with Reichbart Arye, an Israeli firm, which will supply diamond cutting equipment, technology, and training. Diamonds will be cut in the town of Barnaul and in Israel. Additionally, Sakha entered into an agreement with Arda Co., a Japanese jewelry firm, for diamond cutting plants in Sakha. Arda plans to cut 50,000 to 100,000 carats per year for sale in Japan, the Republic of Korea, and Taiwan.

Smolensk Gems NV is a venture between Antwerp-based PHP Diamond, Smolensk Cutting Factory, the Antwerp office of Russalmaz, and Almazjuvelierexport in Moscow. The venture will cut Russian rough into fancy cuts, mainly triangles and princess cuts. The finished goods will be sold in Antwerp.

A recent government decree created the Severoalmaz joint stock company to mine the diamond deposits discovered in the 1980's at Lomonosov in the Archangel region. The decree provides for creating a production complex to mine, sort, and cut diamonds and to make diamond instruments. Severoalmaz will include the Russian corporation Almazzoloto, the Finance Ministry, Archangel Regional Administration, and the Arkhangelskgeologiya enterprise. It is expected that foreign firms will join in providing technical and economic expertise, and assistance in construction of the mining and recovery plants.

Sierra Leone.—The National Provisional Ruling Council of Sierra Leone (which overthrew the President in April 1992) rendered invalid all diamond export licenses issued by the former regime. All sales of diamonds after July were by tender.

Sunshine Mining settled a legal dispute with Boulle Group, its former partner,

and gained 100% control of the Koidu Kemberlite project, believed to contain reserves of 2.5 million carats of diamonds. Sunshine announced plans for a two phase approach to developing the project. Phase 1 would be an approximate 2-year bulk sampling project to substantiate the reserves. Phase 2 would be the construction of a full-scale mine and recovery plant at a cost of about $37 million. The project is anticipated to have a 15-year life.

South Africa, Republic of.—De Beers Consolidated Mines Ltd. brought its new Venetia Mine to full production late in the year. It is reported that the mine will produce about 5.9 million carats per year. Venetia, located in the northern Transvaal near Messina, is a low-cost, high-grade (137 carats per 100 tons) open pit mine. Production from the mine is reported to be 50% to 60% gem-quality stones. Production from the mine is equal to 70% of the country's total production in 1991.

Agreement was reached between De Beers Consolidated Mines Ltd., its customers, and the Government of South Africa on the method of domestic rough diamond distribution. In the past, rough mined in South Africa was offered to domestic cutters before being exported. Now, all rough will be shipped to London and mixed with diamonds from the other producers. Rough for South African cutters is then drawn from the world rough supply.

Three Canadian partners, Stow Resources, Dryden Resources, and Southerera Resources, commissioned the treatment plant for the Leicester diamond mine near Kimberly. A dozen clear white gem-quality diamonds were recovered during startup, including two that are slightly more than 1 carat and one of about 6.5 carats. Previous production from the mine yielded 32,000 carats, with about 50% gem-quality and about 10% larger than 10 carats.

Tanzania.—De Beers' subsidiary Willcroft Co. Ltd. entered into a prospecting and mining agreement with the Ministry of Water, Energy and Minerals. The agreement is for prospecting and mining rights on an area of more than 22,000 square kilometers in the Mwanza, Shinyanga, and Tabora regions. The Ministry also has signed diamond exploration agreements with Reunion Mining Plc. and RZT.

In May, the Tanzania Mineral Dealers Association and the Ministry of Water, Energy, and Minerals of Tanzania held the first gemstone auction in Arusha. Sixty dealers offered goods for sale at the auction attended by 28 buyers from 9 countries. About $200,000 worth of mostly rough tanzanite, ruby, rhodolite garnet, green garnet, chrome tourmaline, and sapphire were sold.

Uruguay.—It is estimated that annual exports of amethyst are about 80 tons valued at more than $500,000. The amethyst is used as mineral specimens, decorator pieces, and as gemstones.

Uzbekistan.—A deposit of industrial diamonds was opened in Tyan-Shan near Tashkent. The diamonds are up to 2 millimeters in diameter, but the deposit also may contain larger gem diamonds. It does allow the republic to enter the ranks of diamond-producing countries.

Zaire.—The volume and value of diamonds marketed through unofficial channels increased after the mutiny in September 1991. The value of diamonds marketed through these channels was estimated to be more than $200 million in 1991, two to five times greater than before the mutiny. The problem seems to have abated somewhat during 1992.

Zimbabwe.—Australian-based Auridiam Consolidated Ltd. recovered about 5,000 carats of diamonds, including a 17-carat gem-quality stone, from the 3-month pilot plant testwork on its Rive Ranch concession. The concession, near the Limpopo River, in southern Zimbabwe, was acquired in the past year after De Beers Consolidated Mines Ltd. and the Government of Zimbabwe could not come to terms. Based on these encouraging results, Auridiam is planning a 200,000-cubic-meter-per-year production plant that would produce about 500,000 carats per year for 10 to 15 years. The diamonds recovered to date were offered for tender in Antwerp.

Reunion Mining Plc. discovered two kimberlites on its concession near Lake Kariba, 300 kilometers west of Harare. Other anomalies in the same area lead the company to believe a group or cluster of pipes may be present. Reunion has 6 additional concessions for diamond exploration in Zimbabwe.

See table 13 for world diamond production by country. *(See table 13.)*

OUTLOOK

World demand for gem diamond can be expected to rise because of increasing effective personal incomes in 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 in 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.

[1]Nassau, K. Gemstone Enhancement. Buttersworth, 1984, pp. 46-60.
[2]Pages 61-78 of work cited in footnote 1.
[3]Pages 25-44 of work cited in footnote 1.
[4]Rapaport Diamond Report. Mar. 6, 1992, Colored Stones Section. V. 15, No 9., p. 26.

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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	Feb.1993	1.5

TABLE 2

DE BEERS' CSO ROUGH DIAMOND SALES AND STOCKS

(Billions of dollars)

Year	Sales	Stocks
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
1992	3.42	3.36

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.
Bixbite	do.	do.	Small	Very high	7.5-8.0	2.63-2.80	do.	1.58	Pressed plastics, tourmaline	Refractive index.
Emerald	do.	Green	Medium	do.	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 (heliodor)	do.	Yellow to golden	Any	Low to medium	7.5-8.0	2.63-2.80	do.	1.58	Citrine, topaz, glass, doublets	
Goshenite	do.	do.	Any	Low	7.5-8.0	2.63-2.80	do.	1.58	Quartz, glass, white sapphire, white topaz	Refractive index.
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.

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:										
Alexandrite	Beryllium aluminate	Green by day, red by artificial light	Former U.S.S.R. (small), Sri Lanka (medium)	High	8.5	3.50-3.84	Double	1.75	Synthetic	Dichroism, inclusions in synthetic sapphire.
Catseye	do.	Greenish to brownish	Small to large	do.	8.5	3.50-3.84	do.	1.75	Synthetic, shell	Gravity and translucence.
Chrysolte	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 strae, bubble inclusions.

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
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.
Feldspar:										
Amazonite	Alkali aluminum silicate	Green	Large	Low	6.0-6.5	2.56	—	1.52	Jade	Cleavage, sheen, vitreous to pearly, opaque, grid.
Labradorite	do.	Gray with blue and bronze sheen color play	do.	Low	6.0-6.5	2.56	—	1.56	do.	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.

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
Pearl	Calcium carbonate	White, pink, or black	Small	do.	2.5-4.0	2.6-2.85	—	—	Cultured and imitation	Luster, structure, X-ray.
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	do.	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.

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
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.
Hiddenite	do.	Yellow to green	do.	do.	6.5-7.0	do.	do.		Synthetic spinel	Do.
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	Peridot, beryl, corundum, glass	Double refraction, refractive index.
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.

[1]Small—up to 5 carats; medium—up to 50 carats; large—more than 50 carats.
[2]Low—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	1970's
Do.		(Inamori)	
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.	Former U.S.S.R.	1980's
Do.	Hydrothermal	Lechleitner	1960's
Do.	do.	Regency	1980's
Do.	do.	Biron	1980's
Do.	do.	Former 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 1992 U.S. GEMSTONE PRODUCTION, BY GEM MATERIALS

Gem materials	Value
Agate	$548,000
Beryl	323,000
Coral (all types)	122,000
Garnet	108,000
Gem feldspar	1,042,000
Geode/nodules	260,000
Fire agate	45,000
Jasper	111,000
Obsidian	4,000
Opal	756,000
Peridot	1,306,000
Petrified wood	211,000
Quartz	638,000
Sapphire/ruby	895,000
Topaz	12,000
Tourmaline	82,000
Turquoise	1,994,000
Total	8,457,000

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] Jan. 1992-Jan. 1993	Average[4] July 1992
0.25	G	VS1	$1,400- $1,400	$1,400
.25	G	VS2	1,200 - 1,200	1,200
.25	G	SI1	970 - 970	970
.25	H	VS1	1,200 - 1,200	1,200
.25	H	VS2	1,100 - 1,100	1,100
.25	H	SI1	950 - 950	950
.50	G	VS1	2,700 - 2,900	2,900
.50	G	VS2	2,500 - 2,600	2,600
.50	G	SI1	2,300 - 2,300	2,300
.50	H	VS1	2,600 - 2,700	2,700
.50	H	VS2	2,400 - 2,500	2,500
.50	H	SI1	2,100 - 2,200	2,200
.75	G	VS1	3,500 - 3,500	3,500
.75	G	VS2	3,200 - 3,200	3,200
.75	G	SI1	2,800 - 2,800	2,800
.75	H	VS1	3,100 - 3,100	3,100
.75	H	VS2	2,800 - 2,800	2,800
.75	H	SI1	2,600 - 2,600	2,600
1.00	G	VS1	4,600 - 4,600	4,600
1.00	G	VS2	4,100 - 4,100	4,100
1.00	G	SI1	3,700 - 3,700	3,700
1.00	H	VS1	4,100 - 4,100	4,100
1.00	H	VS2	3,800 - 3,900	3,900
1.00	H	SI1	3,400 - 3,600	3,600

[1]Gemological Institute of America (GIA) color grades: D—colorless; E—rare white; G-H-I—traces of color.
[2]Clarity: IF no blemishes; VVS1—very, very slightly included; VS—very slightly included; VS2—very slightly included, but not visible; SI1—slightly included.
[3]Jeweler's Circular-Keystone. V. 164, No. 3, Mar. 1993, p. 148.
[4]Jeweler's Circular-Keystone. V. 163, No. 9, Sept. 1992, p. 118.

TABLE 7
PRICES OF U.S. CUT COLORED GEMSTONES, BY SIZE[1]

Gemstone	Carat weight	Price range per carat in 1992[2]	Average price per carat[2]	
			Jan. 1992	Jan. 1993
Amethyst	1	$8 - $18	$13.00	$13.00
Aquamarine	1	75 - 250	175.00	82.50
Emerald	1	2,500- 3,500	2,750.00	2,750.00
Garnet, tsavorite	1	600 - 900	750.00	750.00
Ruby	1	3,000- 4,800	3,900.00	3,900.00
Sapphire	1	800- 2,000	1,400.00	1,400.00
Tanzanite	1	100 - 240	210.00	130.00
Topaz	1	5 - 12	9.00	7.00
Tourmaline, red	1	60 - 125	92.50	92.50

[1]Fine quality.
[2]Jewelers' Circular-Keystone. V. 164, No. 3, Mar. 1993, p. 148. 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	1991		1992	
	Quantity (carats)	Value[1] (millions)	Quantity (carats)	Value[1] (millions)
Exports and reexports:				
Belgium	r2,177,190	r$430.5	2,404,886	$368.6
Canada	r305,702	r32.1	413,285	30.7
France	8,746	23.7	7,455	25.2
Hong Kong	r291,537	r270.4	198,418	312.5
Israel	r364,495	r272.1	335,521	279.0
Japan	r125,260	r196.3	80,953	121.5
Singapore	r20,653	r27.5	24,213	30.9
Switzerland	r116,246	r149.7	52,447	146.4
Thailand	r39,748	r39.7	23,057	17.1
United Kingdom	r20,516	r38.5	16,156	51.7
Other	r240,323	r41.3	393,999	65.8
Total	r3,710,416	r1,521.6	3,950,390	1,449.5

rRevised.
[1]Customs value.
[2]Data may not add to totals 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	1991		1992	
	Quantity (carat)	Value[1] (millions)	Quantity (carat)	Value[1] (millions)
Rough or uncut, natural:[2]				
Belgium	455,621	$40.7	402,763	$81.9
Brazil	106,396	9.8	26,867	1.4
Israel	17,097	10.3	26,699	10.7
Netherlands	18,334	9.2	79,564	17.6
South Africa, Republic of	13,787	7.6	13,405	17.6
Switzerland	64,717	18.9	1,156	9.4
United Kingdom	625,965	249.5	685,544	189.1
Venezuela	20,580	0.3	318	0.1
Other	460,339	181.1	392,059	167.1
Total	1,782,836	527.4	1,628,375	495.0
Cut but unset, not more than 0.5 carat:				
Belgium	789,422	280.1	795,348	270.5
Brazil	41,626	17.6	15,414	6.6
Canada	4,419	1.2	6,558	2.1
Hong Kong	132,735	29.0	247,289	44.1
India	3,373,905	825.4	4,249,843	935.2
Israel	727,175	357.9	670,327	313.0
Netherlands	5,612	1.7	3,338	1.1
South Africa, Republic of	16,517	10.0	7,263	6.3
Switzerland	21,237	6.2	11,055	4.6
United Kingdom	1,424	0.7	4,779	1.4
Other	86,601	20.9	80,899	19.2
Total	5,200,673	1,550.7	6,092,113	1,604.2
Cut but unset, more than 0.5 carat:				
Belgium	592,530	793.9	589,036	776.2
Hong Kong	14,196	34.5	14,879	30.8
India	41,316	33.8	30,634	18.0
Israel	783,799	834.4	915,487	973.8
Netherlands	4,491	13.8	3,928	18.9
South Africa, Republic of	5,291	12.2	5,706	22.4
Switzerland	23,766	115.2	10,712	95.1
United Kingdom	9,018	34.8	20,061	35.1
Other	23,553	41.3	41,319	74.3
Total	1,497,960	1,913.9	1,631,762	2,044.5

[1]Customs value.
[2]Includes some natural advanced diamond.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF GEMSTONES, OTHER THAN DIAMOND, BY KIND AND COUNTRY

Kind and country	1991		1992	
	Quantity (carats)	Value[1] (millions)	Quantity (carats)	Value[1] (millions)
Emerald:				
Belgium	10,782	$1.6	4,381	$0.7
Brazil	1,554,717	6.7	125,548	4.5
Colombia	212,818	51.5	403,988	92.4
France	7,456	3.0	3,753	4.1
Germany	19,828	2.2	149,870	4.3
Hong Kong	114,521	13.4	232,025	19.2
India	1,298,384	22.7	1,208,678	16.5
Israel	134,178	21.3	116,586	21.4
Japan	2,946	0.7	125	0.2
South Africa, Republic of	206	0.3	962	0.1
Switzerland	66,283	23.3	164,283	39.6
Taiwan	414	0.1	3,452	0.3
Thailand	483,037	12.6	299,313	6.6
United Kingdom	8,755	0.9	1,957	1.2
Other	24,980	5.1	240,985	2.5
Total[3]	3,939,305	165.5	2,955,906	213.5
Ruby:				
Belgium	8,127	1.3	9,065	1.1
Brazil	11,517	0.5	6,793	0.3
Colombia	145	(2)	70	(2)
France	4,686	0.9	790	0.6
Germany	15,438	1.6	17,677	1.1
Hong Kong	38,030	4.4	99,817	3.8
India	455,938	1.9	375,745	1.7
Israel	10,736	0.8	12,094	1.5
Japan	647	0.1	3	(2)
Switzerland	72,979	16.5	36,221	23.3
Thailand	r1,715,520	37.3	2,008,030	39.1
United Kingdom	12,089	3.2	2,401	3.3
Other	32,128	2.4	66,233	2.1
Total[3]	r2,377,980	70.9	2,634,939	77.8
Sapphire:				
Australia	3,963	0.3	4,682	0.1
Austria	603	(2)	65	(2)
Belgium	5,044	1.3	6,744	0.7
Brazil	7,932	0.4	23,326	0.2
Canada	8,109	0.4	187,196	0.5
Colombia	111	(2)	82	0.1
France	4,695	1.3	597	1.4
Germany	21,882	0.8	49,194	1.3
Hong Kong	141,486	6.2	113,670	3.8
India	59,588	0.6	71,670	0.5
Israel	10,723	0.8	28,987	1.2
Japan	6,536	0.5	2,159	0.1
Korea, Republic of	1,980	(2)	NA	NA
Singapore	833	0.4	101	(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	1991		1992	
	Quantity (carats)	Value[1] (millions)	Quantity (carats)	Value[1] (millions)
Sapphire—Continued:				
Sri Lanka[4]	54,023	$3.9	85,218	$3.5
Switzerland[4]	21,096	16.2	27,608	13.6
Thailand	3,122,987	46.1	3,991,362	45.5
United Kingdom	15,895	1.4	4,210	1.2
Other	14,062	0.9	13,989	1.4
Total[3]	3,501,548	81.5	4,610,860	75.1
Other:				
Rough, uncut:				
Australia		1.1		2.1
Brazil		35.2		30.2
Colombia		1.4		4.4
Hong Kong		2.0		1.0
Nigeria	NA	0.2	NA	0.2
Pakistan		0.7		0.3
South Africa, Republic of		0.6		0.3
Switzerland		1.0		0.7
United Kingdom		1.2		0.1
Zambia		0.8		1.0
Other		11.8		13.1
Total	NA	56.0	NA	53.5
Cut, set and unset:				
Australia		3.2		3.8
Brazil		9.3		9.0
Canada		0.2		0.4
China		0.8		0.9
Germany		15.2		15.7
Hong Kong	NA	r16.6		17.2
India		7.4		6.9
Japan		r9.4		9.3
Switzerland		1.1		0.8
Taiwan		2.8		3.1
Thailand		72.3		47.5
United Kingdom		2.1		0.7
Other		r14.6		16.0
Total[3]	NA	r155.0	NA	131.4

rRevised. NA Not available.
[1]Customs value.
[2]Data may not add to totals shown because of independent rounding.
[3]Less than 1/10 unit.
[4]Erroneously omitted in 1991.

Source: Bureau of the Census.

TABLE 11
VALUE OF U.S. IMPORTS OF SYNTHETIC AND IMITATION GEMSTONES, INCLUDING PEARLS, BY COUNTRY

(Million dollars[1])

Country	1991	1992
Synthetic, cut but unset:		
Australia	0.5	1.9
Austria	3.4	6.3
France	1.9	1.4
Germany	r8.8	10.3
Hong Kong	1.6	2.9
Japan	.7	1.2
Korea, Republic of	4.9	4.2
Switzerland	2.8	4.6
Taiwan	.5	0.9
Thailand	16.0	23.2
Other	r1.8	1.4
Total	r42.9	58.2
Imitation:		
Austria	r58.6	69.8
Czechoslovakia	r4.0	7.0
Germany	1.8	2.8
Japan	1.5	2.3
Other	3.0	2.7
Total	r69.0	84.6

rRevised.
[1]Customs value.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 12
U.S. IMPORTS FOR CONSUMPTION OF GEMSTONES

(Thousand carats and thousand dollars)

Stones	1991		1992	
	Quantity	Value[1]	Quantity	Value[1]
Diamonds:				
Rough or uncut	1,783	527,424	1,628	495,003
Cut but unset	6,699	3,464,599	7,724	3,648,626
Emeralds: Cut but unset	3,939	165,508	2,956	213,497
Coral and similar materials, unworked	r2,554	r6,741	2,787	6,115
Rubies and sapphires: Cut but unset	5,880	r152,484	7,246	152,886
Pearls:				
Natural	NA	r4,645	NA	3,896
Cultured	NA	r16,812	NA	18,313
Imitation	NA	r2,492	NA	3,710
Other precious and semiprecious stones:				
Rough, uncut	338,300	43,825	408,236	41,446
Cut, set and unset	NA	r133,530	NA	109,233
Other	429	r5,435	281	5,957
Synthetic:				
Cut but unset	r148,203	r42,901	217,059	58,189
Other	NA	r2,099	NA	1,636
Imitation gemstone	NA	r66,507	NA	80,927
Total[2]	XX	r4,635,002	XX	4,839,43

rRevised. NA Not available. XX Not applicable.
[1]Customs value.
Source: Bureau of the Census.

TABLE 13

DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY[1]

(Thousand carats)

Country	1988				1989				1990			
	Natural			Synthetic[4]	Natural			Synthetic[4]	Natural			Synthetic[4]
	Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]	
Angola[e]	950	50	1,000	—	1,165	80	[5]1,245	—	[r]1,060	[r]73	[r]1,133	—
Australia	17,413	17,413	34,826	—	17,540	17,540	35,080	—	17,331	17,331	34,662	—
Botswana	10,660	[r]4,570	15,229	—	[r]10,680	[r]4,570	15,252	—	[r]12,150	[r]5,200	17,352	—
Brazil	[r]350	180	[r]530	—	350	150	500	—	600	900	1,500	—
Central African Republic	284	59	343	—	334	81	415	—	303	78	381	—
China[e]	200	800	1,000	15,000	200	800	1,000	15,000	200	800	1,000	15,000
Côte d'Ivoire[6]	8	3	11	—	9	3	12	—	9	3	12	—
Czechoslovakia[e]	—	—	—	5,000	—	—	—	5,000	—	—	—	5,000
France[e]	—	—	—	4,000	—	—	—	4,000	—	—	—	4,000
Gabon[e]	400	100	500	—	400	100	500	—	400	100	500	—
Ghana[7]	55	[r]465	[r]520	—	[r]124	[r]370	[r]494	—	[r]163	[r]487	[r]650	—
Greece[e]	—	—	—	1,000	—	—	—	1,000	—	—	—	1,000
Guinea[7]	136	10	146	—	[r]137	10	[r]147	—	[r]119	[r]8	[r]127	—
Guyana	1	3	4	—	3	5	8	—	[r]5	[r]13	[r]18	—
India	11	3	14	—	3	12	15	—	3	[r,e]15	[r]18	—
Indonesia[e]	7	22	29	—	7	25	32	—	7	23	30	—
Ireland[e]	—	—	—	60,000	—	—	—	60,000	—	—	—	60,000
Japan[e]	—	—	—	25,000	—	—	—	25,000	—	—	—	25,000
Liberia	67	100	167	—	62	93	155	—	40	60	[e]100	—
Namibia	[r]925	[r]50	[r]975	—	910	[r]20	[r]927	—	[r]750	[r]15	[r]763	—
Romania[e]	—	—	—	5,000	—	—	—	4,500	—	—	—	4,500
Russia[8 9]	—	—	—	—	—	—	—	—	—	—	—	—
Sierra Leone[6]	12	6	18	—	90	39	129	—	66	12	78	—
South Africa, Republic of:												
Finsch Mine	[r]1,320	[r]2,600	3,920	—	[r]1,600	[r]3,000	4,610	—	[r]1,480	[r]2,700	4,178	—
Premier Mine	[r]700	[r]1,540	2,239	—	[r]700	[r]1,520	2,215	—	[r]720	[r]1,600	2,328	—
Venetia Mine	—	—	—	—	—	—	—	—	20	40	62	—
Other De Beers' properties[10]	[r]1,400	[r]520	1,919	—	[r]1,350	[r]530	1,880	—	[r]1,200	[r]460	[r]1,652	—
Other	[r]380	[r]40	426	—	[r]350	[r]50	411	—	[r]380	[r]100	488	—
Total	3,800	4,700	8,504	[e]55,000	4,000	5,100	9,116	[e]60,000	[r]3,800	[r]4,900	8,708	[e]60,000
Swaziland	44	29	73	—	33	22	55	—	25	17	42	—
Sweden[e]	—	—	—	25,000	—	—	—	25,000	—	—	—	25,000
Tanzania	[r]105	[r]45	[r]150	—	[r]105	[r]45	[r,e]150	—	[r]60	[r]25	85	—
U.S.S.R.[e 9 11]	[r]11,000	[r]11,000	[r]22,000	41,500	[r]11,500	[r]11,500	[r]23,000	41,500	[r]12,000	[r]12,000	[r]24,000	41,000
United States	—	—	—	W	—	—	—	W	—	—	—	W
Venezuela	54	[r]75	[r]129	—	70	185	255	—	88	245	333	—
Yugoslavia[e 12]	—	—	—	5,000	—	—	—	5,000	—	—	—	5,000
Zaire	2,724	15,439	18,163	—	2,663	15,092	17,755	—	2,914	16,513	19,427	—
Total	[r]49,206	[r]55,122	[r]104,331	241,500	[r]50,385	[r]55,842	[r]106,242	246,000	[r]52,093	[r]58,818	[r]110,919	245,500

See footnotes at end of table.

TABLE 13—Continued

DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY[1]

(Thousand carats)

Country	1991				1992e			
	Narural			Syn-thetic[4]	Natural			Syn-thetic[4]
	Gem[2]	Indus-trial	Total[3]		Gem[2]	Indus-trial	Total[3]	
Angolae	r899	r62	r e961	—	935	65	1,000	—
Australia	17,978	17,978	35,956	—	21,000	21,000	42,000	—
Botswana	r11,550	r4,950	r16,506	—	10,000	5,000	15,000	—
Brazil	600	900	e1,500	—	600	900	1,500	—
Central African Republic	r296	r82	r379	—	296	82	378	—
Chinae	200	800	1,000	15,000	200	800	1,000	15,000
Côte d'Ivoire[6]	11	4	15	—	11	4	15	—
Czechoslovakiae	—	—	—	5,000	—	—	—	5,000
Francee	—	—	—	e4,000	—	—	—	4,000
Gabone	400	100	500	—	400	100	500	—
Ghana[7]	r175	r525	e700	—	175	525	700	—
Greecee	—	—	—	1,000	—	—	—	750
Guinea[e 7]	r91	6	r97	—	90	5	95	—
Guyana	r7	r38	r e45	—	8	42	50	—
India	3	r15	r18	—	3	15	18	—
Indonesiae	8	24	32	—	6	21	27	—
Irelande	—	—	—	60,000	—	—	—	60,000
Japane	—	—	—	30,000	—	—	—	30,000
Liberia	40	60	e100	—	60	90	150	—
Namibia	1,170	r20	r1,187	—	1,500	50	r1,549	—
Romaniae	—	—	—	4,500	—	—	—	4,000
Russia[8 9]	—	—	—	—	9,000	9,000	18,000	60,000
Sierra Leone[6]	r160	r83	243	—	165	85	250	—
South Africa, Republic of:								
Finsch Mine	r1,200	r2,280	r3,483	—	1,200	2,250	r3,446	—
Premier Mine	700	r1,550	r2,250	—	740	1,700	r2,444	—
Venetia Mine	100	200	303	—	660	1,200	r1,868	—
Other De Beers' properties[10]	r1,500	r400	r1,897	—	1,350	500	r1,849	—
Other	400	r100	r498	—	450	100	r549	—
Total	r3,900	r4,530	r8,431	e60,000	4,400	5,750	10,156	60,000

See footnotes at end of table.

TABLE 13—Continued

DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY[1]

(Thousand carats)

Country	1990				1991[e]			
	Narural			Syn-thetic[4]	Natural			Syn-thetic[4]
	Gem[2]	Indus-trial	Total[3]		Gem[2]	Indus-trial	Total[3]	
Swaziland	r34	r23	r57	—	36	24	60	—
Sweden[e]	—	—	—	25,000	—	—	—	25,000
Tanzania	r70	r30	r100	—	70	30	100	—
U.S.S.R.[e 9 10]	r10,000	r10,000	r20,000	60,000	—	—	—	—
United States	—	—	—	90,000	—	—	—	90,000
Venezuela	r102	r112	r214	—	108	115	223	—
Yugoslavia[e 12]	—	—	—	5,000	—	—	—	5,000
Zaire	3,000	r14,814	r17,814	—	3,000	12,000	15,000	—
Total	r50,694	r55,156	r105,855	359,500	52,063	55,703	107,771	358,750

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.

[1]Table includes data available through May 25, 1993. Total natural 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 Brazil (1988-90), and Central African Republic (1988-90), 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.

[2]Includes near-gem and cheap-gem qualities.

[3]Natural gem and industrial data may not add to totals shown because of independant rounding.

[4]Includes all synthetic diamond production.

[5]Reported figure.

[6]Figures are estimates based on reported exports and do not include smuggled diamonds.

[7]Figures do not include smuggled artisanal production.

[8]Formerly part of the U.S.S.R..

[9]All production in the U.S.S.R. from 1988-91 came from Russia.

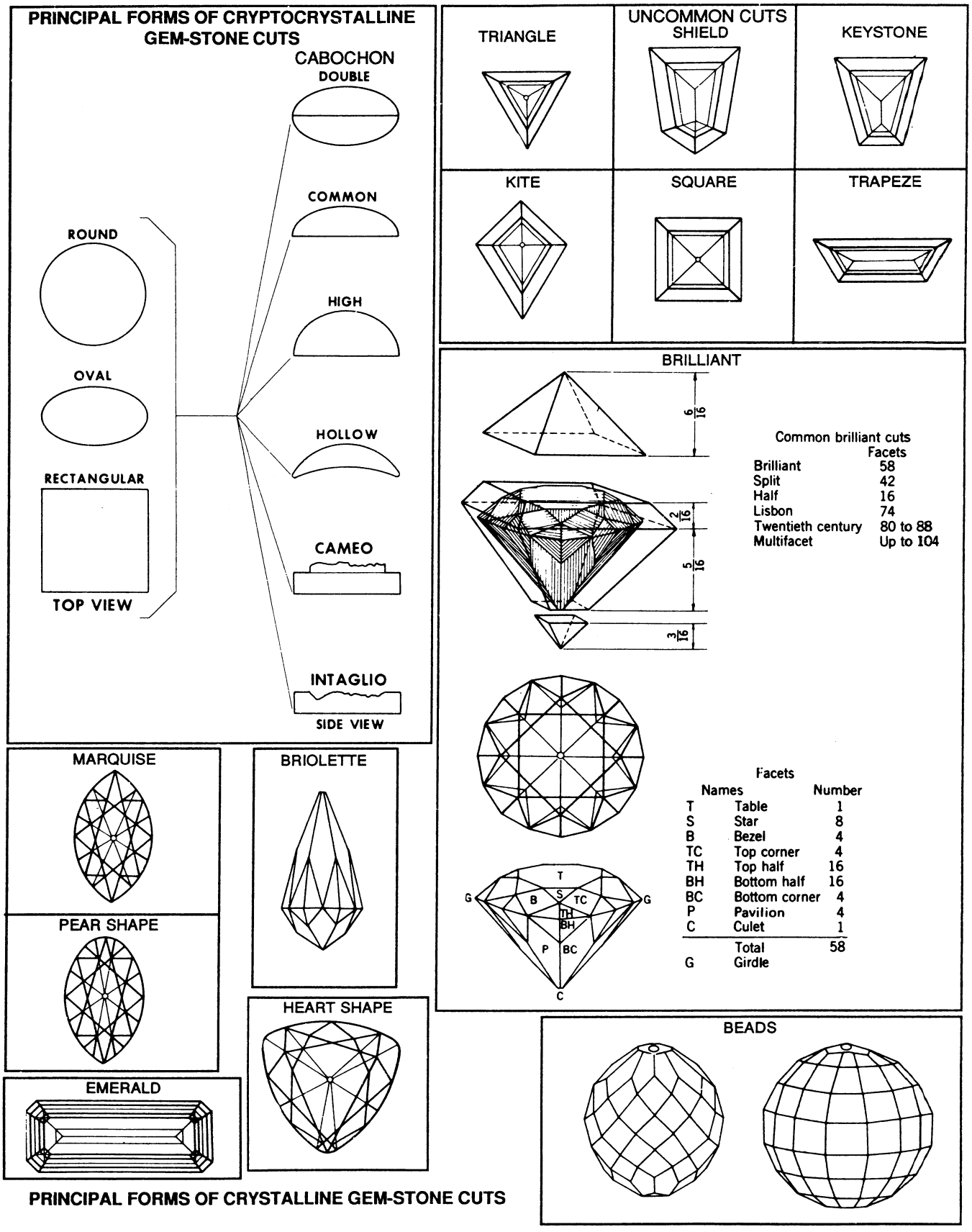
[10]Other De Beers' Group output from the Republic of South Africa includes Kimberley Pool, Koffiefontein Mine, and Namaqualand mines.

[11]Dissolved in Dec. 1991.

[12]Dissolved in Apr. 1992; however, information is inadequate to formulate reliable estimates of individual country production.

FIGURE 1

PRINCIPAL FORMS OF CRYPTOCRYSTALLINE AND CRYSTALLINE GEMSTONE CUTS



PRINCIPAL FORMS OF CRYSTALLINE GEM-STONE 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, lead statistical assistant.

The estimated domestic refinery production and consumption of germanium in 1992 were about 13% and 12%, respectively, below the levels of 1991. 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.

Definitions, 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.

Under the 1992 Annual Material Plan, Public Law 102-484 of October 23, 1992, the Department of Defense was authorized to sell about 713 kilograms of germanium. However, no inventory acquisitions or sales were made during the year, and, as of December 31, 1992, 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 13,000 kilograms, a decrease of about 13% compared with that of 1991. Germanium producers were forced to scale down their output to meet falling demand for the metal by the Department of Defense.

Consumption and Uses

The U.S. Bureau of Mines estimated that consumption of germanium decreased about 12% compared with the level of 1991 as a result of decreasing demand for the metal. The estimated consumption pattern by end use of germanium in 1992 was as follows: infrared systems, 42%; fiber optics, 34%; gamma-ray, X-ray, and infrared detectors, 10%; semiconductors (including transistors, diodes, and rectifiers), 8%; and other applications (catalysts, phosphors, metallurgy, and chemotherapy), 6%.

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.

Martin Marietta Corp., Bethesda, MD, received a contract to provide an advanced infrared search and track (IRST) system to the Air Force by 1997. The IRST system detects and tracks aircraft through an advanced technology that senses the contrast between infrared energy from warm targets and their relatively cooler background. This technology enables the pilot to search for aircraft without having to radiate energy that could reveal the pilot's presence. The value of the contract was expected to be about $50 million.[4]

Markets and Prices

Throughout 1992, 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 1992 because of competition from imported materials.

Free market prices, published by Metal Bulletin (London), remained at a low range of $340 to $350 per kilogram throughout 1992. Prices are likely to remain low for the near future owing to a continuing global oversupply of germanium materials together with low market demand.

Plenty of germanium products were available on the market, and the world's oversupply was further aggravated by Russia'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 $870 per kilogram.[5]

Foreign Trade

In 1992, the estimated germanium content of imports was approximately 12,600 kilograms. Total imports of germanium materials decreased dramatically compared with those of 1991. Germany, China, Spain, the United Kingdom, Russia, and Belgium, in descending order of shipments, accounted for approximately 85% of the total U.S. germanium imports for 1992. *(See table 2.)*

World Review

World refinery production was estimated at 65,000 kilograms, a decrease of about 19% compared with the 1991 level. The decline in world production was attributed to an oversupply and to a lower level of demand for the metal.

Capacity.—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. The total world germanium refinery capacity for 1992 was estimated at 270 metric tons.

Canada.—Cominco Ltd. restarted its germanium refinery plant at Trail, British Columbia, which was closed since December 31, 1990. The refinery produced germanium dioxide from Cominco's own feedstock material.

Germany.—Deutsche Bundespost Telekom, the state-owned network operator, will connect about 1.2 million homes and businesses in Germany to its current fiber-optic network by 1995. This photonic system will provide a wide range of services to the home and/or office, including high-definition television, multimedia computers, and videotelephony. The German officials expect that such a mass deployment of fiber in the local network will stimulate the production of fiber-optic products.[6]

Japan.—Germanium metal production was estimated at 2,700 kilograms, a decrease of about 21% compared with 1991 metal production levels.

Current Research

The U.S. Bureau of Mines investigated the recovery of gallium and germanium from a Tennessee zinc residue and a Utah ore. Leaching and solvent extraction techniques were studied that yielded about 95% gallium extraction and about 73% germanium extraction when the zinc residue sample was tested. Research results showed that about 96% of the gallium and 85% of the germanium content in the ore sample were extracted, using a two-stage countercurrent sulfuric acid leach circuit.[7]

OUTLOOK

In 1992, for the fourth consecutive year, the supply of germanium exceeded the demand for this specialty metal. Germanium supplies are likely to remain high for the next 4 years owing to a global increase in the availability of germanium products in the market. Producers for the third consecutive year were forced to lower prices to maintain their share of the market.

Market analysts agree that all primary germanium producers will probably continue facing difficult times in the near future. This assessment is based on a global oversupply of germanium materials together with a low market demand for the metal due to U.S. defense cutbacks and a world economic recession.

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[1]Weber, J. N. Geochemistry of Germanium. Dowden, Hutchison & Rose Inc., Stroudsburg, PA, 1973, pp. 1-5.

[2]Adams, J. H. Germanium Compounds. Ch. in Encyclopedia of Chemical Technology. Kirk-Othmer, 3d ed., v. 11, 1983, pp. 791-802.

[3]Battelle 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.

[4]Martin Marietta To Deliver Advanced Sensor System for Potential Use on Air Force F-22. Martin Marietta Corp. Press Release, Bethesda, MA, Sept. 21, 1992.

[5]Where necessary, values have been converted from Belgian francs (BF) to U.S. dollars at the average exchange rate of BF34.1=US$1.00.

[6]Photonics Spectra. Germany Announces Mass Fiber Project. V. 26, No. 1, Jan. 1992, pp. 34-36.

[7]Harbuck, D. D. Gallium and Germanium Recovery From Domestic Sources. BuMines RI 9419, 1992, 26 pp.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Germanium. Ch. in Mineral Commodity Summaries, annual.
Germanium. Ch. in Mineral Facts & Problems, 1985 ed.

Other Sources

American Metal Market.
Chemical Abstracts.
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, 1992	Jan. 1, 1992
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 COUNTRY[1]

Country	1991		1992	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Belgium	6,921	$6,877,552	807	$1,673,053
Canada	1,542	390,017	1	3,213
China	504	151,035	2,750	785,047
Denmark	630	25,598	—	—
France	2,449	834,227	—	—
Germany	2,837	1,000,977	3,172	909,387
Hong Kong	2,174	523,160	678	279,582
Israel	81	105,089	94	55,652
Italy	201	48,296	—	—
Japan	17	23,920	24	7,080
Netherlands	908	88,953	80	21,767
Russia[2]	—	—	1,297	153,427
Singapore	43	7,628	—	—
Spain	500	76,035	1,730	222,017
Switzerland	—	—	175	28,984
Ukraine	—	—	566	90,000
U.S.S.R.[3]	375	86,278	400	146,000
United Kingdom	7,652	1,760,000	1,455	495,712
Total	26,834	11,998,765	13,229	4,870,921

[1]Unwrought and waste and scrap.
[2]Formerly part of the U.S.S.R.; data were not reported separately until 1992.
[3]As constituted before Dec. 31, 1991.

Source: Bureau of the Census.

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 Australia, Brazil, and Canada. Domestic survey data were prepared by Dwayne E. Penn, and Lisa P. Conley, statistical assistants. 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, communications 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 1992. The U.S. gold mining industry produced 329,124 kilograms (kg) (10,581,581 troy ounces[1]) of gold, an increase of 11% over production in the previous year. The State of Nevada was once again the Nation's dominant gold-producing State. Since the breakup of the former U.S.S.R., the United States has become the world's second largest gold-producing nation after the Republic of South Africa. For the fourth 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 (USBM), in an effort to provide statistical data on gold that are consistent with international usage, reports gold data in kilograms (kg) and metric tons unless otherwise noted.

DOMESTIC DATA COVERAGE

Domestic mine production data for gold are developed by the USBM 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, 212 responded, representing 97% 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 two decades.

Cumulative world production to date is

estimated at about 112,000 metric tons (3.6 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 11,900 tons (383 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" also may 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 gold, silver, and copper, often with additions of zinc and sometimes a little nickel. White karat golds are usually composed of gold, copper, nickel, and zinc, although platinum and palladium also have 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. In 1991 the LBMA and the Bank of England successfully argued before the European Commission to retain the troy system of measurement for use in the gold and other precious-metals markets. 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 (10.9 to 13.4 kg) of gold with a minimum fineness of 995. The bar must bear the stamp of 1 of the world's 49 approved melters 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. Its melting point is 1,063 °C, and its specific gravity is 19.3. 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 23 square meters (250 square feet) of gold leaf about one-tenth of a micrometer (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, 0.028 cubic meter (1 cubic foot) of pure metallic gold weighs a little more than 544 kg (1,200 pounds); 16.4 cubic centimeters (1 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 also may be encountered. On the Indian subcontinent, for example, the weight of gold may be expressed in terms of tolas; 1 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 also 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 recent years in the United States about 90% of domestic gold production has been derived 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. Ten mines accounted for about 50% of domestic output in 1992; 82% came from mines in California, Montana, Nevada, and South Dakota. The leading producer in most recent years, Newmont Gold Co., provided about 15% 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.

An economic study published by the Nevada Bureau of Mines and Geology at

the University of Nevada,[2] in addressing the issue of foreign ownership of the U.S. precious metals industry, found that almost 60% of U.S. production is owned by American investors or institutions. Canadian and United Kingdom shareholders accounted for about 16% each while the remainder was held by Japanese, European, and other investors. The study also found that the vast majority of domestic ore reserves are largely U.S. owned and controlled.

The South African gold mining industry, accounting for about 27% of current world output, consists of about three 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 the southern Yakutia-Sakha Republic of Russia 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 1.3 grams per metric ton (0.04 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 the average 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 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. 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 causes 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 4.6 cubic meters (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 of about $380 per ounce, the gold recovered by two persons laboring all day would have an approximate value of $23, 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, 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 is intended eventually to be mined to 4,500 meters (14,800 feet).[3]

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 1992, U.S. Treasury stocks stood at 8,144 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 an 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 also would 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 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 ton (0.006 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, which determines 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 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 USBM 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 a 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 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 Issues.—The costs associated with meeting 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 by evaporation. Several 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. 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, increased from about 7,000 in 1985 to more than 16,000 in 1990. Employment at gold mines and mills declined to about 15,000 in 1992. 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,[4] 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 1979-90[5] 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 May 13, the President signed legislation authorizing the minting of 10.4 million special coins to commemorate the 500th anniversary of the discovery of America by Christopher Columbus. The legislation, Public Law 102-281, known as the Christopher Columbus Quincentenary Coin Act, called for the minting of up to 500,000 $5 gold coins weighing 8.359 grams (0.268 troy ounce) each, up to 4 million $1 silver coins weighing 26.73 grams (0.859 troy ounce) each, and up to 6 million half-dollar clad coins. Surcharges included in the price of each coin are paid to the Christopher Columbus Fellowship Fund to establish and endow the Christopher Columbus Fellowship Foundation. The foundation is authorized to award 2-year fellowships to outstanding individuals to encourage new discoveries in all fields of endeavor for the benefit of humankind.

Public Law 102-414, approved by the President on October 14, authorized the minting of up to 300,000 $5 gold coins, 1.0 million silver coins, and 2.0 million half-dollar clad coins to commemorate the 50th anniversary of the involvement of the United States in World War II. As specified by the law, the gold coin is emblematic of the Allied victory and the silver coin is emblematic of the Battle of Normandy. Surcharges included on the price of each coin will be paid to the American Battle Monuments Commission to help fund a memorial in Washington, DC, to honor members of the Armed Forces of the United States who served in World War II and to the Battle of Normandy Foundation to create a U.S. D-Day and Battle of Normandy Memorial in Normandy, France. The metal content of the coins is the same as that specified for the Columbus coins.

Strategic Considerations

Gold is not a National Defense Stockpile item; however, the Treasury had stocks of bullion amounting to about 8,144 tons (262 million ounces) at yearend 1992. Large quantities of gold were also held as commercial and private bullion stocks. Therefore, the availability of gold in a time 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 when time becomes a critical factor, 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 also may 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.

Another issue of concern to the mining industry as well as law enforcement authorities has been the growth in recent years in telemarketing fraud and investment swindles involving sales of gold bullion and investment in questionable mining ventures. The seriousness of the problem prompted the North American Securities Administrators Association Inc. (NASAA) and the Council of Better Business Bureaus Inc. to issue, in late 1988, an Investor Alert entitled "Dirt Pile Gold Swindles." The alert was to educate the public regarding the organization, characteristics, and pitfalls of the class "dirt pile" or "gold-in-the-ground" swindles. 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 fake collector coins.

Production

Of the 329 tons of gold (10.6 million ounces) produced in the Nation in 1992, 71% was attributable to the 25 leading producers. The average recoverable gold content of gold ores processed from lode mines was 1.27 grams per ton (0.037 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.—Gold production in Alaska increased for the third consecutive year, according to a summary of 1992 mineral activity prepared by the Alaska State Division of Geology and Geophysical Surveys (DGGS).[6] Gold production of about 5,000 kg (160,850 ounces) was reported to the USBM. However, an annual survey conducted informally by the DGGS suggests that a total of about 8,163 kg (262,500 ounces) of both lode and placer gold was produced; the comparable total for the previous year was 7,585 kg (243,900 ounces). Owing to the year's lower gold price, the value of the 1992 production was only slightly greater than that of the previous year but 1% less than the value of gold produced during 1990. Gold production during 1992 was derived from 2 lode mines and

197 placer mines. Two lode mines and 202 placer mines produced gold during the previous year. According to the DGGS, a late spring thaw and the early onset of winter in Alaska's interior region during 1992 caused many placer mining operations to lose up to 25% of their seasonal annual production. A comparison of individual unit-cost data reported to the State showed a 10% to 25% improvement during 1992 when compared with those of the previous year. This comparison suggests that 1992 witnessed an improvement in overall placer mine productivity.

Greens Creek Mining Co.'s Greens Creek Mine, on Admiralty Island near Juneau, was the State's largest gold-producing lode mine. During 1992 the mine produced 103,241 tons (113,827 short tons) of sulfide concentrates bearing the principal values of zinc, lead, and silver plus 1,008 kg (32,400 ounces) of gold. In February 1993, as a result of continued depressed metal prices, the decision was made to curtail operations at Greens Creek. All operating and environmental permits will be maintained in anticipation of a resumption of operations once economic conditions improve.

Alaska's largest placer gold producer during 1992 was the Valdez Creek Placer Mine near Cantwell. The mine, owned by Cambior USA, Inc. (75%) and Camindex Resources Inc. (25%), produced about 2,672 kg (85,924 ounces) of gold during the year. This was twice the amount recovered during 1991 when work to temporarily divert Valdez Creek was finally completed. Production at the mine during 1992 as measured by the average daily gravel extraction rate reportedly improved 56% from that of 1991 to 25,740 cubic meters (33,670 cubic yards) per day.

Alaska Gold Co. continued to operate its two Yuba class bucketline stacker dredges on its property in the Nome area. In an attempt to overcome costs and problems association with the current mining process of stripping, thawing, and dredging, the company initiated a pilot project during the 1992 winter season aimed at excavating frozen payable gravel, which is then stored in the wash plant area to be thawed naturally then processed during the 1993 summer season. During the year the company commenced a small-scale exploration project to define areas on its Nome holdings that might be suitable for open pit mining of frozen gold-bearing gravel. The company also operates a dredge at its properties along the Hogatza River. Large placer mining operations were also active near Circle, Fairbanks, Livengood, Ruby, and elsewhere.

Several large gold mines continued to be developed during 1992. In southeastern Alaska, Echo Bay Mines Ltd. continued its involvement in developing the Alaska Juneau (AJ) Mine, immediately behind the capital city of Juneau, and its Kensington joint-venture project, 115 km (72 miles) north of Juneau. Work at the wholly owned AJ Mine during the year focused on increasing the reserve base and completing a new feasibility study aimed at redesigning the planned underground mine and mill to accommodate a capacity of up to 27,200 tons (30,000 short tons) per day. The increased capacity would increase the expected yield to 14 tons (450,000 ounces) of gold per year. Echo Bay also owns the old Treadwell Mine on Douglas Island, across the Gastineau Channel from Juneau. The AJ, Treadwell, and Kensington are all former gold-producing mines.

Twenty-four km (15 miles) northeast of Fairbanks, Fairbanks Gold Ltd., an operating subsiding of Amax Gold Inc., continued engineering, permitting, and design work aimed at developing its Fort Knox Project into a large open pit gold mine. The project, located on 11,300 hectares (28,000 acres) of mostly State land with some private, is projected by the company to begin producing gold at a rate of 9,300 to 11,000 kg (300,000 to 350,000 ounces) per year by late 1995. In the Ester Dome area near Fairbanks, LaTeko Resources Ltd. and its wholly owned subsidiary, Citigold Alaska Inc., continued their evaluation of the Ryan Lode property. Mine design work, metallurgical testing, and delineation of ore reserves at the former gold producer were continuing at yearend. Exploration also was conducted at Ester Dome by several other companies, including American Copper and Nickel, Inc.

Late in 1992, the Alaska Department of Natural Resources began to select its final 8 million hectares (20 million acres) of land from the Federal Government as part of the 1959 Alaska Statehood Act. When Alaska became a State it was awarded 42.6 million hectares (105 million acres) of land; in 1991 and 1992, the State government diligently researched natural resource values to make its final decision by the January 1994 deadline. The USBM provided a computerized Mineral Availability System (MAS) data file and claim status information to the DGGS, the lead State agency determining mineral and energy potential data for the project. In December 1992, initial land nominations were transmitted to the Bureau of Land Management. These nominations included 14 million hectares (35 million acres) selected for high mineral and energy potential. Individuals and companies holding Federal claims and wanting to convert to State ownership were being urged to do so by the DGGS before the 1994 deadline.

Arizona.—Arizona's largest gold mine was Cyprus Gold Co's. Copperstone Mine near Quartzite in LaPaz County. Operated by Cyprus Copperstone Gold Corp., this open pit, milling, and heap-leaching operation, opened in 1987, is on approximately 15 square km (9 square miles) of unpatented lode mining claims held by Cyprus under a long-term lease. During 1992, Copperstone processed ore at capacity and produced 3,614 kg (116,200 ounces) of gold. Economic ore reserves at the mine were depleted in December 1992, and mining ceased. The processing plant will continue in operation through about April 1993 processing mostly low-grade ore previously mined and stockpiled adjacent to the plant. Reclamation of the mine area in conformance with Federal and State permits was under way near yearend.

Gold production continued through the

summer at the Mystic gold mine, in Maricopa County, about 19 km (12 miles) north of Sun City. Fischer-Watt Gold Co., which holds a 100% operating interest in the property, ceased mining operations in the fall and placed the mine on standby status at yearend. Near Wickenburg, in Maricopa County, Pima Mining Co. filed an environmental assessment for its proposed Newsboy Mine. Pima, previously known as Wounded Bull Resources NL, has faced intense local opposition to the proposed open pit and milling operation, designed to produce about 840 kg (27,000 ounces) of gold annually.

In response to weak gold prices, mining operations at the underground Congress Mine in Yavapai County were discontinued in April. The mine's owner, Republic Goldfields Inc., formerly Mylartic Hygrade U.S. Inc., continued to operate the mill through September, processing stockpiled and custom ore at the millsite. Also in Yavapai County, mining continued at the McCabe Mine near Prescott by Magma Gold Ltd., a subsidiary of Magma Copper Co. Mining operations were discontinued in early 1993 owing to unsatisfactory ore grades. A substantial portion of Arizona gold production is also derived as a byproduct of copper mining.

A number of locations, mostly former gold-producing sites, continued to be explored for gold during the year. Properties under study included the Harquahala gold project of Manhattan Minerals Corp. in LaPaz County; Addwest Minerals Inc.'s Gold Road Mine near Oatman in Mohave County; Cambior Inc.'s Gold Basin property 80 km (50 miles) northeast of Kingman; and VLS Minerals Inc.'s Wilson placer project in the La Cholla placer district south of Quartzite, in LaPaz County.

California.—For the sixth consecutive year California was the Nation's second largest gold-producing State.

California's largest gold mine, Homestake's McLaughlin Mine, near Lower Lake, about 113 km (70 miles) north of San Francisco, produced 9,053 kg (291,094 ounces) or 11% more gold than in the previous year. McLaughlin was the site of the first successful commercial application of the autoclave-process technology for the extraction of gold. This large surface mine has produced 54.4 tons (1.75 million ounces) of gold since operations began in 1985. The mine's new flotation circuit, used to treat lower grade refractory ores, was commissioned in late 1991 and became fully operational in 1992. During the year the mine received national recognition from the Wildlife Habitat Enhancement Council for its voluntary wildlife enhancement and conservation efforts.

The State's second largest gold mine was the Mesquite Mine of Gold Fields Operating Co., near Brawley in the Chocolate Mountains of east-central Imperial County. Mesquite began open pit mining and heap leaching at the site in early 1986. To the east in Imperial County, Glamis Gold Ltd., through its subsidiary Chemgold Inc., continued open pit and heap-leaching operations at its Picacho Mine. During 1992, the company completed construction on its No. 5 heap-leaching pad and by November, more than 360,000 tons of ore grading 0.92 gram per ton (0.027 ounce per short ton) had been placed on the pad for leaching. Nearby, Glamis and a partner, Arizona Star Resources Corp., continued exploration on their Indian Rose and Octotillo projects. Glamis' Alto Mine, depleted and closed in 1991, yielded a small quantity of residual gold and, before yearend 1992, neutralization of the heaps, site reclamation, and revegetation of the mine area had been completed. Mining continued at the company's open pit and heap-leaching Yellow Aster Mine near Randsburg in Kern County where the operator, Rand Mining Co., a wholly owned subsidiary of Glamis, began construction at its nearby Baltic Mine project. Baltic is slated to begin production in late 1993 at a rate of about 1,200 kg (40,000 ounces) of gold per year. Also in Kern County, Cactus Gold Mines Co. completed open pit mining at the Cactus Mine in early 1992; heap-leaching production is expected to continue through mid-1994.

In February, following a 4-year hiatus for permitting, Viceroy Gold Corp. poured its first gold at its new Castle Mountain gold project in San Bernardino County. The new facility, an open pit and heap-leaching operation 150 km (65 miles) south of Las Vegas, NV, is expected to produce about 3,100 kg (100,000 ounces) of gold annually during the first 5 years of operation. Leaching solutions are applied to the heaps via drip irrigation. Pipes buried in the heap direct the resultant pregnant solution to closed solution storage tanks designed to provide both wildlife protection and water conservation. Under an agreement with the Nature Conservancy, Viceroy established a 24,000-hectare (60,000-acre) desert tortoise preserve at the adjoining Walking Box Ranch. Lac Minerals Ltd.'s Colosseum Mine, in San Bernardino County, ceased mining activity in 1992. Leaching of stockpiled ore will continue into 1993.

In California's Sierra Nevada/Mother Lode Country, gold mining continued at Sonora Mining Corp.'s Jamestown Mine in Tuolumne County and FMC Gold's wholly owned Royal Mountain King Mine near Copperopolis, Calaveras County, where production at the FMC project rose to more than 2,200 kg (71,000 ounces) in 1992. In June, Brush Creek Mining and Development Co. Inc. officially opened its Ruby Mine. The newly reopened mine, an underground placer, is in Sierra County. Before its closure in 1942 by War Production Board Order L-208, the Ruby Mine had produced more than 5,600 kg (180,000 ounces) of gold. According to the company, the Ruby's coarse gold nuggets are sought after by fabricators of gold nugget jewelry and specimen collectors.

Also in Sierra County, operators of the Original Sixteen to One Mine near Allegheny conducted an unusual experiment that proved successful, according to newspaper accounts and company reports. In early 1992, the operators of the mine began using metal detectors as an underground gold locator tool. Early skepticism by the mine's management disappeared when, after 6

months of experimentation, more than $1 million worth of gold had been detected and recovered. Before the experiment, the mine was having financial difficulty and the company's liquidity was significantly impaired, but the use of metal detectors made a big difference. In one 12-day period, miners reportedly detected and recovered 12 kg (400 troy ounces) of gold. Not surprisingly, the company used some of its new revenue to purchase eight additional detectors. The Original Sixteen to One Mine, developed in an unusually high-grade deposit and first opened in 1911, has reportedly produced more than 31.1 tons (1 million troy ounces) from ore with an average content exceeding 31 grams (1 troy ounce) of gold per ton.

In mid-June, Lassen Gold Mining Inc., a subsidiary of Amax Gold Inc., poured its first bar of production gold at its new Hayden Hill Mine, northwest of Susanville in Lassen County. The new open pit project employs both milling and heap-leaching recovery methods. The mine produced about 900 kg (28,815 ounces) during 1992 and is expected to yield more than 3,400 kg (110,000 ounces) in 1993.

Colorado.—Gold mining and exploration developments in Colorado during 1992 were summarized in a paper prepared by the Colorado Geological Survey (CGS).[7]

Gold production was reported by six Colorado operations during the year. The State's two major gold-producing mines were the San Luis Mine of Battle Mountain Gold Co. (BMG) and the operations of the Pikes Peak Mining Co. joint venture at Cripple Creek.

At the new San Luis Mine, near the town of San Luis, in Costilla County, production during the mine's first full year of production amounted to 1,710 kg (55,000 ounces), or 20% below company expectations. An operating problem with elevated cyanide levels in the tailings pond necessitated intermittent shutdowns until midyear, when the problem was finally resolved. BMG expects the San Luis, also known as El Plomo, to yield about 2,180 kg (70,000 ounces) in 1993.

At Cripple Creek, in Teller County, the Cripple Creek and Victor Gold Mining Co., a joint venture of Pikes Peak, a wholly owned NERCO Inc. subsidiary, and Golden Cycle Gold Co., produced 1,320 kg (42,451 ounces) of gold in 1992, establishing a new record but falling short of a 1992 goal of about 2,020 kg (65,000 ounces) projected earlier. The partner's Mine Dump program exceeded the goal of 311 kg (10,000 ounces), and mining, crushing, and heap leaching of ore from the Globe Hill and Ironclad open pits continued. However, the discovery of a solution leak in April necessarily delayed operations while repairs were made. The fluids were reportedly almost completely contained on the pads, but action was taken to neutralize any fluids that might have escaped. The partners began permitting at their Cresson deposit in midyear; construction was scheduled for 1993 with initial gold production planned for 1994. Extensive exploration also was continued on lands held in the vicinity of Cripple Creek.

Spraying of the heaps at Colorado's largest heap-leaching mine, the Summitville Mine, near Del Norte in Rio Grande County, ceased in March and reclamation work was begun by the operator, Summitville Consolidated Mining Co., a subsidiary of Glamis Resources Ltd. About 9,330 kg (300,000 ounces) of gold was recovered during the 5 years of mine life. Reportedly, environmental problems and a failure in the mine's basic design led to substantial losses for the company, which filed for bankruptcy in December. The U.S. Environmental Protection Agency was expected to manage the cleanup efforts at the site.

Other gold producers in Colorado during the year included ASARCO Incorporated Black Cloud Mine at Leadville in Lake County and Franklin Consolidated Mining Co. Inc.'s Franklin Mine near Idaho Springs in Clear Creek County. Near Central City in Gilpin County, Solution Gold Ltd. recovered gold by reprocessing old mine tailings in the Central City mining district. Exploration for new gold deposits and of known gold deposits was conducted at a number of sites throughout the State during the year.

Idaho.—Gold production in Idaho declined 5% from production achieved during the previous year. Idaho's largest gold mine, Pegasus Gold's Black Pine Mine in Cassia County, poured its first gold bar in January and proceeded to fulfill its first full year of production with a yield of about 1,500 kg (48,700 ounces) of gold and 460 kg (14,900 ounces) of silver. Ore mined from the new mine's Tallman and B pits is placed directly without crushing on the mine's unusual five-celled, valley fill leach pad, which also incorporates a countercurrent leachate system. Pegasus has outlined three separate deposits at the Black Pine operation, which is near Bridge, 95 km (60 miles) southeast of Burley.

The State's second largest gold mine is NERCO's open pit DeLamar Mine, in Owyhee County, where about 1,180 kg (38,000 ounces) of gold and 57 tons (1.8 million ounces) of silver were recovered during 1992. During the year, NERCO started up its new $7 million acidification, volatilization, and reabsorption (AVR) plant to recycle cyanide used at the DeLamar site. The company also moved ahead with permitting for its Stone Cabin property 8 km (5 miles) from DeLamar. Permitting efforts, however, were reportedly slowed by wetland issues and changes in corporate priorities.

In Butte County, Idaho Gold Corp., an 85%-owned subsidiary of Bema Gold Corp., completed mining in early 1992 at its Champagne Mine, 32 km (20 miles) east of Arco. Gold and silver production through secondary and tertiary retreatment of the heaps will continue into 1993, and a heap neutralization program will begin during the first half of that year. Bema also has four gold deposits under evaluation and review in the Elk City area of Idaho County.

In Valley County, seasonal mining and heap-leaching operations were resumed at MinVen Gold Corp.'s Stibnite Mine near Yellow Pine. Production during the year was about 20% greater than that of 1991.

Also near Yellow Pine, at Hecla's Yellow Pine Unit, the company poured its final ounce of gold at the recently depleted facility where open pit mining and heap-leaching operations began in 1988. A unique reclamation and neutralization process that uses naturally occurring, nonpathogenic bacteria has been employed to neutralize the spent ore on the Yellow Pine leach heaps. During 1992, the Unit received the Pacific Northwest Pollution Control Association's Industrial Pollution Control Award for Idaho for innovative strides toward water quality improvement. Hecla and Barrick Gold Exploration Inc. signed a letter of intent to explore and develop the refractory sulfide deposit remaining on the property. However, Barrick withdrew from the agreement at the end of the year. Also in Valley County, Coeur d'Alene Mines Corp.'s closed Thunder Mountain Mine gained national recognition for voluntary wildlife enhancement and conservation efforts. Coeur-Thunder Mountain Inc. was 1 of only 21 companies nationally to be awarded a "highest habitat" certification under the corporate wildlife habitat program of the Wildlife Habitat Enhancement Council. The Thunder Mountain Mine had ceased operation in 1990 following exhaustion of the known ore reserves.

Atlanta Gold Corp. continued drilling and evaluating its surface and underground reserves at the Atlanta property in Elmore County. Forty-eight km (30 miles) southwest of Challis in Custer County, Hecla's Grouse Creek Mining Corp. conducted a major drilling project on land held around the Grouse Creek project. In early 1993, the company announced the discovery of a deeper, higher grade ore zone in the proposed pit area at the project. Selection of a target date to begin construction of the new mine was delayed by concerns relating to weak metal prices. Development of Meridian Gold Co.'s large beartrack property near Salmon, in Lemhi County, was further deferred pending an improvement in the price of gold. The 85-square-hectare (53-square-mile) property reportedly contains about 26 tons (839,000 ounces) of proved and probable heap leachable gold.

The Idaho Department of Parks and Recreation opened a new mining interpretive center in Custer County near Challis, at the intersection of U.S. 93 and State Highway 75; it includes interpretive displays and audiovisual programs on Idaho's mining history. A circle road tour was developed with a number of posted stops, including the historic Yankee Fork gold dredge that operated on the Yankee Fork of the Salmon River in the late 1940's.

Montana.—Mining and mineral developments in Montana during 1992 were summarized in a report prepared by the Montana Bureau of Mines and Geology.[8] For yet another year, Pegasus Gold was Montana's leading gold-producing company, mining gold-bearing ore at four separate operations in Montana. The largest gold-producing mine in the State was Pegasus Gold's Zortman-Landusky Mine, in the Little Rocky Mountains of Phillips County, where about 3,515 kg (113,000 ounces) of gold was recovered during 1992. Operations at the Zortman-Landusky facility are focused on two separate surface mines several kilometers apart where gold is recovered using heap-leaching methods. Mining during the year was confined to the Landusky side while work on the mine's Zortman Extension project was focused on metallurgical work and on obtaining State permits. In March 1992, Zortman Mining Inc., the operating company at the Zortman-Landusky operation, which began in 1979, celebrated the recovery of its millionth troy ounce of gold. Production at Pegasus Gold's Beal Mountain Mine, south of Butte in Silver Bow County, amounted to a record 1,624 kg (52,200 ounces) of gold, an increase of about 10% over that of the previous year. A new crushing circuit installed during the year aided in achieving improved gold recovery. In Jefferson County, Pegasus Gold's Montana Tunnels gold, lead, silver, and zinc mine also produced gold at record levels. The mine recovered 2,320 kg (74,700 ounces), which was nearly 20% more than that in 1991. Tonnage of ore mined at Montana Tunnels increased by 7% during 1992, but the major factors leading to higher gold production were improved recoveries and higher than anticipated ore grades. About 15% of the gold was recovered by a new gravity circuit installed in 1991, and the remaining precious-metals values were recovered from lead concentrates that were processed at Asarco's smelter in East Helena, MT. Pegasus also continued leaching residual gold and conducting metallurgical tests at its Basin Creek Mine in Lewis and Clark County. Surface gold mining operations at Placer Dome's wholly owned Golden Sunlight Mine near Whitehall increased 30% in 1992 to 3,230 kg (103,870 ounces), mostly as a result of higher grades of ore mined. During the year the company completed constructing and lining a new tailings facility. Also, five environmental groups brought a suit contesting the issuance of the mine's operating permits. To the southeast, at Jardine, in Park County, equal partners Homestake and TVX Gold Inc. produced 1,320 kg (42,500 ounces) of gold at their Mineral Hill Mine. Mineral Hill, operated by TVX, is an underground facility accessed by three adits and operating as a zero discharge facility. The mine processed a record 159,000 tons (175,000 short tons) of ore during the year. Exploration conducted by the partners at nearby Crevice Mountain confirmed a new area of mineralization. Permitting was initiated for further work at the new find. In eastern Park County, near Cooke City, Crown Butte Resources Ltd. continued to pursue permitting and to evaluate its large New World gold, copper, and silver project. Responding to environmental concerns, the company reportedly revised its operating plans to eliminate open pit mining and the use of cyanide. The property is mostly on private land near the northeast corner of Yellowstone National Park.

To the north, in Fergus County, Canyon Resources Corp. produced 1,862 kg (59,857 ounces) of gold at its Kendall Mine, near Lewistown. Kendall, an open pit and heap-leaching facility, first began

operation in 1988. Although the company essentially completed its exploration for additional ore reserves on the property during 1992, it is anticipated that known ore reserves will be sufficient to support 2 more years of active mining and gold production with 1 or 2 years of continued leaching after mining ceases. The company conducted extensive exploration drilling during the year on its 27.6%-held McDonald gold deposit near Lincoln in Lewis and Clark County. Canyon, together with its partner Phelps Dodge (72.75%), earlier formed the Seven-Up Pete Joint Venture to explore and develop the McDonald gold deposit, which, at the end of the year, was reported by the company to contain an estimated 255 tons (8.2 million ounces) of gold; this is a nearly 57% increase in estimated contained metal since the end of 1991. A preliminary feasibility study completed in 1992 indicated that production at the McDonald could average approximately 9.3 tons (300,000 ounces) of gold per year. Extensive engineering, metallurgical, hydrologic, and biologic environmental baseline studies were initiated during 1992.

As in past years, many generally small, intermittent placer operations were active along favorable drainages in western Montana. Beginning in 1992, an estimate of the aggregate production derived from these operations has been appended as a footnote to table 2, Mine Production of Gold in the United States, by State.

Nevada.—For more than a dozen years Nevada has been the Nation's leading gold-producing State; if Nevada were a sovereign nation it would be ranked as the world's fourth largest gold producer. Thirteen of the Nation's leading 25 gold mines in 1992 were in the Silver State and yielded more than 60% of domestic gold production during the year. Gold is also the State's principal mineral commodity, accounting for about 87% of the total value of nonfuel minerals output during 1992.

Nevada and the Nation's dominant gold-producing company, Newmont Gold Co. (NGC), produced gold from its extensive operations in Elko and Eureka Counties, near the town of Carlin. During 1992, NGC produced nearly 50 tons (1,587,900 ounces) of gold from five surface mines feeding five nearby mills and four heap-leaching facilities. NGC's total cash cost to produce 1 ounce of gold during 1992 amounted to $207 compared with $203 during the previous year. Overall, nearly 146 million tons of material was mined from the company's deposits in 1992. Proven and probable reserves at yearend 1992 on NGC's Elko and Eureka County properties amounted to 605.2 tons (19.5 million ounces) compared with 625.6 tons (20.1 million ounces) at the end of 1991. Of these reserves, NGC reported that 94% was located on private land. Gold Quarry, the largest mine operated by the company, produced 28.6 tons (927,800 ounces) in 1992 compared with 32.2 tons (1,034,500 ounces) in 1991. As the Gold Quarry pit has deepened in the near-surface oxide ore, mining has begun to encounter refractory sulfide material interspersed with the oxidized ore reserves. Eventually all of the deeper ore mined at Gold Quarry will be refractory and, therefore, will need to be appropriately pretreated. In the meantime, refractory elements in the oxide material have had a negative effect on gold recovery. To counter this problem and still meet its production target of about 50 tons (1.6 million ounces), NGC increased the quantity tons treated in 1992 and initiated a roaster program for the treatment of higher grades of refractory ore. The company also continued the testing of its proprietary bioleaching process for low-grade gold-bearing refractory materials. In December, NGC signed an agreement with Barrick Goldstrike Mine Inc., a wholly owned subsidiary of American Barrick Resources Corp., for the joint development of the Post ore body that extends across their common border in the northern region of the Carlin Trend. The lower and deep zones of the Post ore body, also known as the Deep Post Deposit, contain approximately 288 tons (9.25 million ounces) of gold. The two parties will share the cost of mining the Post in proportion to their nearly equal interests in the contained gold. The agreement also allows NGC to process Barrick's low-grade refractory material, which is estimated to contain more than 31.1 tons (1.0 million ounces) of gold.

Gold production at Barrick Goldstrike Mines' Goldstrike Mine in Eureka County, at 34.5 tons (1.1 million ounces), was more than double the nearly 17 tons (546,146 ounces) produced in 1991. The sharp rise in production arising from the mining of higher grade ore served to reduce Goldstrike's production costs from $318 per ounce ($10.22 per gram) in 1991 to $199 ($6.40 per gram) in 1992. The company reported that its Betze Development Plan, begun in 1989 to access and develop its Betze deposit, was virtually completed and that the higher grade sulfide ore in the Betze pit had been exposed before yearend in concert with the timely commissioning of a second mill, the second and third autoclave units, and a new oxygen processing plant. The company also reported that ore reserves had been increased during the year to 653 tons (21 million ounces) from the 574 tons (18.5 million ounces) reported at the end of 1991. Ultimately, as provided for in the December agreement with NGC, the Betze and Deep Post deposits will be accessed by one large open pit to be known as the Betze-Post pit. In early 1992, the company announced plans to develop its Meikle Mine, 1.6 km (1 mile) north of the Goldstrike Mine. The Meikle deposit, formerly known as the Purple Vein Deposit, is scheduled to be brought into operation as an underground mine in 1996; average annual gold production is projected at about 12.5 tons (400,000 ounces). During the year, Barrick also maintained its 26.25% share in the Pinson Mine, northeast of Winnemucca in adjoining Humboldt County. Gold production at Pinson during 1992 amounted to about 1,584 kg (51,000 ounces).

Northwest of the Goldstrike operation, in Elko County, Dee Gold Mining continued milling and heap-leach production at its Dee Mine, where 1,207 kg (38,818 ounces) of gold was recovered

during the year. Nearby, at the Ivanhoe (Hollister) Mine, ore reserves from the first phase of the mining operations were essentially exhausted in early 1992. In midyear NGC acquired a 75% interest in the property, and leaching of residual gold in the existing heaps continued through yearend. NGC acquired the property because of its potential to add new reserves for future recovery.

In the Independence Mountain Range northeast of Carlin, partners Independence Mining Co. Inc. and FMC Gold Co. produced about 9,950 kg (320,000 ounces) of gold at their Jerritt Canyon Mine during 1992, down about 15% from the previous year because of lower ore grades processed. The mine moved a record 35 million tons of material during the year and increased mill throughput by 3% to about 7,400 tons per day. Exploration to discover new resources continued at a high rate, and during the peak season, up to 24 drill rigs and a team of 23 geologists drilled 921 holes, reportedly locating significant mineralization in 54% of the holes. Sixteen km (10 miles) north of Jerritt Canyon, Independence continued open pit operations at its wholly owned Big Springs Mine, where nearly 7,800 kg (250,000 ounces) of gold has been recovered since 1988.

Combined gold production at Santa Fe Pacific Gold Corp's. two surface mines, the Rabbit Creek Mine and the new Lone Tree Mine, both in eastern Humboldt County, amounted to about 9,200 kg (295,000 ounces). In mid-August, the Lone Tree operation completed its first full year of operation. Other large gold mines, all surface operations, in Humbolt County included Amax Gold Inc.'s Sleeper Mine, Granges Inc.'s Crofoot/Lewis Mine, Rayrock Mines Inc.'s Marigold Mine, Gold Fields Operating Co.'s Chimney Creek Mine, and FirstMiss Gold Inc.'s Getchell Mine. Aggregated gold production at these five operations amounted to about 25 tons (800,000 ounces) during the year. In late May, Gold Fields celebrated the pouring of the millionth ounce (31.1 tons) of gold recovered at its Chimney Creek Mine since the mine was opened in December 1987.

To the west in Washoe County, Amax Gold completed mining the known ore reserves at its Wind Mountain open pit and heap-leaching mine in early 1992. Leaching of stacked ore continued through yearend. Similarly, Western Hog Ranch Co. completed mining at its Hog Ranch Mine north of Gerlach. Leaching will continue until the existing heaps are depleted. In Story County, south of Reno, Miramar Mining Corp. began production at its Golden Eagle Mine near Virginia City. The new open pit and heap-leaching facility, formerly known as the Flowery Mine, is scheduled to produce at least 620 kg (20,000 ounces) of gold and 7 tons (225,000 ounces) of silver per year. In Lander County, St. George Metals Inc. poured its first bar of doré at its newly opened Dean Mine, 24 km (15 miles) south of the town of Battle Mountain. High-grade ore mined from the underground workings is processed by milling and heap-leaching facilities 16 km (10 miles) from the mine site. Nearby, Battle Mountain Gold Co. (BMG) produced about 5,530 kg (178,000 ounces) of gold and 13.2 tons (426,000 ounces) of silver at its Battle Mountain Complex. Owing to depletion of high-grade mill ore at BMG's Fortitude pit, milling operations at the complex were scheduled to end in early 1993. Milling may, however, be resumed later if a low-grade milling opportunity under evaluation at yearend proves feasible. By yearend, the company also had identified a large heap-leachable deposit, designated the Reona project, within the complex area.

At the McCoy and Cove gold and silver property of Echo Bay Mines, 23 km (16 miles) south of the BMG complex, the company had another record-breaking year of operation, producing 9,377 kg (301,512 ounces) of gold and 246.4 tons (7,921,496 ounces) of silver from two separate gold deposits 1.6 km (1 mile) apart. During 1992, surface and underground mining at the Cove deposit moved ahead to the extent that the underground levels were overtaken by the open pit in early 1993. The 6% increase in gold production and 41% increase in silver production over 1991 were reportedly attributed to mining and milling the greater quantities of higher grade sulfide encountered at depth. Heap-leaching recovery methods are also employed at the McCoy/Cove operation to treat lower grade ore.

At the Cortez Mine, about 50 km (30 miles) southeast of McCoy/Cove along the Lander County/Eureka County line, improved grades and recoveries led to an increase in gold production to about 2,330 kg (75,000 ounces) in 1992. The company, Cortez Gold Mine Joint Venture, continued to explore its Pipeline and South Pipeline discoveries near the Cortez operation in Lander County. The planned surface mining project, called the Pipeline Project, is expected to be in production by early 1995. In White Pine County on the Alligator Ridge Trend, U.S.M.X. Inc. poured its first gold in mid-June at its new Yankee Mine. The new open pit and heap-leaching facility is U.S.M.X.'s third producing mine in the Alligator Ridge area. About 335 kg (10,800 ounces) of gold was reportedly recovered from the Yankee during 1992. The other two nearby U.S.M.X. mines are the Alligator Ridge and the Casino/Winrock.

At Round Mountain, about 100 km (60 miles) north of Tonopah in Nye County, Round Mountain Gold Corp. recovered about 11.5 tons (370,000 ounces) of gold and 9.8 tons (317,000 ounces) of silver at its Round Mountain Mine. Gold production at Round Mountain, an open pit and heap-leaching operation, increased by 9% in 1992 owing primarily to the discovery of a high-grade vein from which more than 1,600 kg (52,000 ounces) of gold was recovered. A company geologist reportedly recovered 50 kg (1,600 ounces) of gold in one afternoon using only a geologist's pick for a tool. Coarse gold of the sort contained in the high-grade discovery requires milling rather than heap leaching so the company installed a small mill and, using gravity separation methods, extracted the coarse-free milling gold from stockpiled high-grade vein material that contained nearly 2 ounces of gold per short ton. Near Beatty in southern Nye

County, Lac Minerals Ltd. recovered 10.1 tons (323,825 ounces) of gold and about 9.7 tons (313,000 ounces) of silver at its Bullfrog Mine. Lower grade open pit ore reserves at Bullfrog have been nearly exhausted, and the transition to mining higher grade ore from the underground extension of the ore body was well under way by yearend.

Oregon.—There were no primary lode gold mines active in Oregon during the year. However, as in past years, several placer mines, including Bonanza Mining Co.'s mine on Pine Creek in Baker County, were in operation. Bonanza began reclamation at the site and extended its exploration to properties held nearby.

Formosa Resources Corp. resumed underground mining activities at its Silver Butte copper, gold, and zinc mine near Riddle, in Douglas County. Concentrates were trucked to Vancouver, WA, then shipped to Japan for further processing. Plexus Resources Corp. continued development and permitting work at its Bornite Project. Plans for the Bornite Project, to be an underground producer of copper, gold, and silver, called for mining 318,000 tons (350,000 short tons) of ore per year. The property is near Mill City in Marion County.

In September, the Oregon Environmental Quality Commission (EQC) granted final approval to new regulations governing chemical-process mining operations in Oregon. The new regulations focused primarily on new or future precious-metal mines using cyanide or other chemical recovery processes. In 1990, Atlas Precious Metals Co. had announced plans to spend $80 million to develop its then recently discovered gold deposit known as Grassy Mountain, in Malheur County. The mine was to produce 3,100 kg (100,000 ounces) of gold annually and bring 190 jobs with a $6 million payroll to Malheur County in eastern Oregon. Following the announcement, citizen protests, largely in western Oregon, spurred the EQC to develop the new regulations and for Atlas to postpone development at Grassy Mountain. In October 1992, Newmont Mining Corp. announced that it had acquired, through a lease, the exploration, development, and mining rights to the Grassy Mountain project from Atlas. Grassy Mountain reportedly has proven and probable reserves of 31 tons (1 million ounces) of gold and 77 tons (2.5 million ounces) of silver.

Gold exploration in Oregon continued but at a lower level than in past years. In Malheur County, ICAN Minerals continued drilling at its Racey "porphyry" gold deposit 65 km (40 miles) south of Baker. In Baker County, Cracker Creek Gold Mining Co. and Cable Cove Mining Co. continued small-scale exploration efforts at their respective properties, the Bourne and the Herculean projects.

South Carolina.—Commercial gold production began in South Carolina before 1830, and gold has been produced in that State discontinuously since that time. During 1992, gold was produced at four South Carolina mines and the State was the only gold-producing State east of the Mississippi River during the year. By yearend, however, mining operations at two of the four mines had been suspended pending improved gold market conditions.

The State's largest gold mine in 1992 was Kennecott Ridgeway Mining Co.'s Ridgeway Mine in Fairfield County. Ridgeway, an open pit and milling facility employing vat leaching recovery methods, produced 5,007 kg (161,000 ounces) during the year. In early 1992, the company, a subsidiary of RTZ's Kenncott Corp., acquired Galactic Resource's 48% interest in the property and thereby acquired sole proprietorship. In McCormick County, near the Georgia-South Carolina border, Consolidated Nevada Goldfields Corp. had, by the end of its fiscal year on June 30, produced 489 kg (15,731 ounces) of gold and 587 kg (18,860 ounces) of silver at its Barite Hill Mine. Ore stacking at the open pit and heap-leaching mine's reusable leaching pad ended in early September, and leaching was terminated in late September. Concurrently, construction of a new permanent leach pad was completed and stacking and leaching of ore was begun in October. The new 1.4-million-ton-per-year (1.5-million-short-ton-per-year) leaching facility had, by yearend, yielded 146 kg (4,687 ounces) of gold, despite restraints on leaching and mining imposed by abnormally high rainfall. Mining operations were suspended at the Brewer Mine, near Jefferson in Chesterfield County, in early November. Processing ore on the leach pad was expected to continue at least through mid-1993. Brewer Gold Co., the operator, indicated near yearend that a decision to permanently close the mine was dependent on the outlook for mining costs and gold prices as well as the results of exploration under way on adjoining properties. Site reclamation at the surface and heap-leaching operation was expected to proceed, possibly into 1994. In September, the company's earlier request to transport ore from a deposit near Buford in adjoining Lancster County to the Brewer site was denied by Lancaster County authorities.

Gold mining had been suspended at the Haile Mine of Piedmont Mining Co. near Kershaw in mid-1991, but heap leaching and gold recovery continued into early 1992. In May, Amax exercised its 1991 option and acquired a 62.5% interest in the property and, effective July 1, Amax and Piedmont, through wholly owned subsidiaries, formed a joint venture, the Haile Mining Venture, to proceed with further development of the property. If warranted, the partners plan to develop a large-scale mining operation at the Haile property, which covers approximately 1,500 hectares (3,700 acres) of private or fee property in Lancaster County. Further drilling, evaluation, environmental studies, and permitting will continue in 1993 with the reported objective of completing a bankable feasibility study in early 1994.

South Dakota.—The Homestake Mine at Lead, the Nation's largest underground gold mine, increased its production 24% over that of the previous year to more than 12.3 tons (396,626 ounces). By implementing a new underground operating strategy, the company was able to reduce the total cost of producing 1 ounce of gold at the Lawrence County

facility from $400 per ounce ($12.86 per gram) in 1991 to $337 per ounce ($10.84 per gram) in 1992. Homestake's new strategy included withdrawing work force and equipment from uneconomic mining areas and transferring them to areas with higher grade ore. Following receipt of State approval, the company continued expanding its newly developed open pit, also known as the Open Cut, developed on the site of the original gold strike in 1876. Work was also continued on the new North Drift designed to connect the existing underground operations with a recently outlined ore body discovered earlier and located about 5 km (3 miles) to the north.

Gold production at South Dakota's second largest mine, Wharf Resources (USA) Inc.'s Wharf Mine, formerly known as the Annie Creek Mine, increased to 2,960 kg (95,186 ounces). During 1992, feed for the heap-leaching process was derived from several open pits, one of which, the Annie Creek pit, was mined out and undergoing backfilling with waste rock near yearend. The Wharf Mine is 5 km (3 miles) west of Lead. In October, Wharf assumed management of the Golden Reward Mine, 13 km (8 miles) southeast of Lead. Gold production at Golden Reward, an open pit and heap-leaching facility, amounted to about 1,590 kg (51,000 ounces) compared with 1,262 kg (40,590 ounces) produced during the previous year. Ownership interests in the property were revised during the year giving, Wharf 60% and partner MinVen Gold 40%. Production at MinVen's wholly owned Gilt Edge Mine, 8 km (5 miles) southwest of Lead, amounted to about 840 kg (21,000 ounces). The decrease from the previous year's level reflected the gradual depletion of the mine's presently permitted oxide ore reserves. These were mined out by yearend, and mining operations were suspended at that time. MinVen received regulatory approvals in August to proceed with a bulk heap-leach test on Gilt Edge sulfide ores.

Bond Gold Richmond Hill Inc. produced 945 kg (30,373 ounces) of gold in 1992 at its Richmond Hill Mine. The company, a subsidiary of Lac Minerals, announced plans to close the mine 6 to 9 months earlier than originally planned. The Richmond Hill property, 8 km (5 miles) northwest of Lead, is an open pit and heap-leaching operation. In midyear, acidic water draining from waste ore piles at the property led to a State order to cease most mining activity; however, leaching and metal production was not affected and continued into 1993.

On election day, November 3, voters in South Dakota passed a ballot initiative designed to impose new acreage and reclamation standards on the Black Hills gold mining industry. The initiative, which was approved by 59% of the voters, limits new mines to 130 hectares (320 acres) and allows existing mines to expand by 81 hectares (200 acres). After that, site reclamation is to be required on an hectare-for-hectare basis before any expansion is allowed. Underground mines, such as the Homestake gold mine at Lead, are exempt.

Utah.—The Bingham Canyon Mine of Kennecott Corp., one of the Nation's leading gold-producing mines for many years, produced 16 tons (515,000 ounces) of gold during 1992, a 12% increase in gold production over that of the previous year. The mine, owned by RTZ and operated by Kennecott, produces gold and silver as byproducts of its copper mining activities. In March, Kennecott announced plans to invest $800 million to construct a new on-site smelter, expand the existing copper refinery, and construct a new precious-metals refinery. The new facility would employ the latest technology, enabling it to meet current and anticipated future environmental regulations, including air quality standards that will become effective in 1995.

Kennecott's Barney's Canyon gold mine, about 6.4 km (4 miles) north of the Bingham pit, produced 3,608 kg (116,000 ounces) of gold in 1992. Ore reserves at the open pit and heap-leaching facility, which began production in December 1988, are estimated to be sufficient for about 3 1/2 years; however, there may be potential for additional reserves to extend the mine life.

American Barrick's Mercur Mine in Tooele County produced 3,770 kg (121,239 ounces) of gold at an average operating cost of $262 per ounce ($8.42 per gram). Extremely hard, jasperoid ores mined throughout the year reduced the tonnage of ore milled; however, the higher gold content of the hard ore compensated for the reduced throughput.

In southwestern Utah, gold production continued at the Goldstrike Mine, an open pit and heap-leaching operation in Washington County about 65 km (40 miles) northwest of St. George. Negotiations to purchase the mine, operated by Tenneco Minerals Co., were begun by U.S.M.X. in early 1993. The mine produces about 1,180 kg (38,000 ounces) of gold annually.

American Consolidated Mining Co. and Goldstack Resources, Ltd. explored their copper and gold discoveries at the Gold Hill property in Tooele County, and Centurion Mines Corp. reported the discovery of a gold- and silver-bearing zone on properties held in the Tintic Mining District in western Utah. The company also identified a gold target on its property in the Dugway Mining District 145 km (90 miles) west of Salt Lake City.

Washington.—USBM data on aggregate gold production for the State of Washington have been largely withheld over the past decade to avoid disclosing company proprietary data; however, the Washington State Division of Geology and Earth Resources, in its annual review of Washington's mineral industry,[9] indicated that gold production by the State's three major gold mining operations, the Cannon Mine, the Republic Unit, and the Kettle River Project, amounted to nearly 8,800 kg (283,000 ounces) during 1992.

Washington State's largest gold mine, the Cannon Mine at Wenatchee, Chelan County, produced 4,192 kg (134,786 ounces) of gold and 7,573 kg (243,498 ounces) of silver from nearly 450,000 tons (490,000 short tons) of ore. Cannon is a joint venture between Asamera Minerals (U.S.) Inc. and Breakwater Resources Ltd. Only about 2 more years

of ore reserves remain to be mined at the Cannon operation; in anticipation of the projected depletion date, some operations, such as the mill, began to be scaled back in 1992.

In Ferry County, near Republic, Hecla Mining's underground Republic Unit, where gold was first produced in 1896, recovered 1,815 kg (58,343 ounces) of gold and 9,329 kg (299,957 ounces) of silver in 1992. Although gold production was down 25% from that of the previous year because of lower ore grades, a record 93,400 tons (103,000 short tons) of ore was milled. In an attempt to replenish the mine's high-grade ore reserves, Hecla has intensified its exploration efforts over the past 2-years. Several promising targets in the Republic area have been identified, and 1993's exploration will focus on those areas. During 1992, construction was completed on a first-level on-site refinery to process concentrates from the mill. The mine now ships doré bars for parting into refined gold and silver bullion.

The only other Washington State mine producing gold in 1992 was Echo Bay's Kettle River project, west of Curlew in Ferry County. Production for the year amounted to 2,794 kg (89,848 ounces). At yearend, Echo Bay acquired the 30% interest of the joint-venture partner, Crown Resources Corp., thereby increasing Echo Bay's interest to 100%. The Kettle River project, scattered over 5,700 hectares (14,000 acres), has been developed around five separate deposits. The Kettle deposit was mined out in 1992, and ore from the Key West and Key East deposits was slated to replace the Kettle ore as soon as Kettle ore, stockpiled at the company's mill at the Overlook Mine, has been processed. Underground mining at the Overlook deposit was temporarily curtailed and milling operations were reduced pending an improvement in gold market conditions. Tunneling and other development work was continued at the Lamefoot deposit, about 5 km (3 miles) from the mill, to enable the Lamefoot to become the principal source of mill feed by 1994.

To the west, near Chelan in Okanogan County, work was continued on the development of the Crown Jewel deposit by owners Battle Mountain Gold (operator) and Crown Resources. Permitting for the new project was begun in 1992, the draft environmental impact statement is expected to be delivered in 1993, and gold production is expected to begin in early 1995 at a rate of 5,440 kg (175,000 ounces) per year. The Crown Jewel deposit is only a 40-hectare (100-acre) part of holdings that exceed 3,200 hectares (8,000 acres), known as the Crown Jewel exploration project. As in recent past years, gold exploration in Washington generally was concentrated in Chelan, Ferry, Okanogan, and Stevens Counties.

Consumption and Uses

Reported data on gold consumed in the domestic industrial market, shown in table 8, account for only a part of the overall market for gold in commercial applications. 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 1992 declined for the third consecutive year owing, in part, to continued apparent investor disinterest.

Contracts for gold futures traded during 1992 represented about 18,670 tons (600 million ounces) compared with those of the previous year, when the equivalent of more than 21,000 tons (680 million ounces) was traded. The New York-based Commodity Exchange Inc. (COMEX) was, as in the previous year, by far the Nation's dominant gold futures exchange.

Gold loans between commercial depository banks and gold producers continued to be an acceptable method of financing new mine development or expansion of existing facilities. Gold loan activity generally peaked in 1988, and many mines that benefitted earlier from gold loan programs have begun to repay their original loans with newly mined gold.

Stocks

Stocks of refined bullion held by industrial users at yearend were substantially less than stocks on hand at yearend 1991. Repeating a pattern established in past years, when viewed on a quarterly basis, the greatest decline in industrial stocks was reported during the first quarter of the year; this may reflect a withdrawal 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, were about 46.5 tons (about 1.5 million ounces), nearly 7% less than those held at the end of the previous year. Deliveries to the market during the fourth quarter of the year were substantial; this was reflected in a 23% decline from the year's level held at the end of the third quarter.

Markets and Prices

The Engelhard Industries/London daily final price of gold during the year was bound by highs of about $360 per troy ounce in January and July and a low of about $331 in November, its lowest level since January 1986. The average for the year was $344.97 per troy ounce or about $27 greater than the previous annual low of about $318 per troy ounce established in 1985. Some factors contributing to the lackluster performance of the price during 1992 included periodic heavy bullion sales to the market by some central banks, producers, and investors; a deteriorating and unsettled world economic situation accompanied by fluctuating currency values and some apparent asset deflation; continuing conflict and uncertainty in eastern Europe; and the reluctance of many investors to seek the safe haven of gold for some of their assets while benefitting from the widespread availability of alternative investment vehicles.

Foreign Trade

For the third consecutive year, total U.S. exports of refined gold increased over those of the previous year. These refined exports registered an increase of 47% over those of 1991, and the rate of annual growth was the steepest recorded during the 4-year period. Exports of gold in ores and concentrates, and doré and precipitates, also increased. Exports of waste and scrap declined for the second consecutive year. Total exports during 1992 increased more than 36% over those of 1991. The principal recipient nations for gold in all classes of exports were Canada, Hong Kong, Switzerland, and the United Kingdom. Nearly 80% of the refined bullion exported during the year went to Hong Kong, Switzerland, Taiwan, and the United Kingdom.

Total imports of gold during the year were about 3% below those of 1991. Imports of refined bullion declined 4% during the same period. Brazil, Canada, and Chile were the principal sources of refined bullion imports in 1992. Imports of doré and precipitates, mostly of Canadian origin, registered a threefold increase over those of the previous year.

World Review

Nineteen ninety-two marked the 13th consecutive year of growth in world gold mine production. The rate of growth, however, failed to match the high rates of growth achieved during the late 1980's.

With the release of its annual statistical review of world gold supply and demand, Gold Fields Mineral Services Ltd. (GFMS)[10] continued a comprehensive statistical series begun by its predecessor, Consolidated Gold Fields PLC, more than one-quarter of a century ago. To mark the occasion, GFMS included in the annual Gold Survey a brief summary of the data on gold supply and demand and gold price movements during the 25-year period up to 1992. For the first time in the history of the Gold Survey, which has always shown supply and demand in the Western World, the opportunity to expand the coverage to include data previously unavailable from the Communist bloc nations has been afforded by the breakup of the former U.S.S.R. and the economic liberalization in China. Responding to these changes, GFMS was able to take the first steps toward expanding its supply and demand coverage on a global basis.

In its review of the gold market in 1992, GFMS observed that despite market problems associated with a steady decline in real gold prices over the past 5 years the strength of the demand for physical gold was undiminished, particularly the demand for gold used in the fabrication of jewelry products. It was the developing world that accounted for most of the increased jewelry output, with increased fabrication in many Southeast Asian nations responding to the market opportunities afforded by the rapid economic growth and increasing prosperity in China. Despite the increased level of demand the price continued to weaken. The principal reason for the lower prices, according to the review, was the net disposal to the market of nearly 600 tons (19.3 million ounces) by the central banks of several nations, notably Belgium, Canada, and the Netherlands, the highest level since 1968, and well in excess of the 544 tons (17.5 million ounces) sold into the market by the U.S. Treasury and the IMF during 1979.

Overall, the world gold market absorbed a record supply of 3,182 tons (102.3 million ounces) during 1992. On the demand side, despite a nearly 330-ton (10.6-million-ounce) increase in world jewelry fabrication over that of 1991, a new record for the fifth year running, most other components of fabrication showed only modest performance with growth in dental and decorative applications more than compensating for weakness in the electronic sector brought on by stagnation in the computer industry and weakness in the defense and consumer electronics sectors.

Data collected by GFMS on the hoarding of small bars for investment outside of Europe and North America showed a nearly 13% increase over 1991. Declines in hoarding in the Far East and considerable dishoarding in Brazil and Indonesia were more than offset by substantial increases in many Middle Eastern nations and in India. The quantity of gold absorbed in official coin fabrication programs declined 40% from that of the previous year. The absence of special programs such as the Japanese Akihito coin issue in 1991 was largely to blame for the decline.

Australia.—Despite a 4% decline in gold production from 1990 to 1991, Australia's gold output in 1992 resumed the upward trend begun in 1981 as production during the year registered an increase of about 2.5% over that of the previous year. Many of the factors contributing to the reduced performance during 1991 persisted into 1992, exacerbated to a great extent by the continuing weakness in world gold prices, which, together with the removal of the income tax exemption in 1991, forced many smaller gold mines to close.

Accounting for a major percentage of Australia's production during 1992, the State of Western Australia maintained its long-held position as the nation's dominant gold-producing State, followed by the State of Queensland and the Northern Territory. The largest gold-producing mine complex in Western Australia during the year was the Super Pit operation in Kalgoorlie. The Super Pit was also the nation's largest open pit mine. The Super Pit is operated by Kalgoorlie Consolidated Gold Pty. Ltd., which also operates the Mount Percy open pit and the Mount Charlotte and Fimiston underground operations, all along Kalgoorlie's famous Golden Mile. Homestake Gold of Australia Ltd. owns 50% of these Golden Mile producers while the remainder is held by Poseidon Gold Ltd. (PosGold). Production from the Super Pit during the year amounted to 14.8 tons (474,825 ounces). PosGold also maintained interests in a number of other Western Australian gold operations, including the Big Bell Mine, near Cue, and the Karonie and Jubilee Mines and Kaltails gold recovery project, all near Kalgoorlie. The open pit Big Bell, jointly owned with Placer Pacific Ltd., produced

a record 4,874 kg (156,708 ounces) of gold in 1992.

Gold production at the Telfer Mine near Nullagine, operated by Newcrest Mining Ltd. produced 11.8 tons (380,090 ounces) of gold by milling and heap-leaching recovery methods during the year. Newcrest's other gold interests in Western Australia included the Ora Banda and the New Celebration Mines, both near Kalgoorlie; their 1992 gold production was, respectively, 4,753 kg (152,830 ounces) and 2,440 kg (78,472 ounces).

Western Mining Corp. (WMC) owned or managed four gold mines in Western Australia, which contributed 19.4 tons of gold to WMC's account during the company's fiscal year ending in June 1992. WMC's mines included several mines in the Kambalda-St. Ives area south of Kalgoorlie and multiple mine operations near the west Australian towns of Kalgoorlie, Lancefield, Leinster, Mount Magnet, and Norseman. WMC also holds a 48% interest in Alcoa of Australia's Hedges Gold Mine 97 km (60 miles) southeast of Perth. The Hedges property yielded 5,194 kg (167,005 ounces) of gold associated with bauxite. Elsewhere, WMC owns or participates in the operations of the Goodall Mine in the Northern Territory, which recovered 1,388 kg (44,642 ounces); the Stawell Mine in Victoria, which produced 1,802 kg (57,930 ounces); and the Roxby Downs or Olympic Dam Mine in South Australia; which, in addition to uranium and copper, produced 71 kg (22,851 ounces) in fiscal 1992.

Gold production at the Boddington Mine, near Alcoa's Hedges Mine, amounted to 10.9 tons (351,627 ounces). At both the Boddington and the Hedges Mines, the gold ore body underlies commercial bauxite deposits. Reynolds Metals Co., a 40% participant in the Boddington gold project, also owns the Marvel Loch gold mine and a 50% interest in the Mount Gibson gold project, both in Western Australia. Also in Western Australia, production was begun at Resolute Resources Ltd.'s Marymia Mine 200 km (124 miles) north of Meekathara. Asarco Australia Ltd. announced plans to build the world's largest bacterial oxidation plant to treat sulfide ores from its gold operation at Wiluna. Homestake placed its Fortnum Mine near Meekathara on care and maintenance owing to continued low ore grades and low gold prices.

In Queensland, production at Placer Pacific's 70%-held Kindston Mine, 200 km (124 miles) west of Cairns, amounted to 5,889 kg (189,359 ounces) during 1992. Battle Mountain Gold continued to experience good production at its Pajingo underground mine with 1,462 kg (47,000 ounces) recovered during the year. The deposit is expected to be depleted by mid-1993 with milling of stockpiled ore to cease by early 1994. Carpentaria Gold Pty. Ltd., a subsidiary of MIM Holdings Ltd., officially began production at its Tick Hill Mine in early 1992, at an annual rate of 3,110 kg (100,000 ounces) of gold. In northern Queensland, Ashton Mining poured its first gold bar at the Rishton Mine. The new open pit project is designed to recover 1,244 kg (40,000 ounces) of gold per year.

At Cobar in western New South Wales, CRA Ltd. began operations at its Peak Mine in October. The new, highly automated underground facility is designed to recover about 3,110 kg (100,000 ounces) of gold annually. Copper, lead, silver, and zinc also will be recovered as byproducts. The recovery plant, employing a column flotation recovery system to separate the base metal constituents, is reportedly the first of its kind in the world.

The Government of Australia decided during 1992 to end the restrictions that have long applied to foreign investment in mining (excluding uranium) by abolishing the requirement that foreign investment proposals have a minimum of 50% Australian equity and Australian control of the project's controlling body. Under the new provisions, by which foreign companies can now own up to 100% of such properties, all foreign investment proposals in the mining industry will be approved unless judged contrary to the national interest. U.S. companies have been major participants in Australian mining, especially for gold, for many years.

In 1992, Australia's legal tender Kangaroo coins reportedly became the world's best selling gold coin, a position formerly occupied by the Canadian Maple Leaf coin. The Kangaroo was introduced in March 1991 and includes coins weighing 2 ounces, (62.2 grams), 10 ounces, (311 grams), and 1 kg (32.2 ounces). In April 1992, Gold Corp Australia, the seller of Australia's legal tender coins, announced the introduction of its new 1 kg (32.2 ounces) silver bullion coin, known as the Kookaburra, as well as a set of new 2-ounce (62.2 grams) and 10-ounce (311 grams) silver coins. The new coins all have legal tender status.

Canada.—The steady growth in Canadian gold production since 1981 was replaced in 1992 with a 10% decline from that of 1991 when a record 176,552 kg (5.7 million ounces) was produced. Continuing the previous year's trend toward the closure of marginal mines, there were 50 primary gold mines operating in Canada at the end of 1992 compared with 60 at the close of 1991. These 50 mines accounted for 88% of the gold produced during the year, according to an annual review of Canadian gold developments prepared by the Canadian Department of Energy, Mines and Resources.[11]

The Province of Ontario was again the dominant gold-producing Canadian region. Of the 74 tons (2.38 million ounces) of gold produced in Ontario, more than 50% was derived from three major mines in the Hemlo area; these mines, all opened in 1985, were the Page-Williams Mine, the Golden Giant Mine, and the David Bell Mine. The Page-Williams and the nearby David Bell Mine are owned by Homestake Canada Inc. and the Teck Corp. Golden Giant is owned by Hemlo Gold Mines Inc. Homestake also owns 25% of another Hemlo area mine, the Quarter Claim property.

Gold production in Canada's second largest gold-producing Province, Quebec, declined from 51.9 tons (1.67 million ounces) in 1991 to 44.5 tons (1.43

million ounces) in 1992. The decline reflected the closure of seven mines and production decreases at several others. Of the seven closures, six were attributed to exhaustion of ore reserves. No mines were brought into productive status during 1992, but the Sleeping Giant Mine of Aurizon Mines Ltd., which closed in 1991, was expected to be reopened in early 1993 with Cambior Inc. as the operator. Operations at the Casa Berardi area Golden Pond East Mine of TVX Gold Inc. and Golden Knight Resources Ltd. 100 km (62 miles) north of LaSarre, were suspended in April following an inflow of overburden material into the upper level of the mine. Full production was expected to resume early in the new year.

Near Couteau Bay on the southwest coast of New Foundland, Royal Oak Mines Inc. reopened its recently acquired Hope Brook Mine, which had been closed since the summer of 1991. Hope Brook, originally opened in 1987 as an open pit and heap-leaching operation, was later developed as an underground facility by a subsidiary of BM Resources Canada Inc. Royal Oak's production target for 1993 was reportedly 3,730 kg (120,000 ounces) of gold.

In the Northwest Territories, nine workers were killed in September by an explosion at Royal Oak's Giant Mine on the north shore of Great Slave Lake. At the time of the underground explosion the operation was in the midst of a bitter labor dispute. An investigation into the incident by the Royal Canadian Mounted Police was under way at yearend. The mine, which began production in 1948, produces about 3 tons of gold annually.

Near Smithers, in Canada's west coast Province of British Columbia, Timmins Nickel Inc. opened its Dome Mine. Production is estimated at about 350 kg (11,000 ounces) per year. In midyear Homestake, through its takeover of the Corona Corp., became the principal partner and operator at the rich Eskay Creek gold development property in northern British Columbia. A feasibility study was completed during 1992, and production could begin by late 1995. Homestake also had interests in three other gold-producing mines in British Columbia: the Snip, Nickel Plate, and Golden Bear. In midyear Cheni Gold Mines Inc. exhausted the ore reserves at its Lawyers Mine in the Toodoggone River area north of Smithers, and development at Placer Dome's 70%-held Mount Milligan copper-gold property near Prince George was halted owing to low gold prices.

Ghana.—Gold production in the Republic of Ghana rose for the fifth consecutive year, increasing 18% during 1992 to 31,031 kg (997,670 ounces). Financing was completed in November for the expansion of Ashanti Goldfields Corp. (Ghana) Ltd.'s Ashanti Mine, near Obuasi. The expansion will increase the mine's gold production by about 50% to 31 tons (1 million troy ounces) per year by mid-decade. Part of the 3-year expansion includes the construction of a 220,000-ton-per-month bioleaching plant. When commissioned, the plant will be the world's largest bioleaching facility. The bioleaching process will be used to prepare the mine's gold-bearing sulfide ore reserves for conventional milling. The $140 million financing includes $40 million provided by the World Bank's International Finance Corp. (IFC). The loan, which may be drawn by the company in either dollars or gold, is the first such commodity-linked loan structured by the IFC. The loan package also carries two separate gold-hedging provisions advantageous to Ashanti. Ashanti Goldfields is a joint venture between the Government of Ghana (55%) and Lonrho Plc (45%).

In eastern Ghana, Sikamen Gold Resources Ltd. commissioned a new floating washplant at its Goldenrae placer mine near Kiki. The new plant, which replaced an earlier facility that failed to perform to specifications since the mine was opened in late 1990, is expected to produce 460 to 560 kg (15,000 to 18,000 ounces) of gold per year. An additional plant is scheduled to be in place and operating by mid-1993. In late 1992, Ghanian Australian Goldfields Ltd. (GAG) started production at its new Iduapriem Mine near Tarkwa in southwestern Ghana. The new open pit mine, which is expected to produce about 3,110 kg (100,000 ounces) of gold per year, is operated by GAG, which is owned by Golden Shamrock Mines, the Government of Ghana, the IFC, and private investors.

Latin America.—Of the nearly 20 gold-producing nations of Latin America, more than one dozen registered an increase in production during 1992 relative to the previous year. Nations achieving the strongest rate of growth from 1991 were Bolivia, Chile, Colombia, French Guiana, Mexico, Peru, and Venezuela. As in recent years, the improved business, investment, and regulatory climates in many of these nations continued to attract gold exploration firms worldwide, especially North American companies.

Bolivian gold production registered a strong 34% increase over that of the previous year but failed to match the nearly 5,200 kg (167,000 ounces) of gold produced during 1990. Battle Mountain Gold Co. (BMG) continued development work at its Kori Kolo gold mine, and full operation was expected to begin by the end of the first quarter of 1993. The mine, in Bolivia's Altiplano near Oruro, 165 km (102 miles) southeast of La Paz, is owned by Empresa Mineral Inti Raymi S.A. (IRSA), which in turn is 85%-owned by BMG and 15%-owned by Bolivian-based Zeland Mines. Kori Kolo was initially opened by IRSA in 1984 as a small heap-leaching operation treating oxide ore. BMG acquired an interest in the property in early 1989. The existing oxide operations yielded 1,680 kg (54,000 ounces) of gold during 1992. The expanded operations include new milling capacity designed to accommodate both the remaining oxide ores as well as the much larger underlying gold-bearing sulfide deposit developed in recent years. Annual production at the expanded facility is expected to be about 7,600 kg (245,000 ounces) of gold and 33 tons (1.06 million ounces) of silver. Gold and silver discoveries in the Santa Cruz Department of Eastern Bolivia reportedly sparked a classic gold rush into that

remote part of the nation. In mid-December, a mudslide buried more than 50, and possibly hundreds, of people in the small remote Bolivian placer mining camp of Llipi, about 130 km (80 miles) north of Bolivia's capital city of La Paz. Llipi, on the Tipuani River, reportedly was home to more than 1,200 miners and their families. Mudslides are just one of the many hazards accepted by the thousands of independent, unregulated placer miners working in remote frontier areas of Bolivia, Brazil, Peru, and elsewhere in Latin America.

Brazilian gold production, at 76 tons (2.4 million ounces), was essentially the same as production achieved during 1991. As gold production by Brazil's regulated or formal sector has risen over recent years, the amount of gold recovered by the nation's independent gold miners or "garimpeiros" has declined. For the most part, the formal sector has increasingly focused on mining relatively large, capital-intensive lode deposits while the garimpeiros fortunes continue to be generally dependent on mining small placer deposits along major rivers and streams in remote frontier areas of the country such as in the states of Roraima, Amazonas, and Pará. In these areas, portable, makeshift equipment and rugged living conditions are the norm. As the placer deposits of one area are deleted, garimpeiros migrate to other gold-bearing areas and reestablish their operations. During 1992, as the gold played out on the Brazilian side of the border between Brazil and Venezuela, migrating prospectors trespassed into Venezuela and were confronted by that nation's military forces. A series of border clashes between the two parties reportedly ended with the arrest of 350 gold miners. Much of the gold recovered by the garimpeiros escapes official accounting and instead is smuggled out of Brazil or may be used to barter for day-to-day necessities.

Brazil's regulated gold mining industry continues to expand with each passing year. The nation's largest gold mining company is Mineraçao Moro Velho (MMV), which operates gold mines in the State of Minas Gerais at Itajobi, Nova Lima, Raposos, Sabará, and Pitanqui and in the States of Bahia and Goias at Jocobina and Sierra Grande, respectively. MMV produced about 12,300 kg (395,450 ounces) of gold in 1992. Companhia Vale de Rio Doce (CVRD), the second largest company, produced about 11,300 kg (363,300 ounces) from two mines in the State of Minas Gerais, two in the State of Bahiá, and one in the State of Pará. CVRD's new Igarapé Bahia Mine completed its first full year of production in September. Brazil's third largest gold producer in 1992 was Rio Paracatu Mineraçao SA's Morro do Ouro Mine in Minas Gerais, where about 5,100 kg (164,600 ounces) of gold was recovered.

Chilean gold production increased 16% during 1992. Chile's largest gold mine, El Indio, near La Serena in the high Andes Mountains close to the Argentinean border, produced 7,100 kg (228,270 ounces) of gold plus values in silver and copper during 1992. The El Indio complex, consisting of the El Indio Mine and the nearby Tambo Mine, is 83%-held by LAC Minerals through a subsidiary, Compania Minera El Indio. The mine complex includes one open pit, underground mines on nine distinct vein systems, plant facilities, a heap-leach facility, and three camps. In April, Amax Gold acquired an indirect 90% interest in the small Guanaco heap-leaching project, which had been in operation under the previous owners since the mid-1980's. At yearend, work was under way to more than triple the mine's capacity to 160,000 tons per month. The expansion was expected to result in an annual gold production rate of 1,870 to 2,500 kg (60,000 to 80,000 ounces). The recovery plant of the Guanaco facility had formerly been in operation at Sociedad Contractual Minera Vilacollo's Choquilimpie Mine, which was exhausted and closed in November. Also in November, Amax agreed to acquire a 50% interest in the Refugio Project, east of Copiapo, in the Maricunga Mining District of central Chile. Amax expects to bring Refugio into production in about 2 years. Also in the Maricunga District, Placer Dome and TVX Gold Inc. completed their first full year of open pit and milling operations at their LaCoipa Mine, producing 61,000 kg (196,000 ounces) of gold and 500 tons (16.1 million ounces) of silver. Nearby to the north, gold production at Homestakes's wholly owned El Hueso Mine increased 8% to 2,190 kg (70,400 ounces). In mid-1992, BMG completed its first full year of production at its new San Cristobal Mine in the Atacama desert of northern Chile. Overcoming persistent startup problems, the new open pit and heap-leaching operation recovered 1,800 kg (58,000 ounces) of gold during 1992. BMG owns a 56.52% interest in San Cristobal through its affiliate, Niugini Mining Ltd. Despite weaker world gold prices, Chile abounds with precious-metals projects ranging from highly speculative ventures to highly advanced projects.

With 37 tons (1.2 million ounces) of gold produced in 1992, Colombia retained its position as Latin America's second largest gold-producing nation. Gold production is derived primarily from small to medium lode and placer mining operations in the Colombian divisions or Departments of Antioquia, Caldas, Chocó, and Tolima. Gold exploration and development, especially by foreign interests, in Colombia's many gold-bearing districts continues to be hampered by inaccessibility and by terrorist activity. On January 17, 1991, the Government of Colombia lifted its restrictions on holding, marketing, and trading in gold by Colombian residents.

In Costa Rica, Minera Rayrock Inc. continued gold exploration on its Bellavista property, 112 km (69 miles) west of San Jose. In April, Newmont Mining Corp. (NMC) and Mallon Resources Corp. signed an agreement for NMC to explore Mallon's Rio Chiquito property in the Guanacaste Province of northern Costa Rica. Mallon operated a small gold and silver mine on part of the property until mid-1989. Several other companies, including Phelps Dodge, BMG, Greenstone Resources Ltd., and Minnova Inc., maintained exploration projects in Costa Rica during 1992.

Reserves of oxide ore, long the source

of gold production at Rosario Dominicana S.A.'s Pueblo Viejo Mine in the Dominican Republic, have been exhausted. In April, a new processing plant was inauguarated to process lower grade or "transitional" material. Later, the company received permits to begin mining the large gold-bearing sulfide ore body. Processing of the sulfide ore will require the construction of processing facilities projected to cost $200 million. Canyon Resources Corp. and its partners, BMG, announced a gold discovery at the joint venture's EL Higo Exploration Concession in the Bonao area of the Dominican Republic.

In Western Guyana, construction was completed in late 1992 at the Omai Mine in Essequibo County. The new open pit mine, 160 km (100 miles) south of Georgetown, the capital, is reportedly expected to yield about 8.7 tons (260,000 ounces) of gold annually during the first 7 years of operation. The mine's new 12,000-ton-per-day mill began operation on December 15, milling ore with an approximate grade of 1.7 grams per ton. The mill is scheduled to reach full capacity by mid-1993. The mine is owned by Cambior Inc. (60%), Golden Star Resources Ltd. (35%), and the State of Guyana (5%). Elsewhere in Guyana, gold and diamonds continued to be recovered at the numerous placer mines operated by independant miners along many of Guyana's rivers and streams.

Mexican gold production increased 12% during 1992. During the year Mexico's new mining law become effective. The new law is designed to encourage increased foreign mineral investment and participation, as well as provide greater access to lands available for exploration; royalties previously imposed on new production were eliminated. Most of Mexico's gold is still produced as a byproduct of silver and base metal production; however, a number of new gold properties have been opened or were under development, especially in the Mexican State of Sonora. In November, Phelps Dodge Corp. and its partner, the Ariztequé Group, completed the first full year of heap-leach production at their new open pit Santa Gertrudis Mine in Sonora. Also in Sonora, Hecla Mining Co. continued development on its La Choya project near Sonoita. When production begins in mid-1993, La Choya is expected to produce 1,600 to 1,800 kg (50,000 to 60,000 ounces) of gold per year. East of Magedalena, Sonora, Red Rock Mining Corp., and it Australian partner, Wahalla Mining Co., continued open pit and heap-leaching development at the Amelia gold project. Similar activity was also reportedly under way at Campbell Resources Inc.'s. La Colorada property, a former producer, near Hermosillo in the La Colorada district of Sonora.

In mid-1992, Newmont Mining agreed with its partners to move ahead with production in mid-1993 at its Yanacocha gold project, 20 km (12 miles) north of Cajamarca in northern Peru. More than 3,100 kg (100,000 ounces) of gold will be recovered at Yanacocha annually using heap-leaching recovery methods. Liberalization of Peruvian gold laws in 1991 has reportedly ended problems associated with gold smuggling and led to an increase in the number of informal miners pursuing gold mining opportunities in Peru's numerous and remote lode and placer mining sites. An informal survey conducted in 1991 by U.S. Embassy personnel concluded that the approximately 25,000 miners pursuing placer gold in the Madre de Dios and Cuzco Departments, for example, were recovering about 1 gram (0.032 ounce) of gold per day—roughly equivalent in volume to about 5 grains of rice.

In Uruguay, American Resources Corp. (ARC), a publicly held copper and gold mining company based in San Francisco, CA, began operations near yearend at its Mahoma Mine and mill, about 100 km (62 miles) northwest of Montevideo. The mine, developed within the Florida Greenstone Belt north of Montevideo, is reportedly that country's first gold mine utilizing carbon-in-leach (CIL) recovery technology. The mine's transportable, 1,000-ton-per-day CIL plant, previously operated in Austraila, is expected by ARC to recover more than 1.2 tons (40,000 ounces) of gold in 1993 from ores mined by open pit methods at three separate gold deposits.

Exploration for gold, in addition to exploration that has long been conducted in gold fields throughout South America, also has been focusing in recent years on various islands of the Carribbean region where gold had formerly been mined or detected; this activity during 1992 included exploration or examination of the potential for gold on the islands of Aruba and Jamaica, the Republic of Cuba, and the Commonwealth of Puerto Rico.

Oceania.—Papua New Guinea's gold production, after declining to 14 tons (451,707 ounces) by 1980, had by 1992, increased nearly sixfold to 80.4 tons (2.6 million ounces). This increase was accomplished despite the forced closure in 1989 of CRA's 53.6%-held Bougainville copper mine on Bougainville Island, a major producer of byproduct gold. Papua New Guinea's largest gold mine, Placer Pacific Ltd.'s Porgera Mine, in the highlands of Enga Province, produced 46 tons (1,485,077 ounces) of gold from both surface and underground operations. The 22% increase in production over the previous year was reportedly attributed to increased mill throughput and improved recoveries, which were achieved through the operation of a new pressure oxidation circuit that came on-line in October 1991. CRA's Mount Kare alluvial project, also in Enga Province about 18 km (12 miles) southwest of Porgera, was attacked for a second time in less than 1 year by a group of 15 to 17 armed men in early January. The attack forced closure of the mine and resulted in more than $2 million in damage. The Mount Kare deposit, developed by Mount Kare Alluvial Mining Pty. Ltd., was discovered in 1988 by CRA Minerals (PNG) Ltd. CRA retains a 51% interest in the mine and has granted more than 5,000 local landowners the remaining 49% share in the mine under a unique arrangement to avoid conflict over ownership of the mineral wealth. The attack, reportedly led by a disgruntled ex-employee, involved the systematic destruction of equipment, including buildings, earth-moving equipment, and a helicopter. Production

was resumed at the mine in August. In late 1992, to resolve squabbles over the mine's ownership, CRA reportedly offered to relinquish its 51% interest in the property but only to the rightful landowners. Mount Kare is about 480 km northwest of the nation's capital of Port Moresby.

At the Misima Mine in Milne Bay Province, Misima Island Mines Pty. Ltd., wholly owned by Placer Dome, produced 11,642 kg (374,300 ounces) of gold during 1992. Higher ore grade and improved mine throughput were responsible for the 11% increase over 1991 production.

In the far west of Enga Province at Mount Fulbian, gold production at the OK Tedi copper-gold mine declined 29% from the previous year to 9.8 tons (313,862 ounces). Copper production, however, increased somewhat over that of 1991. Low water levels affected the shipment of gold-bearing copper concentrates from the remote mine site from time to time during the year. In 1982, during construction of the mine, the river ceased flowing completely, thus halting the movement of barges along the 1,290-km (800-mile) route between the mine and Port Moresby.

Development work was continued during the year at the giant Lihir Island gold deposit on a small island off the east coast of the Island of New Ireland. The Lihir project, which could begin production in 1993, is targeted to produce about 18.7 tons (600,000 ounces) of gold annually. The project is owned by partners RTZ Corp. (80%) and Niugini Mining Ltd. (20%). The mine is being developed on the coast and in the crater of an extinct volcano where control of high-temperature ground water has been one of the many problems tackled by the development team since the deposit was discovered more than 10 years ago.

Gold production in Fiji declined 7% from that of 1991, owing primarily to a slow recovery from an earlier labor dispute at the island's principal gold producer, the Emperor Mine at Vatukoula on the island of Viti Levu. Emperor first began gold and silver production in 1935. Both open pit and underground mining has been employed at the Emperor; however, surface mining ceased in late 1992. Ore from the open pit had been stockpiled and will be processed during 1993. The Vatukoula tailing project, begun in 1991, ceased operations in late 1992 owing to metallurgical problems that led to unacceptably low metal recoveries. Some gold exploration was conducted in the Fiji Islands, including investigations by Placer Pacific at its Namosi copper and gold deposit on Viti Levu. CRA investigated gold targets on Viti Levu and Vanua Levu.

In West Irian on the Indonesian side of the island of New Guinea, Freeport Indonesia, Inc. produced 19.9 tons (641,000 ounces) of gold at its Grasberg/Ertsberg copper and gold deposit. Grasberg reportedly possesses the largest published gold reserves of any single operating mine in the world. Freeport is planning to increase annual gold production from the operation to more than 37 tons (1.2 million ounces) by 1996. The company continued exploration of the Big Gossan copper-gold prospect near the original Ertsberg mine site and began exploration on its newly acquired 2.6-million-hectare (6.5-million-acre) exploration area north of the Grasberg Mine. In January, Kelian Equatorial Mining, 90%-held by CRA, poured its first bar of production gold at the new open pit Kelian Mine. The new mine, in the Province of East Kalimantan, produced 14,535 kg (467,311 ounces) of gold and 15,333 kg (494,967 ounces) of silver during 1992. Gold exploration continued throughout the islands of Indonesia. Discoveries were reportedly made in the West Java Province and on Wetar Island. Newmont reported that drilling was in progress at its Minahasa prospect on the Island of Sulawesi and its Batu Hijau prospect on the Island of Sumbawa.

On New Zealand's North Island near Waihi, Cyprus Gold New Zealand Ltd. began commercial operations in February at its new Golden Cross project. The new surface and underground operation produced about 2,720 kg (87,400 ounces) of gold. At yearend, Cyprus was evaluating the possible sale of its 80% interest in the project; the remaining 20% interest is held by the Todd Corp. Ltd., a private New Zealand company. Within the town of Waihi, Amax Gold Ltd. produced 2,368 kg (76,126 ounces) of gold at its 33.53%-held Waihi Mine. Amax's partners in the open pit mine, which began production in mid-1988, are ACM Gold Ltd. and Mineral Resources (NZ) Ltd. New Zealand's largest gold mine, the Macraes Mine, 60 km (37 miles) north of Dunedin in the Otago region of the South Island, produced 3,200 kg (103,000 ounces) of gold during 1992. The mine is owned by Macraes Mining Co. Ltd.

Other Asia.—Gold production in the Philippine Islands declined 4% from the previous year, reflecting cutbacks and closures at several Philippine mines. In late December, Benguet Corp. announced the shutdown of its underground Acupan and Balatoc gold mines near Baguio. The phaseout of mining operations, which followed an earlier announced round of closures and cutbacks at other company-owned mines in Benguet Province on the Island of Luzon, was reportedly attributed to continuing low gold prices and the improved value of the Philippine peso. Cutbacks also were initiated by several other Philippine gold mining companies. Gold production was begun in February at Benguet's Grand Antamoc gold mining project in the Antamoc Valley north of Manila in Benguet Province. The new open pit and milling operation reportedly yielded 2,749 kg (88,400 ounces) of gold during the year.

The Philippines' second largest gold mine, the Masbate Mine of Atlas Consolidated Mining and Development Co. in the Aroroy gold district of Masbate Island, reportedly produced about 2,500 kg (80,500 ounces) of gold or about the same as that in the previous year. Both open pit and underground mining methods are employed. Drilling and exploration were continued at CRA's 40%-held Far Southeast copper and gold project at Lapanto on the Island of Luzon. An underground drilling project was under way and will extend well into 1993. Philex Mining Corp. continued

development at its Bulawan gold project on Negros Island. Small-scale artisinal mining continued throughout the Philippines and especially on the southern island of Mindanao.

On Japan's northern Island of Hokkaido, a prospecting team fielded by the Nissho Iwai Corp., Australian Gold NL, and MIM Holdings Ltd. reportedly discovered a high-grade gold deposit at the Heisei Buho Mine west of Sapporo. One drill sample reportedly returned 72.8 grams per ton (2.1 ounces per short ton) of gold and 56 grams per ton (1.6 ounces per short ton) of silver. Further exploration will be needed to determine if this is a minable deposit.

In a move to liberalize its gold markets, an agreement in principle was reached during mid-January by the Government of Taiwan to abolish a ban imposed in 1949 on the trading and exporting of gold by private citizens. Currently, only certain Government agencies and firms are permitted to trade gold bullion. Finalization of the new regulations was expected to occur later in the year.

On February 5, the Government of Thailand reportedly removed its 5% import duty on gold. Before October 1991, when the 5% duty was established, the duty on imported gold stood at 35%. Removal of the duty will allow Thai jewelry manufacturers to purchase gold at international prices and was expected to spur domestic gold jewelry fabrication. Earlier in the year the Government introduced a 7% value added tax on consumer goods; gold is reportedly more or less exempt from the value added tax in that the tax is refunded when the gold is sold or exported.

Russia and the Former U.S.S.R.—Before the dissolution of the U.S.S.R., that country ranked as one of the world's largest gold-producing nations. In late 1991, the U.S.S.R. dissolved into 15 separate countries. The gold-producing countries in the former U.S.S.R., in declining order of production, are Russia, Uzbekistan, Kazakhstan, Kyrgyzstan, Tajikistan, Armenia, and Georgia. The Ukraine has significant potential gold deposits, which it is trying to develop. From 1926 until the recent dissolution, all matters pertaining to gold, including all data on production, had been classified as state secrets. Beginning in mid-1992, production data for the various gold-producing states of the former U.S.S.R. became available (shown in table 11). In 1992, Russian secrecy laws were reportedly amended to permit access by the International Monetary Fund (IMF) to annual gold data for 1989 through 1991. The resolution to permit disclosure was passed in conjunction with Russia's induction into the IMF. Russia, by far the dominant gold-producing country in the former U.S.S.R., produced nearly 60% of the 252 tons (8.1 million ounces) of aggregate from former U.S.S.R. producers listed in table 11. More than one-half of Russia's gold is produced in the Magadan region of the far eastern region of Russia while other important gold-producing areas include the Yakutia region of northeastern Russia and the Lena River area further west.

The Russian gold mining industry is highly organized, with the chain of management beginning with the state and progressing downward through regional gold associations, then to large gold mining companies, and finally to independent gold prospecting companies called "artels." About 250 artels reportedly exist in the former U.S.S.R. and have been responsible for more than one-half of the gold produced in recent years. Artals may employ up to 1,000 people; they are highly independent, mobile, and better able to exploit unattractive gold deposits, especially alluvial deposits, than the larger corporations. At the end of 1991, Glavalmazzoloto 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 Rosalmazzoloto (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.

As in the previous 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 have been able to establish tentative ties with emerging Russian businesses. One U.S. company, for example, Newmont Mining Corp., announced in early 1992 that a joint-venture agreement had been signed with the former Soviet Republic of Uzbekistan to produce gold for export. The joint project would employ Newmont's leaching technology to treat low-grade gold ore stockpiled at the Muruntau gold mine in Uzbekistan. The Muruntau Mine is the largest open pit gold mine in the world, producing 56 tons (1.8 million ounces) of gold annually. The stockpile contains an estimated 150 million tons of material with an average grade of 1.16 grams per ton (0.03 ounce per short ton). Construction of the project was expected to begin in 1992, with gold output slated to begin in late 1993. Newmont's success notwithstanding, many questions remained to be answered before foreign companies could proceed to establish firm, workable relationships. There is still considerable 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. By the same token, considerable uncertainty exists on the part of gold miners in the former U.S.S.R. as to exactly how to approach potential foreign investors and how to establish a workable and equitable relationship of the sort required to develop the apparently vast resources.

South Africa, Republic of.—The world's dominant gold-producing nation, the Republic of South Africa, increased production more than 2% during 1992 to 613,900 kg (19.1 million ounces). The increase could be attributed primilary to a more than 3% improvement in the average recovery grade of ore mined from 5.20 grams per ton (0.152 ounce per short ton) mined in 1991 to 5.37

grams per ton (0.157 ounce per short ton) mined during 1992. In terms of the tonnage of ore processed annually, 106 million tons (117 million short tons) was milled during 1992 by the nearly three dozen mines representing the membership of the Chamber of Mines of South Africa. This tonnage compares with 107 million tons (118 million short tons) milled by chamber members during the previous year and represents the third consecutive year in which the tons of ore milled has declined. This decline can be partially attributed to the industry's drive to maintain productivity and profitability by concentrating on the selective mining of higher grade reserves. Significant strides continued to be made in reducing the rate of increase in working costs per unit of gold produced; the rate of increase in average annual production costs slowed from 10% between 1989 and 1990 to 4% in 1991 and less than 1% by the end of 1992. This achievement was all the more remarkable considering that the average domestic inflation rate during 1992 was 14%.

Unlike many other major gold-producing nations where production is highly mechanized, South African gold mines are extremely labor intensive. Wages paid during 1992 amounted to more than one-half of the total production costs, and many mines not amenable to mechanization have been increasingly under pressure to maintain employment and to meet demands for increased wages during a difficult period of stagnant world prices. Some operations are approching a point at which further reductions in employment will become counter productive. This, combined with the continuing downward trend in capital expenditures in real terms on operating mines, implies reduced longevity as higher grade ore reserves become depleted. In addition to pursuing every possible cost savings in labor and processing, many mines continued their hedging activities on the world's futures markets. Expanded hedging activities by a number of mines since 1989 have reportedly raised the average price received in terms of South African rands by nearly 2%. Some industry observers have speculated that without an improvement in the economic conditions affecting the mines that some marginal operations will soon be forced to close and production will decline, possibly to below 500 tons by the year 2000.

The South African gold mining industry is denominated by six major corporate groups or "houses," including Anglo American Corp. of South Africa Ltd. (AAC), Gold Fields of South Africa Ltd. (GFSA), Johannesburg Consolidated Investment Co. Ltd. (JCI), Anglovaal Ltd., Gencor Ltd., and Rand Mines Ltd.

Gold production costs for chamber members ranged during 1992 from a low of $169 per ounce ($5.43 per gram) recovered at Gencor's Bracken Mine to a high of $388 per ounce ($12.48 per gram) at the Stilfontein Mine, also owned by Gencor. The average cost per troy ounce during 1992 was $265.

The largest South African gold mines, in metric tons of gold produced, included AAC's Freegold Mine with 115.7; the Vaal Reef Mine, also owned by AAC, at 75.4; GFSA's Driofontein Mine with 57.3; AAC's Western Deep Levels Mine with 38.4; and JCI's Randfontein Mine with 31.7.

To reduce costs and streamline mining operations, Gengold, the gold mining division of Gencor, announced in mid-1992 a plan to merge its two largest mines, Kinross Gold Mines and Winkelhaak Mines, both in the Evander area of the Orange Free State (OFS). The main purpose behind the proposal reportedly was to have the Winkelhaak Mine operating under the tax shield of Kinross and thereby justify a capital expansion program required to access deeper ore via a new subvertical shaft project. In the fall of 1992, AAC announced that it had begun construction on a new high-grade deep level gold mine in the Moab area of the OFS. The new 2,149-hectare (5,300-acre) area to be developed is contiguous to AAC's Vaal Reefs Exploration and Mining Corp.'s Vaal Reefs Mine. Production is expected to begin in 1997 and, when fully operational, to produce 13 tons (418,000 ounces) of gold per year. The ore body at Moab will be accessed via a 2,500-meter (8,200-foot) main shaft and two subshafts to a total depth of 3,700 meters (12,140 feet). AAC's 47.9%-held SA Land and Exploration (Sallies) operation, which had been recovering gold by treating rocks and mine dumps in the goldfields southeast of Johannesburg, ceased operations in August.

In an effort to conserve cash, several of the large gold mining companies placed exploration projects on hold and generally reduced their expenditures for exploration. Smaller companies, however, tended to forge ahead with spending on existing projects, which have been under way for several years. JCI's South Deep Exploration Co. continued exploration on the Ventersdorp Contact Reef adjacent to the company's Western Area Mine in the OFS. In the northern OFS, Anglovaal and its 53%-owned subsidiary, Middle Witwatersrand, continued exploration in the Bothaville Gap area of the OFS. One exploration project near Anglovaal's Lorain Mine reportedly uncovered results sufficient enough to justify continued support.

On January 1, 1992, South Africa's new Minerals Act came into effect. The new legislation, in addition to repealing or amending various existing statutes affecting mining in general, eliminates the state's exclusive right to mine precious metals and stones. The change also eliminated state-issued mining leases and the payment of royalties, and introduced strict environmental and reclamation requirements.

Current Research

The USBM 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.[12] Because gold mining is pursued in many nations, the results of the ongoing work may, like USBM's earlier work in heap leaching, ultimately benefit a broad segment of the industry worldwide. In recent years, the USBM's research relating to gold mining has generally focused on the use of cyanide in the recovery process. The

USBM 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 USBM was also investigating the leaching of metals from very low-grade ores with the aid of 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. The outlook for a sustained high rate of world gold demand, according to GFMS in its annual review,[13] depends to a large extent on three key factors: maintenance of the growth in Chinese consumption, avoidance of full-scale recessions in Western Europe and Japan, and decisions that may be made in the future by the world's central banks regarding the future composition, disposition, and makeup of their gold reserve assets. The review notes that despite a net positive increase in Western gold investments since the second half of 1992, what the central banks ultimately may decide to do or not to do with their reserves remains a key factor in inhibiting renewed investor purchases. The threat of heavy disposals such as those seen during 1992 may be seen by some potential investors as a deterrent to price stability. On the other hand, GFMS suggests that, were the official sales of last year to be repeated, there is every reason to believe that they could once again be absorbed without further damaging the market.

Because the fortunes of the domestic gold market as a component of the global market are inextricably tied to international developments, especially those that influence the world market price for gold, those key influences cited by GFMS for the world market outlook also may be seen as key factors affecting the domestic outlook for gold demand. With regard to the domestic supply side and new mine production in particular, the continued viability of the domestic gold exploration and mining sector and maintenance of the United State's position as the world's second-largest gold producer depends to a large extent on the outcome of the current debate over proposed changes to the General Mining Law and the extent to which other emerging regulatory initiatives affecting mining and rural enterprise in general progress.

[1]Ounce refers to troy ounce. One kilogram of gold weighs 32.1507 troy ounces.

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[11]Couturier, G. Precious Metals—Gold. The No. Miner Mag. v. 8, No. 2, Mar. 1993, pp. 25—27.

[12]U.S. Bureau of Mines. Research 1992. BuMines, 1992, 175 pp.

[13]Work cited in footnote 10.

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TABLE 1
SALIENT GOLD STATISTICS

		1988	1989	1990	1991	1992
United States:						
Mine production	kilograms	200,914	265,731	r294,189	r295,957	329,124
Value in dollars per troy ounce	thousands	r$2,831,278	r$3,268,553	r$3,640,820	r$3,456,786	$3,650,328
Percentage derived from:						
Precious-metal ores		W	W	W	W	W
Base metal ores		W	W	W	W	W
Placers		2	2	1	1	1
Refinery production:						
Domestic and foreign ores	kilograms	137,829	183,685	r225,183	r224,675	283,951
Secondary (old scrap)	do.	r61,391	r51,756	r43,809	r47,546	53,396
Imports for consumption:						
Refined	do.	57,590	96,967	64,755	147,491	141,251
Other	do.	34,867	55,537	32,764	r31,258	33,089
Exports:						
Refined	do.	271,335	123,599	140,923	174,377	256,845
Other	do.	56,902	87,492	155,474	109,750	112,006
Gold contained in imported coins[2]	do.	17,947	13,218	8,429	3,514	NA
Net deliveries from foreign stocks in Federal Reserve Bank	do.	208,277	132,231	51,464	61,595	136,389
Stocks, Dec. 31:						
Industry[3]	do.	38,360	30,462	37,065	39,411	36,713
Futures exchange[4]	do.	44,634	69,727	50,881	49,893	46,453
Volume of U.S. Gold Futures Trading[5]	metric tons	29,920	31,065	30,260	21,200	18,669
Department of the Treasury:[6]						
American Eagle gold coin[7]	kilograms	17,416	16,544	17,397	13,713	11,133
Other numismatic gold coins	do.	8,626	1,349	695	952	965
Consumption in industry and the arts	do.	111,836	115,078	118,065	r114,333	109,639
Price:[8] Average per troy ounce		$438.31	$382.58	$384.93	$363.29	$344.97
Employment[9]		13,100	15,100	16,100	15,100	14,700
World:						
Production, mine	kilograms	r1,873,803	r2,030,114	r2,132,953	r2,148,743	e2,247,840
Official reserves[10]	metric tons	35,829	r35,652	r35,619	r35,547	35,240

eEstimated. rRevised. NA Not available. W Withheld to avoid disclosing company proprietary data.

[1]Calculated by the Gold Institute from reports by the Bureau of the Census.

[2]Net imports (exports).

[3]Unfabricated refined gold held by refiners, fabricators, dealers, and U.S. Department of Defense.

[4]Commodity Exchange Inc. only. Stocks held by other exchanges estimated to be less than 2% of totals shown.

[5]Exchanges: Commodity Exchanges Inc., Chicago Board of Trade International Monetary Market (1988 only), and Mid-America Commodity Exchange.

[6]Sales to market fiscal year 1988-90. Fiscal year begins Oct. 1, of previous year indicated. Gold bullion disbursements to U.S. Mint coin programs fiscal 1991.

[7]Sales program began Oct. 20, 1986.

[8]Engelhard Industries quotation.

[9]Mine Safety and Health Administration.

[10]Held 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	1988	1989	1990	1991	1992
Alaska[1]	4,210	5,756	3,232	r3,200	5,003
Arizona	4,549	2,768	5,000	r6,195	6,656
California	22,442	29,804	29,607	r30,404	33,335
Colorado	5,126	3,448	2,357	3,181	3,763
Idaho	3,218	3,057	W	3,348	3,177
Michigan	W	W	—	—	—
Montana[2]	9,175	12,434	13,012	r13,715	13,994
Nevada	114,322	153,995	179,078	r180,382	203,165
New Mexico	W	1,076	888	W	W
Oregon	W	W	W	—	W
South Carolina	W	W	W	W	6,747
South Dakota	13,981	16,123	17,870	16,371	18,681
Utah	W	W	W	W	W
Washington	W	W	9,620	9,954	8,802
Total	200,914	265,731	r294,189	r295,957	329,124

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Total."

[1]These 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: 1988—8,258; 1989—8,852; 1990—7,206; 1991—7,585; and 1992—8,163.

[2]In addition to reported data shown in the table, placer production was estimated by the State to have been as follows, in kilograms: 1992—84.

TABLE 3

TWENTY-FIVE LEADING GOLD-PRODUCING MINES IN THE UNITED STATES IN 1992, 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	Homestake	Lawrence, SD	Homestake Mining Co.	Gold ore.
5	Smokey Valley Common Operation	Nye, NV	Round Mountain Gold Corp.	Do.
6	Bullfrog	do.	LAC Minerals	Do.
7	Jerritt Canyon (Enfield Bell)	Elko, NV	Independence Mining Co. Inc.	Do.
8	McCoy and Cove	Lander, NV	Echo Bay Mining Co.	Do.
9	McLaughlin	Napa, CA	Homestake Mining Co.	Do.
10	Paradise Peak	Nye, NV	FMC Gold Co.	Do.
11	Chimney Creek	Humboldt, NV	Goldfields Mining Corp.	Do.
12	Getchell	do.	FMG Inc.	Do.
13	Mesquite	Imperial, CA	Goldfields Mining Corp.	Do.
14	Battle Mountain Complex	Lander, NV	Battle Mountain Gold Co.	Do.
15	Rabbit Creek	Humboldt, NV	Rabbit Creek Mining Inc.	Do.
16	Ridgeway	Fairfield, SC	Ridgeway Mining Co.	Do.
17	Sleeper	Humboldt, NV	Nevada Gold Mining Inc.	Do.
18	Jamestown	Tuolumne, CA	Sonora Mining Corp.	Do.
19	Lone Tree	Humboldt, NV	Santa Fe Pacific Mining Co.	Do.
20	Cannon	Chelan, WA	Asamera Minerals (U.S.) Inc.	Do.
21	Mercur	Tooele, UT	Barrick Goldstrike Mines Inc.	Do.
22	Copperstone	La Paz, AZ	Cyprus Copperstone Gold Corp.	Do.
23	Barney's Canyon	Salt Lake, UT	Kennecott Corp.	Do.
24	Zortman-Landusky	Phillips, MT	Pegasus Gold Inc.	Do.
25	Golden Sunlight	Jefferson, MT	Golden Sunlight Mines Inc.	Do.

TABLE 4

GOLD PRODUCED IN THE UNITED STATES, BY STATE, TYPE OF MINE, AND CLASS OF ORE

Year and State	Placer (kilograms of gold)	Lode			
		Gold ore		Silver ore	
		Metric tons	Kilograms of gold	Metric tons	Kilograms of gold
1988	4,754	127,883,933	181,891	W	W
1989	5,711	169,380,297	236,207	W	W
1990	2,579	r199,123,615	r271,930	W	W
1991	2,888	r218,163,758	r271,837	W	W
1992:					
Alaska	W	W	W	—	—
Arizona	—	W	W	—	—
California	W	25,377,752	W	—	—
Colorado	—	W	W	—	—
Idaho	—	W	W	—	—
Montana	—	16,909,543	11,617	—	—
Nevada	W	164,180,070	201,277	W	W
New Mexico	—	W	W	—	—
Oregon	W	—	—	—	—
South Carolina	—	W	6,747	—	—
South Dakota	—	8,350,389	18,681	—	—
Utah	—	W	8,767	—	—
Washington	—	W	8,802	—	—
Total	4,727	236,771,802	299,757	W	W
Percent of total gold	1	XX	91	XX	W

	Lode				Total	
	Copper ore		Other[1]			
	Metric tons	Kilograms of gold	Metric tons	Kilograms of gold	Metric tons	Kilograms of gold
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	r156,175,612	W	W	W	r362,624,535	r294,189
1991	r196,307,948	W	W	W	r423,306,016	r295,957
1992:						
Alaska	—	—	W	W	W	5,003
Arizona	W	W	—	—	116,642,268	6,656
California	—	—	—	—	25,377,752	33,335
Colorado	—	—	W	W	3,309,380	3,763
Idaho	—	—	W	W	4,348,984	3,177
Montana	W	W	W	W	39,565,274	13,994
Nevada	—	—	W	16	170,853,630	203,165
New Mexico	W	W	—	—	W	W
Oregon	W	W	—	—	W	W
South Carolina	—	—	—	—	W	6,747
South Dakota	—	—	—	—	8,350,389	18,681
Utah	W	W	—	—	W	W
Washington	—	—	—	—	W	8,802
Total	200,467,384	W	W	W	448,986,615	329,124
Percent of total gold	XX	W	XX	W	XX	100

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Total." XX Not applicable.

[1]Includes gold-silver, 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 AND METHOD OF RECOVERY

Year and State	Cyanidation		Smelting of concentrates			Smelting of ore		Other processes[1]		Total ore processed[2] (metric tons)	Total 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)	Ore treated (metric tons)	Gold recovered (kilograms)		
1988	133,042,143	173,493	207,228,838	3,969,256	21,057	W	W	W	W	340,614,832	200,914
1989	172,294,506	228,040	189,266,803	3,827,109	30,283	W	W	W	W	391,059,545	265,731
1990	r197,583,498	r264,494	163,749,630	3,649,072	25,828	W	W	W	W	r362,624,535	r294,189
1991	r220,998,776	r266,048	201,369,753	3,907,816	r24,482	W	W	W	W	r423,306,016	r295,957
1992:											
Alaska	—	—	W	W	W	W	W	—	—	W	[3]5,003
Arizona	W	W	115,631,492	2,232,479	W	W	W	—	—	116,642,268	6,656
California	23,377,752	W	—	—	—	—	—	—	—	25,377,752	[3]33,335
Colorado	2,863,927	3,012	W	W	W	W	W	—	—	3,309,380	3,763
Idaho	W	W	W	W	W	—	—	—	—	4,348,984	3,177
Montana	16,909,543	11,617	22,005,526	263,974	2,006	—	—	650,205	371	39,565,274	13,994
Nevada	170,853,629	203,118	—	—	—	1	W	—	—	170,853,630	[3]203,165
New Mexico	—	—	W	W	W	W	W	—	—	W	W
Oregon	—	—	W	W	W	—	—	—	—	W	W
South Carolina	W	6,747	—	—	—	—	—	—	—	W	6,747
South Dakota	8,350,389	18,681	—	—	—	—	—	—	—	8,350,389	18,681
Utah	6,117,934	8,572	W	W	W	45,361	195	—	—	W	W
Washington	W	W	W	W	W	—	—	W	W	W	8,802
Total	243,111,199	298,637	204,815,351	3,998,649	22,806	W	W	W	W	448,986,615	324,397

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Total," where applicable.

[1]Includes metal recovered by gravity methods.

[2]Includes 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.

[3]Includes some placer production to avoid disclosing company proprietary data.

TABLE 6
GOLD PRODUCED IN THE UNITED STATES BY CYANIDATION[1]

Year	Extraction in vats, tanks, and closed containers[2]		Leaching in open heaps or dumps[2]	
	Ore treated (metric tons)	Gold recovered[3] (kilograms)	Ore treated (metric tons)	Gold recovered[4] (kilograms)
1988	30,779,239	100,817	102,262,904	72,676
1989	42,464,260	121,716	129,830,246	106,324
1990	r47,614,538	135,764	r149,968,960	r128,730
1991	r61,221,904	r169,270	r159,776,872	r96,778
1992	65,220,811	185,169	177,890,388	113,468

rRevised.
[1]May include small quantities recovered by leaching with noncyanide solutions and by proprietary processes.
[2]May include tailings and waste ore dumps.
[3]May include small quantities recovered by gravity methods.
[4]May include metal recovered by leaching of previously mined ore at some inactive mines.

TABLE 7
U.S. REFINERY PRODUCTION OF GOLD

(Kilograms)

Raw material	1988	1989	r1990	r1991	1992
Concentrates and ores:					
Domestic and foreign	137,829	183,685	225,183	224,675	283,951
Old scrap	r61,391	r51,756	43,809	47,546	53,396
New scrap	r66,186	r105,942	100,553	105,086	109,545
Total	r265,406	r341,383	r369,544	377,307	446,892

rRevised.
[1]Data do not add to total shown because of independent rounding.

TABLE 8
U.S. CONSUMPTION OF GOLD,[1] BY END-USE SECTOR

(Kilograms)

End use	1988	1989	1990	1991	1992
Jewelry and the arts:					
Karat gold	57,959	60,877	69,801	79,875	78,634
Fine gold for electroplating	1,469	1,283	429	373	581
Gold-filled and other	7,598	7,364	8,132	3,819	3,546
Total[2]	67,027	69,524	78,362	84,067	82,761
Dental	7,576	7,927	8,700	8,485	6,543
Industrial:					
Karat gold	1,104	1,215	1,020	1,068	1,082
Fine gold for electroplating	15,088	20,684	17,251	12,624	10,476
Gold-filled and other	21,034	15,723	12,725	r8,089	8,777
Total[2]	37,226	37,621	30,996	r21,781	20,336
Small items for investment[3]	7	7	7	—	—
Grand total[2]	111,836	115,078	118,065	r114,333	109,639

rRevised.
[1]Gold consumed in fabricated products only; does not include monetary bullion.
[2]Data may not add to totals shown because of independent rounding.
[3]Fabricated bars, medallions, coins, etc.

TABLE 9

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 (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
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	10	98	64,204	653,748	45,536	486,266	174,377	2,038,850	284,127	3,178,962
1992:										
Belgium	—	—	2,455	27,968	—	—	—	—	2,455	27,968
Brazil	—	—	—	—	99	1,125	299	3,325	398	4,449
Canada	5	31	30,559	217,591	14,411	117,477	12,335	139,714	57,310	474,814
China	—	—	64	588	256	3,558	1,587	19,063	1,907	23,209
France	—	—	15,154	168,822	16,297	179,760	425	4,785	31,877	353,367
Germany	—	—	6,145	63,387	1,706	18,906	1,606	19,240	9,457	101,533
Hong Kong	—	—	11	104	1,944	21,850	42,936	491,743	44,891	513,697
Israel	—	—	79	819	164	1,514	392	4,221	636	6,554
Japan	—	—	121	1,232	1,414	14,653	10,890	117,721	12,424	133,605
Korea, Republic of	—	—	3	43	339	3,386	1,243	14,061	1,585	17,490
Malaysia	4	43	—	—	—	—	1,000	12,325	1,004	12,368
Mexico	—	—	7	76	3	33	12,838	142,287	12,848	142,396
Saudi Arabia	—	—	—	—	—	—	501	5,699	501	5,699
Singapore	—	—	313	1,316	—	—	6,163	71,408	6,476	72,723
Spain	—	—	1	8	—	—	1,458	16,099	1,459	16,107
Sweden	—	—	901	9,634	83	556	—	—	984	10,190
Switzerland	—	—	1,455	16,867	9,139	101,426	38,644	425,013	49,239	543,307
Taiwan	(5)	4	—	—	1	3	40,115	472,139	40,116	472,146
United Arab Emirates	—	—	—	—	—	—	625	6,920	625	6,920
United Kingdom	15	110	3,473	37,889	5,114	54,061	83,034	903,346	91,636	995,407
Other	6	33	226	2,527	38	354	753	8,267	1,022	11,181
Total[4]	30	221	60,968	548,873	51,008	518,661	256,845	2,877,377	368,851	3,945,133

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, export data may not be comparable with previous years' data.
[2]Bullion also moves in both directions between U.S. markets and foreign stocks on deposit in the Federal Reserve Bank. Montetary gold excluded.
[3]Includes gold content of base metal ores, concentrates, and matte destined for refining.
[4]Data may not add to totals shown because of independent rounding.
[5]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 10

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)
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	992	10,874	24,668	126,264	5,597	66,735	147,491	1,721,576	178,749	1,925,449
1992:										
Argentina	—	—	1,274	45	—	—	52	583	1,326	628
Belgium	—	—	—	—	—	—	1,128	12,472	1,128	12,472
Brazil	—	—	164	1,038	—	—	3,594	39,180	3,758	40,218
Bolivia	—	—	11	94	—	—	25,549	282,478	25,560	282,572
Canada	7	89	5,251	32,036	13,643	141,652	89,308	998,105	108,208	1,171,882
Chile	—	—	124	443	424	4,074	6,301	69,536	6,848	74,053
Costa Rica	—	—	408	2,631	549	5,994	13	77	969	8,702
Dominican Republic	—	—	3,412	15,923	573	5,427	—	—	3,985	21,350
Ecuador	—	—	—	—	507	5,445	406	4,200	913	9,645
Guyana	—	—	1,050	2,577	—	—	105	1,101	1,155	3,678
Malaysia	—		427	1,848	—	—	—	—	427	1,848
Mexico	314	3,497	720	706	487	5,489	198	2,123	1,718	11,816
Netherlands	—	—	596	518	—	—	—	—	596	518
Panama	—	—	160	771	276	2,160	128	1,304	564	4,236
Peru	1	10	—	—	—	—	3,558	36,681	3,559	36,691
Philippines	—	—	957	245	121	1,507	8	87	1,086	1,839
Swaziland	—	—	—	—	346	2,532	—	—	346	2,532
Switzerland	—	—	6	64	2	21	4,570	51,291	4,578	51,375
Trinidad and Tobago	—		425	5,161	—	—	125	1,316	550	6,477
United Kingdom	—	—	13	144	—	—	208	2,389	220	2,535
Uruguay	—	—	—	—	—	—	5,334	57,711	5,334	57,711
Other	29	281	653	2,132	165	1,239	666	7,551	1,513	11,206
Total[4]	351	3,877	15,649	66,376	17,092	175,542	141,251	1,568,186	174,341	1,813,984

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, export data may not be comparable with previous years' data.
[2]Bullion also moves in both directions between U.S. markets and foreign stocks on deposit in the Federal Reserve Bank. Monetary gold excluded.
[3]Includes gold content of base metal ores, concentrates, and matte destined for refining.
[4]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11

GOLD: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1988	1989	1990	1991	1992[e]
Argentina	962	1,150	[e]1,200	1,478	1,500
Armenia[3]	—	—	—	—	300
Australia	156,950	203,563	244,137	234,218	240,000
Belize	—	—	1	5	5
Bolivia	4,889	3,595	5,198	[r]3,500	[6]4,688
Botswana[e 4]	21	66	45	[r]20	20
Brazil[5]	[r]112,159	[r]102,849	[r]85,098	[r]75,844	76,000
Burkina Faso[e]	9,300	7,600	[r]5,300	8,000	8,000
Burundi	14	18	9	25	32
Cameroon[e]	8	8	8	8	8
Canada	134,813	159,494	167,373	[r]176,552	[6]158,049
Central African Republic	382	328	241	[r]176	175
Chile	20,614	22,559	27,503	[r]28,668	33,300
China[e]	78,000	90,000	100,000	120,000	140,000
Colombia	29,014	29,506	29,352	[r]34,844	37,000
Congo	[r e]4	[r]3	[r]7	[r]12	5
Costa Rica[7]	313	387	[e]460	[r]550	550
Côte d'Ivoire	6	13	20	1,100	1,750
Dominican Republic	5,785	5,238	4,354	[r]3,160	2,000
Ecuador	[r]10,200	[r]10,390	[r]10,710	12,000	11,000
Ethiopia[8]	728	745	[r]848	3,038	3,000
Fiji	4,273	4,221	4,115	[r]3,333	[6]3,102
Finland	2,035	2,491	2,813	[r]2,200	1,600
France	2,753	3,303	4,236	[e]3,700	4,000
French Guiana	530	544	870	[r]1,417	1,600
Gabon[9]	138	81	[e]80	[r]50	50
Georgia[3]	—	—	—	—	200
Germany:					
Eastern states	2,000	2,047	1,751	—	—
Western states[e]	16	16	18	—	—
Total	2,016	2,063	1,769	[r e]10	—
Ghana	11,601	13,358	16,840	26,310	[6]31,031
Guatemala	—	48	62	31	40
Guinea	[e 10]2,000	[e 10]2,120	[10]6,340	[r]4,453	[6]2,113
Guyana[e]	2,330	3,200	3,500	[r]3,600	3,700
Honduras	127	[r]160	[r]156	[r]179	180
Hungary[e]	560	500	500	600	600
India[11]	1,942	1,827	1,983	1,973	2,000
Indonesia[12]	4,738	6,155	11,158	16,879	[6]37,983
Iran[e]	400	400	500	800	1,000
Japan	7,310	6,098	7,303	[r]8,299	[6]8,893
Kazakhstan[3]	—	—	—	—	24,000
Kenya	17	15	25	[r]20	20

See footnotes at end of table.

TABLE 11—Continued

GOLD: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1988	1989	1990	1991	1992[e]
Korea, North[e]	5,000	5,000	5,000	5,000	5,000
Korea, Republic of[11]	11,121	14,270	20,760	[r]20,809	21,000
Kyrgyzstan[3]	—	—	—	—	1,000
Liberia[13]	677	734	[e]600	[e]600	700
Madagascar	90	45	[r]216	[r e]200	200
Malaysia	2,929	2,884	2,594	[r]2,777	[6]3,513
Mali[e]	[14]2,650	[14]3,000	[14]5,200	[r]4,900	5,700
Mexico	9,098	8,613	8,338	[r]8,937	10,000
Mongolia[e]	1,000	1,200	1,000	800	900
Mozambique	—	—	63	394	750
Namibia	240	336	[r]1,605	1,857	[6]2,009
New Zealand	2,404	4,766	[r]4,626	[r]6,758	9,700
Nicaragua	878	1,410	[e]1,200	1,154	[6]1,323
Panama	—	—	85	194	[6]250
Papua New Guinea	38,129	27,538	[r]31,938	60,780	[6]80,390
Peru	9,164	9,898	[r e]10,000	[r]8,682	9,500
Philippines	30,482	29,992	24,591	24,938	24,000
Portugal	267	295	[e]350	[e]360	350
Romania[e]	5,000	6,000	6,000	5,000	4,000
Russia[3]	—	—	—	—	146,000
Rwanda[e]	15	745	700	700	700
Saudi Arabia	[e]1,000	2,900	3,536	[r]4,300	4,600
Sierra Leone[15]	[r]44	[r]226	[r]32	[r]26	[6]92
Solomon Islands	47	[r]33	[e]35	[e]30	25
South Africa, Republic of	621,000	607,460	[r]605,100	601,013	[6]613,900
Spain	[r]7,882	[r]8,566	[r]8,705	[r]8,600	8,000
Sudan[e]	300	500	100	50	150
Suriname[e]	[r]22	31	30	30	30
Sweden	3,590	5,120	6,326	[r]6,247	6,000
Taiwan[11]	236	269	72	—	—
Tanzania	52	116	[r]1,629	[r]2,799	2,800
Tajikistan[3]	—	—	—	—	500
U.S.S.R.[16]	277,600	304,000	302,000	[r]260,000	—
United States	200,914	265,731	[r]294,189	[r]296,805	[6]329,124
Uzebistan[3]	—	—	—	—	80,000
Venezuela	3,502	3,867	7,700	4,215	5,000
Yugoslavia	4,620	3,741	8,190	6,000	5,000
Zaire[e]	[r]12,500	[r]10,600	[r]9,300	[r]8,800	8,000

See footnotes at end of table.

TABLE 11—Continued

GOLD: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1988	1989	1990	1991	1992[e]
Zambia[17]	227	129	129	[r]136	140
Zimbabwe	14,191	[r]16,003	16,900	[r]17,800	18,000
Total	[r]1,873,803	[r]2,030,114	[r]2,132,953	[r]2,148,743	2,247,840

[e]Estimated. [r]Revised.

[1]Table contains data available through July 19, 1993.

[2]Gold is also produced in Burma, Cuba, Czechoslovakia, Norway, Senegal, Thailand, and several 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.

[3]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[4]Only 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 1988-92.

[5]Officially reported figures are as follows, in kilograms: Major companies: 1988—22,159 (revised); 1989—22,849 (revised); 1990—30,098; 1991—33,844; and 1992—34,000 (estimated). Garimpos 1988—34,288 (revised); 1989—29,678 (revised); 1990—71,815 (revised); 1991—55,525 (revised); and 1992—46,000 (estimated).

[6]Reported figure.

[7]Gold purchases by Banco Central from placer deposits and mines; actual production estimated to be at least twice this amount.

[8]Year ending June 30 of year stated.

[9]Does not include undocumented production from small artisanal production.

[10]Figures include reported mine production of 324 kilograms in 1988; 1,202 kilograms in 1989; 1,745 kilograms in 1990; 1,453 kilograms in 1991; and 1,113 kilograms in 1991 from the SAG mine. Remainder represents approximate reported sales to Government of artisanal prodution. Figures do not include artisanal production smuggled out of the country.

[11]Refinery output.

[12]Excludes 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.

[13]These figures are based on gold taxed for export and include gold entering Liberia undocumented from Guinea and Sierra Leone.

[14]Includes production from Kalana Mine and artisanal production. 1990 includes Syama Mine production.

[15]Data are based on official exports and do not reflect gold moved through undocumented channels.

[16]Dissolved in Dec. 1991.

[17]Year beginning Apr. 1 of year listed.

FIGURE 1
HEAP-LEACH PROCESS COMPONENTS

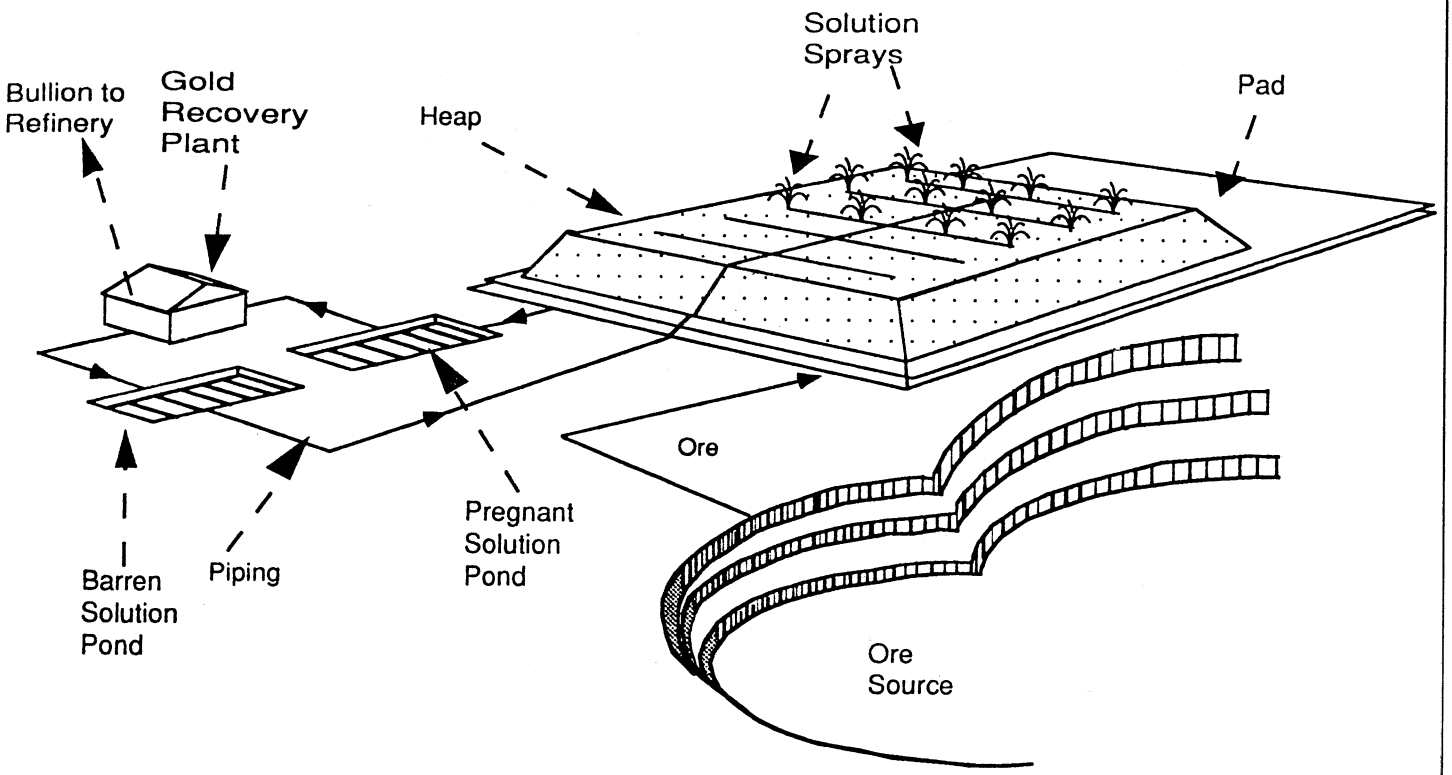
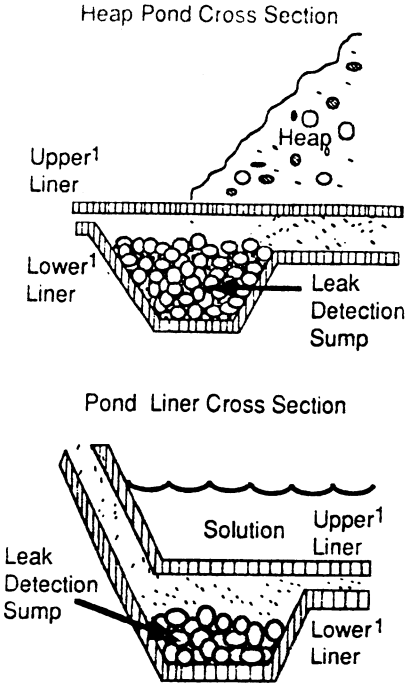
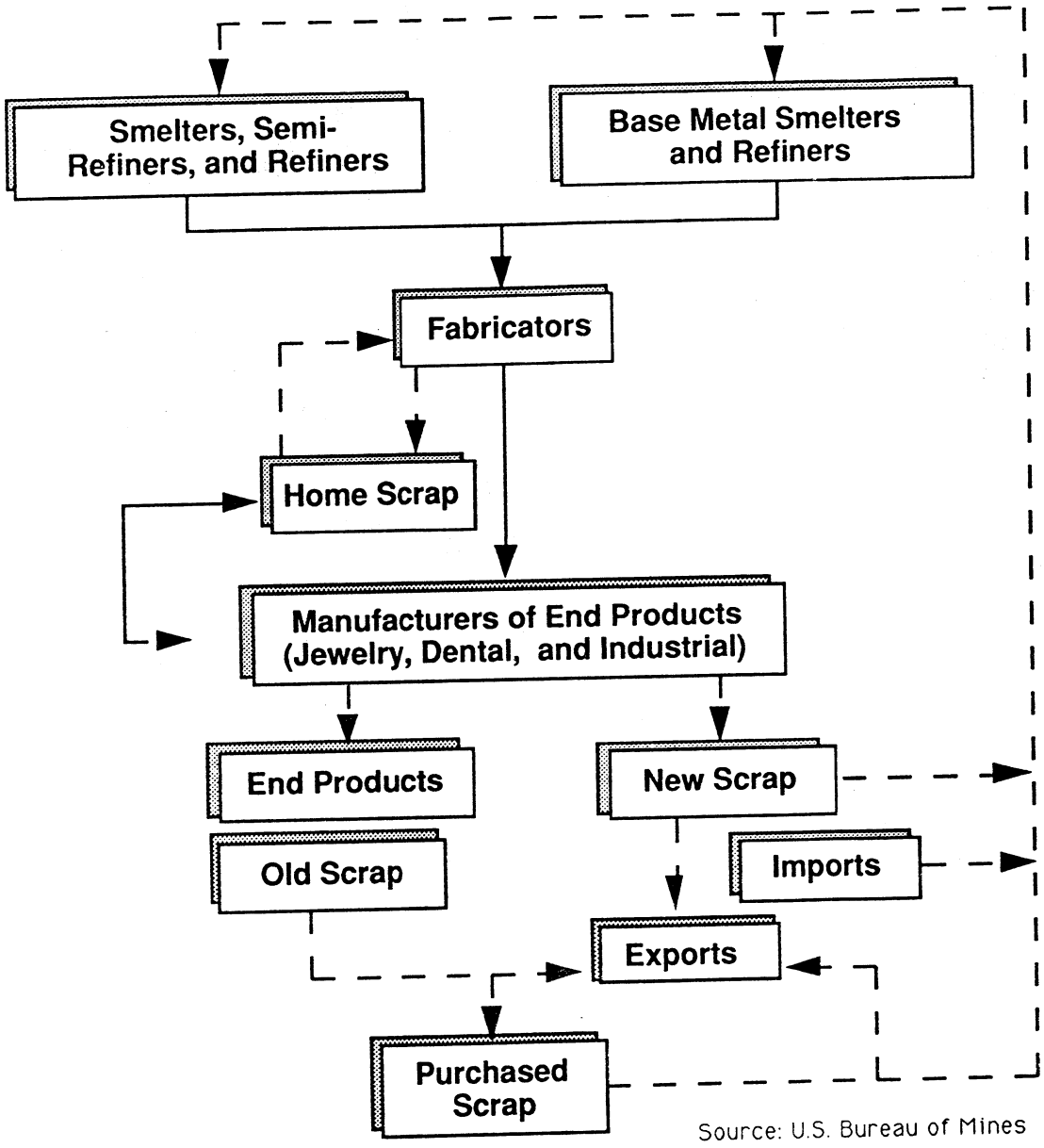


FIGURE 2
HEAP AND POND LINER CROSS SECTIONS



[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 26 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 1992. Graphite supplies exceeded industrial demand to a major degree. Most prices of the major kinds of graphite dropped substantially from those of 1991. However, most quoted prices only began to reflect the oversupply at the end of the year. Production of manufactured graphite and graphite fibers increased 10% and 11%, respectively.

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 4. *(See table 1.)*

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. Detailed breakouts are given in the 1988 Minerals Yearbook chapter. All tonnages are reported in metric tons, unless otherwise noted.

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 lump graphite 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 a few former Soviet republics (not Ukraine or Russia) and certain other nations are subject to a higher duty.

Operating Factors

Environmental Issues.—Because there was no mining of graphite this year, there were no environment-related issues. Future mining of graphite is highly improbable; there are no domestic reserves and resources are low grade and expensive to recover. 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.

Postconsumer waste mostly returns to the environment in simple and nonpolluting ways. Graphite products that have contact with molten iron and steel slowly dissolve in it during use. This applies to refractories crucibles, foundry facings, and electrodes, plus a few less important uses, which combine to account for about 75% of total usage. Other important products such as pencils and brake linings slowly dissipate as they are used, almost on an atom-by-atom basis.

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 very 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 operation, including marketing, probably does not exceed 500.

ANNUAL REVIEW

Legislation and Government Programs

No acquisitions of graphite for the strategic and critical materials stockpile occurred in 1992. Sales of Madagascar crystalline flake from the stockpile totaled 454 tons in 1992 compared with 106 tons in 1991. *(See table 2.)*

Production

United Minerals Co. continued its suspension of production of its amorphous graphitic material from its Montana mine in 1992. Output of manufactured graphite increased 10% to about 252,000 tons, at 29 plants, with a likelihood of some unreported production for in-house use. Production of all kinds of graphite fiber and cloth increased 11% to 3,600 tons.

In March, BASF Corp. decided to leave the graphite fiber industry and put up for sale its graphite fiber production plant at Rock Hill, SC, and its graphite fiber composite-intermediate plant at Anaheim, CA. In November, Toho Rayon Co. announced that is would take over the sales end of the business and supply the fiber from Japan. BASF will close the Rock Hill plant in mid-1993. This will at least help ameliorate the severe oversupply of graphite fiber around the world. One hopeful sign was the Toray Industries Inc. announcement that it would build a graphite fiber composite-intermediate plant at Frederickson, WA, to supply nearby Boeing operations. Another hopeful sign was the General Motors Corp. announcement that it would build a pilot plant to test its in-house research discovery of some years ago that has lead to a cheap new fiber production process. Some of the fiber, actually a carbon filament fiber, is being tested in composites.

A review article put the events of the past few years in perspective; to summarize, fiber producers will continue to have hard times until there is improvement in their major aerospace markets, which can presently not be foreseen.[1] *(See tables 3 and 4.)*

Consumption and Uses

Reported consumption of natural graphite increased 15% to about 41,780 tons, according to a survey of more than 230 users. The three major uses of natural graphite were refractories, brake linings, and in packings, which together accounted for 58% of reported consumption. *(See table 5.)*

Nonclay refractories are represented by two important use 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 again this year. 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 $1,481 per ton from $1,524 (revised). The price for amorphous graphite (including small amounts of amorphous-synthetic graphite mixtures) dropped slightly to $677 per ton from $707 (revised).

The index of unit value for high-modulus fiber produced in the U.S. (1973=100) was 44 in 1992, compared with 38 the previous year. *(See table 6.)*

Foreign Trade

The United States changed its tariff classification to the Harmonized Code on January 1, 1989. This has made the 1988 and 1990-92 import and export statistics somewhat noncomparable.

Total exports of natural graphite increased 4%. Exports of graphite electrodes totaled 76,000 tons valued at $178.4 million, of which 29,784 tons ($75.0 million) went to Canada, 6,650 tons ($13.9 million) to Venezuela, 5,919 tons ($15.7 million) to Japan, and the balance to other destinations.

Imports of natural graphite increased 48% from those of 1991. Imports of natural graphite from Canada increased dramatically. *(See tables 7, 8, and 9.)*

World Review

Graphite markets in the world were generally in difficulty; Japan was a prominent example. However, the U.S. market did show some improvement. Quoted graphite prices finally began to reflect reality and had sizeable drops in several categories. Present and prospective sales of U.S. stockpile graphite overhung the market, as did worries about the production of synthetic crystalline graphite from kish, a steelmaking waste. The worries are clearly premature because the pilot plant in Chicago did not produce anything in 1992. When successful, pilot plant production will be negligible and allow only test marketing. Full commercial production from kish on a significant scale is at least several years away. Production and export of Canadian graphite increased significantly this year, particularly from Cal Graphite Corp.

Canada.—Cal Graphite Corp. expanded its sales quite significantly this year. The mill was operating at slightly less than one-half capacity and is alleged to make a product from its refinery at Huntsville, Ontario. Stratmin Inc. brought its mill much closer to full capacity; according to published sources, it sold 6,800 tons of product in 1991 and 16,000 tons in 1992; it expects to sell 20,000 tons in 1993.

Canadian graphite activity has significantly lessened as the market has gotten poorer. Mart Mining & Exploration Ltd. did some drilling on its micaceous graphitic schist deposit near Labrador City. Quinto Mining Corp. is evaluating byproduct graphite production at a gold prospect near Lumby, British Columbia.

A comprehensive article on the beneficiation of graphite ores, primarily Canadian, appeared this year. Emphasizing flotation, it gives a summary of process data and of analytical data.[2]

Japan.—Imports of all kinds of natural graphite in 1992 totaled 73,258 tons, compared with 122,650 tons in 1991 and 126,527 tons in 1990. Imports of graphite by kind in 1992 were 28,496 tons of crystalline powder or flakes, 75% or more of which can pass through a 105-micron sieve (92% by ton from China), 24,805 tons of amorphous other than powder or flake (66% from China), 16,578 tons of amorphous powder or flakes (sic) other than that 75% or more of which can pass through a 105-micron sieve (51% from China), and a small balance of two other kinds.

Madagascar.—Societe Miniere de la Grande Ile is looking for a partner to help it expand its Ambatonitamba operation. Recent discoveries have increased mine reserves to 1 million tons. Installation of new flotation equipment has improved the product quality so much that it seldom drops below 90% carbon content.

Norway.—Elkem Skaland A/S completed the reconstruction of its mill and produced graphite from January to June, suspended operations, and started up again in November.

Sweden.—Anro Graphite AB has investigated a number of graphite prospects near its Kringelgruvan deposit. The firm is thinking of opening a mine and plant.

Tanzania.—Samax Ltd. and its partners are planning to open an operation 14 kilometers south of Kilimanjaro Airport. Feasibility studies are complete, and some equipment has been purchased. The beneficiation plant

is planned to have a capacity of 15,000 tons per year of predominantly coarse crystalline flake of a good carbon content and is targeted to come on-stream at the end of 1993. Reserves assay 7% carbon, exceed 20 million tons, and are not covered with overburden. Tanzanite and tsavorite, two gemstones, are also said to be found at the same location and may be extracted as coproducts or byproducts.

Current Research

A revised and updated graphite chapter emphasizing science and technology was published in the Kirk-Othmer Encyclopedia of Chemical Technology (Fourth Edition). Major sections cover physical and chemical properties, geographical occurrence, and end use.[3]

Late in the year, an announcement from Pennsylvania State University of a cheap process to convert graphite to diamond at low pressure initiated a multisided controversy. The new process was said to cut costs by a factor of 10 and involves subjecting a solid piece of graphite mixed with diamond dust, which acts as a seed, to a temperature of 800° to 900° C in the presence of hydrogen. Two firms made counterclaims and everyone is now racing to patent.

Fullerenes have been discovered in nature—in rocks on Earth and in outer space. Fullerenes, compounds with 60 to 70 carbons arranged in a soccerball structure sometimes with noncarbon atoms, have been found as films lining cracks in a shiny black rock called shungite from the Karelia area of Russia. Fullerenes also were discovered in the microscopic debris from a meteorite that had collided with a satellite. In both instances, painstaking precautions were taken in the examination and analysis leading to identification.

A simple method of producing fullerene tubes has been discovered, making them a viable substitute for graphite fibers. The method involves running electricity between two graphite rods in a helium-filled reaction vessel. The tubes conduct electicity and should be stiffer than graphite fiber; they may even be semiconductors. The fullerene tubes can suck up gases and a variety of small molecules. The sucking strength gets stronger as the tube radius gets smaller.

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. Production capacity is unlikely to increase from the present level while the overcapacity exists.

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[1]Reisch, M. S. Carbon Fiber Makers Seek New Markets as Military Orders Decline. Chem. & Eng. News, v. 70, No. 31, Aug. 3, 1992, pp. 16-17.

[2]Andrews, P. R. A. The Beneficiation of Canadian Graphite Ores: A Review of Processing Studies at CANMET. CIM Bull., v. 85, No. 960, May 1992, pp. 76-83.

[3]Taylor, H. A. Natural Graphite. Kirk-Othmer Encyclopedia of Chemical Technology, 4th ed., Wiley, 1992, pp. 1097-1117.

OTHER SOURCES OF INFORMATION

U.S. Bureau of Mines Publications

Graphite. Ch. in Mineral Commodity Summaries, annual.
Graphite. Ch. in Annual Report, annual.
Graphite. Reported annually in Mineral Industry Surveys.

Other Sources

Chemical Week.
European Chemical News.
Industrial Minerals (London).
Materials Engineering.
Wall Street Journal.

TABLE 1
SALIENT NATURAL GRAPHITE STATISTICS

		1988	1989	1990	1991	1992
United States:						
Production	metric tons	W	W	—	—	—
Apparent consumption	do.	42,799	50,867	38,676	14,170	29,527
Exports	do.	11,068	11,452	11,537	19,374	20,217
Value	thousands	$5,815	$7,421	$9,481	$11,345	$12,244
Imports for consumption	metric tons	53,867	62,319	50,213	33,544	49,744
Value	thousands	$23,238	$33,707	$35,222	$21,662	$25,538
World: Production	metric tons	r575,068	r608,877	r598,256	r596,036	e567,390

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.

TABLE 2
U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND STOCKS OF NATURAL GRAPHITE IN 1992, BY TYPE

(Metric tons)

Type	Goal	National stockpile inventory
Madagascar crystalline flake	(1)	15,156
Sri Lanka amorphous lump	5,715	4,934
Crystalline, other than Madagascar and Sri Lanka	(2)	1,754
Nonstockpile-grade, all types	—	846

[1]This commodity no longer has a goal as such; a goal might be considered to be the 6,207 tons that has not been authorized for disposal.
[2]This commodity no longer has a goal as such; all of it has been authorized for disposal.

Source: Defense National Stockpile Center, Inventory of Stockpile Materials as of Dec. 31, 1992.

TABLE 3
PRINCIPAL PRODUCERS OF SYNTHETIC GRAPHITE IN 1992

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. Marys, PA	Motor brushes and unmachined shapes.
Fiber Materials, Inc.	Biddeford, ME	Other.
Fiber Technology Corp.	Provo, UT	
Fortafil Fibers Inc.	Rockwood, TN	High-modulus fibers.
BF Goodrich Co., Engineered Systems Div., Super Temp Operation	Santa Fe Springs, CA	Other.
Grafil Inc.	Sacramento, CA	High-modulus fibers.
Hercules Inc.	Salt Lake City, UT	Do.
HITCO Materials Group, British Petroleum Co. Ltd.	Gardena, CA	Cloth.
Minerals Technology, Inc. Specialty Minerals Corp.	Easton, PA	Other.
National Electrical Carbon Co.	Fostoria, OH	Motor brushes, unmachined shapes, cloth.
NAC Carbon Products, Inc.	Punxsutawney, PA	Other.
Polycarbon, Inc.	Valencia, CA	Cloth.
Showa Denko Carbon Inc.	Ridgeville, SC	Electrodes.
SIGRI Great Lakes Carbon Corp.		
Do.	Hickman, KY	
Do.	Morganton, NC	Electrodes, unmachined shapes, crucibles, motor brushes, other.
Do.	Niagara Falls, NY	Do.
Do.	Ozark, AR	Do.
Superior Graphite Co.	Russellville, AR	Electrodes.
Do.	Hopkinsville, KY	Other.
Textron Specialty Materials	Lowell, MA	High-modulus fibers.
The Carbon/Graphite Group Inc.	Niagara Falls, NY	Anodes, electrodes, crucibles, refractories, unmachined shapes, motor brushes, refractories, other.
Do.	St. Marys, 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.
Zoltek Corp.	St. Charles, MO	High-modulus fibers.

[1]Cloth includes low-modulus fibers; motor brushes include machined shapes; crucibles include vessels.

TABLE 4

U.S. PRODUCTION OF SYNTHETIC GRAPHITE, BY END USE

End use	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Anodes[1]	4,442	$13,003	W	W
Cloth and fibers (low-modulus)	234	14,650	255	$22,599
Crucibles and vessels and refractories[1]	W	W	W	W
Electric motor brushes and machined shapes	1,269	15,222	1,339	16,510
Electrodes	154,397	327,360	161,278	336,155
Graphite articles[2]	—	32,210	—	28,364
High-modulus fibers	3,009	127,129	3,345	145,622
Unmachined graphite shapes	5,891	39,704	3,152	23,752
Other	r2,159	r30,212	8,771	54,765
Total	r171,401	r599,490	178,140	627,767
Synthetic graphite powder and scrap[3]	r58,820	r33,122	69,762	34,808
Grand total	r230,221	r632,612	247,902	662,575

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

[1]Anodes, crucibles/vessels and refractories end products are included in the "Other" products category.

[2]Includes all items for which quantity data are usually unavailable.

[3]Includes lubricants (alone /in greases), steelmaking carbonraisers, additives in metallurgy, and other powder data.

TABLE 5
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)
1990:[3]	r21,027	r$32,070	r21,191	r$12,256	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[4]	464	1,480	296	291	760	1,771
Crucibles, retorts, stoppers, sleeves, nozzles	W	W	W	W	1,136	1,521
Foundries[5]	827	1,123	2,798	1,510	3,625	2,633
Lubricant group:						
Lubricants	r595	r1,113	r1,573	r1,162	r2,168	r2,275
Packing; other[6]	2,888	5,408	166	338	3,054	5,746
Pencils	r2,344	r3,305	254	169	r2,598	r3,474
Powdered metals	1,513	2,642	45	87	1,558	2,729
Refractories	r7,651	r9,364	r3,379	r989	11,031	10,353
Rubber	45	104	r502	r435	r547	r539
Steelmaking	W	W	W	W	1,167	792
Other[7]	628	1,601	1,912	2,398	2,540	3,999
Withheld uses	1,253	1,739	1,050	574	—	—
Total[2]	r20,482	r31,221	r15,951	r11,274	r36,434	r42,495
1992:						
Batteries	146	303	—	—	146	303
Brake linings	2,221	3,016	5,145	4,307	7,366	7,323
Carbon products[4]	619	1,912	625	438	1,244	2,350
Crucibles, retorts, stoppers, sleeves, nozzles	W	W	W	W	1,029	1,434
Foundries[5]	864	936	1,888	1,006	2,752	1,942
Lubricant group:						
Lubricants	764	1,197	2,337	1,357	3,101	2,554
Packing; other[6]	3,759	5,402	143	247	3,902	5,649
Pencils	2,670	3,661	261	179	2,931	3,840
Powdered metals	1,739	3,426	225	204	1,964	3,630
Refractories	9,147	12,067	3,812	1,551	12,959	13,618
Rubber	100	235	491	397	591	632
Steelmaking	W	W	W	W	1,466	1,025
Other[7]	1,156	2,256	1,167	1,238	2,323	3,494
Withheld uses	1,083	1,538	1,412	921	—	—
Total[2]	24,268	35,949	17,506	11,845	41,774	47,794

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Withheld uses."
[1]Includes mixtures of natural and manufactured graphite.
[2]Data may not add to totals shown because of independent rounding.
[3]Changes to 1990 data apply to the "Refractories" end-use category only.
[4]Includes bearings and carbon brushes.
[5]Includes foundry facings.
[6]Includes ammunition, packings, and seed coating.
[7]Includes paints and polishes, antiknock 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 6
REPRESENTATIVE YEAREND GRAPHITE PRICES

(Per metric ton)

	1991	1992
Industrial minerals:		
Crystalline large flake, 85% to 90% carbon	$650-$1,200	$400- $800
Crystalline medium flake, 85% to 90% carbon	450- 1,000	350- 750
Crystalline small flake, 80% to 90% carbon	400- 600	300- 550
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	970	687
Lump and chip, Sri Lankan	1,442	1,073
Amorphous, Mexican	119	125

Source: Industrial Minerals, No. 291, Dec. 1991, p. 62, and No. 303, Dec. 1992, p. 66.

TABLE 7
U.S. EXPORTS OF NATURAL AND ARTIFICIAL GRAPHITE, BY COUNTRY[1]

Country	Natural[2]		Artificial[3]		Total	
	Quantity (metric tons)	Value[4]	Quantity (metric tons)	Value[4]	Quantity (metric tons)	Value[4]
1991:						
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	206	325,814	704	685,519	910	1,011,333
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
Venezuela	2,548	1,667,876	484	547,418	3,032	2,215,294
Other	r3,786	r2,730,224	r5,651	r9,228,824	r9,437	r11,959,048
Total	19,374	11,345,140	37,662	29,875,828	57,036	41,220,968
1992:						
Canada	5,180	3,389,714	14,833	6,370,111	20,013	9,759,825
France	29	94,717	1,051	1,688,774	1,080	1,783,491
Germany	71	188,884	721	646,165	792	835,049
Japan	260	432,090	4,539	10,167,361	4,799	10,599,451
Korea, Republic of	71	43,918	1,656	1,850,319	1,727	1,894,237
Mexico	9,430	3,643,596	1,279	726,634	10,709	4,370,230
Netherlands	118	42,040	3,381	1,688,756	3,499	1,730,796
Venezuela	659	951,675	671	472,197	1,330	1,423,872
Other	4,399	3,457,008	6,356	9,078,595	10,756	12,535,603
Total	20,217	12,243,642	34,487	32,688,912	54,705	44,932,554

rRevised.

[1]Numerous countries for which data were reported have been combined within the "Other" category under the "Country" list.

[2]Amorphous, crystalline flake, lump or chip, and natural, not elsewhere classified. The applicable Harmonized Tariff Schedule (HTS) nomenclature title and code(s) are: "Natural graphite in powder or in flakes"/"Other;" HTS Nos. 2504.10/.90.0000.

[3]Includes data from the applicable "Harmonized Tariff Schedule" (HTS) nomenclatures: "Artificial graphite" and "Colloidal or semicolloidal graphite;" their respective HTS code Nos. are: 3801.10/.20.0000.

[4]Values are f.a.s.

Source: Bureau of the Census.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF NATURAL GRAPHITE, BY COUNTRY

Country	Crystalline flake[1]		Lump or chippy dust		Other natural crude and refined[1]		Amorphous		Total	
	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)
1990	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	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	—	—	—	—	[3]	2	—	—	[3]	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
1992:										
Armenia[4]	[3]	7	—	—	—	—	—	—	[3]	7
Austria	—	—	—	—	—	—	20	10	20	10
Belgium	—	—	—	—	3	4	—	—	3	4
Brazil	1,611	2,495	—	—	9	14	—	—	1,620	2,509
Canada	7,470	4,856	—	—	9,130	5,400	—	—	16,600	10,256
China	4,400	2,136	—	—	2,396	1,536	1,663	436	8,459	4,108
Finland	[3]	3	—	—	—	—	—	—	[3]	3
France	41	74	—	—	109	462	—	—	150	[4]537
Germany	51	149	—	—	13	101	—	—	64	250
India	178	88	—	—	160	173	—	—	338	261
Italy	[3]	1	—	—	—	—	—	—	[3]	1
Japan	3,181	1,349	—	—	9	65	—	—	3,190	1,413
Macau	—	—	—	—	—	—	40	30	40	30
Madagascar	2,011	1,730	—	—	1,341	1,003	—	—	3,352	2,733
Mexico	—	—	—	—	387	259	13,970	1,752	14,357	2,011
Russia[4]	—	—	—	—	15	35	—	—	15	35
Sri Lanka	—	—	492	528	—	—	—	—	492	528
United Kingdom	46	73	—	—	4	9	—	—	49	82
Zimbabwe	994	760	—	—	—	—	—	—	994	760
Total	19,983	13,721	492	528	13,576	9,061	15,693	2,228	49,744	25,538

[1]The information framework from which data for this material were derived originated from Harmonized Tariff Schedule (HTS) base data.
[2]Customs values.
[3]Less than 1/2 unit.
[4]Formerly part of the U.S.S.R.

Source: U.S. Bureau of Mines, adjusted from the Bureau of the Census.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF GRAPHITE ELECTRODES, BY COUNTRY

Country	Graphite electrodes[1]	
	Quantity[2] (metric tons)	Value[3] (thousands)
1991:		
Canada	1,689	$1,820
Germany	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
Other	1,646	2,710
Total	26,871	45,635
1992:		
Canada	1,417	1,696
Germany	3,884	7,280
India	1,358	2,299
Italy	4,466	7,425
Japan	5,678	9,940
Mexico	8,218	11,075
Spain	878	1,579
Other	1,489	2,446
Total	27,388	43,740

[1]The applicable Harmonized Tariff Schedule (HTS) code and nomenclature title is: (HTS 8545.11.0000); "Electric Furnace Electrodes."
[2]For both 1991 and 1992, data for countries reflecting less than 500 metric tons each for yearly imports have been combined under the "Other" category in the "Country" list.
[3]Customs values.

Source: Bureau of the Census.

TABLE 10
WORLD GRAPHITE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1988	1989	1990	1991	1992e
Argentina	24	100	e100	e100	90
Austria	7,577	15,307	22,205	r20,000	20,000
Brazil (marketable)[2]	34,520	31,650	r28,890	r26,965	30,000
Burma	—	—	45	e40	—
Canada (exports)	4,900	6,000	10,200	6,200	17,400
China e (exports)	r120,000	r150,000	r140,000	r150,000	115,000
Czechoslovakia e	e15,000	14,676	12,171	e12,000	11,800
Germany	9,666	r10,584	10,437	r10,400	10,000
India (mine)[3]	57,325	58,000	61,000	r69,922	70,000
Korea, North e	25,000	35,000	35,000	35,000	38,000
Korea, Republic of:					
Amorphous	107,767	100,282	98,987	r75,239	75,000
Crystalline flake	678	1,186	703	r1,552	1,500
Madagascar	14,106	15,863	18,036	r14,079	14,000
Mexico:					
Amorphous	47,871	38,304	r22,553	r35,315	30,400
Crystalline flake	1,735	1,942	r2,365	r1,943	2,000
Namibia	—	—	—	e200	200
Norway	—	1,800	r5,000	r6,930	7,000
Romania e	12,000	[4]10,000	10,000	10,000	10,000
Russia[5]	—	—	—	—	15,000
Sri Lanka	8,547	4,163	5,469	r6,381	7,000
Turkey (mine)	12,911	r11,873	r18,712	r25,867	30,000
Ukraine[5]	—	—	—	—	50,000
U.S.S.R. e [6]	84,000	84,000	80,000	75,000	—
United States	W	W	—	—	—
Zimbabwe	11,441	18,147	16,383	r12,903	13,000
Total	r575,068	r608,877	r598,256	r596,036	567,390

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.
[1]Table includes data available through May 10, 1993.
[2]Does not include the following quantities sold directly without beneficiation, in metric tons: 1988—18,200 (revised); 1989—14,250; 1990—13,000; 1991—13,500; and 1992—14,400 (estimated).
[3]Indian marketable production is 10% to 20% of mine production.
[4]Reported figure.
[5]Formerly part of the U.S.S.R.; data were not reported separately until 1992.
[6]Dissolved in Dec. 1991.

GYPSUM

By Lawrence L. Davis

Mr. Davis, a physical scientist with 37 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for gypsum since 1985. Domestic survey data were prepared by R. Jean Jones, statistical assistant; and international data tables were prepared by Amy Burk, Section of International Data.

Demand for gypsum products increased in 1992, a result of increased construction activity, especially in new housing starts that increased 19% to 1.2 million units. The quantity of crude gypsum mined, calcined gypsum produced, and wallboard products shipped was greater than in 1991.

Sales of gypsum products increased 13% to 25 million short tons, but value remained about the same at $1.3 billion. Increased competition caused lower prices for gypsum products. Imports for consumption of crude gypsum increased 4% to about 7.9 million tons. Total value of gypsum product exports increased 13% to $97 million.

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 gypsum that are in compliance with Public Law 100-418, will begin to report data in metric units.

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 116 operations to which the annual survey request was sent, 114 responded, representing 98% 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, $CaSO_4 \cdot 2H_2O$, 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, $CaSO_4 \cdot 1/2H_2O$, is a manufactured hemihydrate product produced by partial calcination of gypsum. It is produced by heating gypsum at temperatures to 350° F. The hemihydrate product, commonly called plaster of paris, is called stucco by the wallboard manufacturers. When water is added to form a paste, the calcined material reabsorbs water and 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 $CaSO_4 \cdot 2H_2O$. 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, usually 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 1 1/2 inch plus 3/8 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, $CaSO_4 \cdot 2H_2O$, to the hemihydrate product, $CaSO_4 \cdot 1/2H_2O$. 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 31 companies at 58 mines in 19 States. Production increased 5%. Leading producing States, in descending order, were Oklahoma, Iowa, Texas, Michigan, Nevada, California, 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 Temple-Inland Forest Products Corp., 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; USG's Sperry Mine, Des Moines County, IA; Harrison's Cement Mine, Caddo County, OK; USG's Shoals Mine, Martin County, IN; National's Tawas Mine, Iosco County, MI; USG's Alabaster Mine, Iosco County, MI; Temple-Inland's Fletcher Mine, Comanche County, OK; National's Sun City Mine, Barber County, KS; and Briar's Briar Mine, Howard County, AR. These 10 mines accounted for 42% of the national total. Average output for the 58 active mines increased 11% to 280,000 tons.

Gypsum was calcined by 13 companies at 70 plants in 28 States, principally for the manufacture of gypsum wallboard and plaster. Calcined output increased 8% in tonnage and 4% in value. Leading States, in descending order, were California, Iowa, Texas, Florida, Nevada, and New York. These 6 States,

with 27 plants, accounted for 47% of the national output.

Leading companies were USG, 20 plants; National Gypsum, 18 plants; Georgia-Pacific, 10 plants; Domtar, 7 plants; and Celotex, 4 plants. These 5 companies, operating 59 plants, accounted for 83% 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 James Hardie Gypsum Inc.'s Las Vegas plant, Clark County, NV. These 10 plants counted for 30% of the national production. Average calcine production for the 70 U.S. plants was 237,000 tons, a 10% increase.

A total of 695,000 tons of byproduct gypsum, valued at $4.2 million, was used, principally in agriculture but some for gypsum wallboard manufacturing. Approximately 90% was of nonphosphogypsum origin compared with 78% in 1990.

According to the Gypsum Association, yearend gypsum wallboard plant capacity for producing 1/2-inch regular wallboard increased slightly to 24.19 billion square feet per year. Total wallboard shipments were 19.2 billion square feet, 79% of capacity. Continued weakness in the wallboard market caused many plants to operate well below capacity level. Domtar's plants at Florence, CO, and at Sweetwater, TX, remained closed throughout the year. *(See tables 2 and 3.) (See figure 1.)*

Consumption and Uses

Apparent consumption, defined as production plus net imports plus industry stock changes, of crude gypsum, including byproduct gypsum, increased 6% to 24.6 million tons. Net imports provided 32% of the crude gypsum consumed. Apparent consumption of calcined gypsum increased 8% to 16.5 million tons.

Yearend stocks of crude gypsum at mines and calcining plants were 2.6 million tons. Of this, 43% was at calcining plants in coastal States.

Of the total gypsum products sold or used, about 25% 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 1992, 53% 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, 64% 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, 82% was 1/2-inch and 10% was 5/8-inch.

In descending order, the leading sales regions for prefabricated products were the South Atlantic, East North-Central, Pacific, and Middle Atlantic. Together these regions accounted for 62% of the total. *(See tables 4 and 5.) (See figure 2.)*

Markets and Prices

On an average value-per-ton basis, f.o.b. mine or plant, crude gypsum increased slightly to $6.18, calcined gypsum decreased slightly to $15.04, and byproduct gypsum increased 34% to $6.01. Prefabricated products were valued at $70.05 per ton, plasters at $132.90 per ton, and uncalcined products at $10.33 per ton.

Quoted prices for gypsum wallboard products were published monthly in Engineering News-Record. Spot prices in December, based on truck lots delivered to the job, showed a wide range. Regular 1/2-inch wallboard prices ranged from $93 per thousand square feet at Cincinnati to $160 at Detroit and Minneapolis. The average price in December for 20 cities was $124 per thousand square feet, with some minor discounts for prompt payment. This represented a 7% increase compared with that of December 1991.[1]

Although demand for gypsum products increased compared with 1991, the value of sales remained about the same at $1.3 billion, well below the record high $2.5 billion in sales achieved in 1986. The overall low level of prices for gypsum products continued to cause problems for the industry. At yearend, National Gypsum, the second largest gypsum company, remained under chapter 11 bankruptcy protection, and USG, the Nation's largest, was preparing a restructuring of debt plan in anticipation of filing for bankruptcy protection.

Foreign Trade

Imports for consumption of crude gypsum increased 4% to 7.9 million tons. Net imports represented 32% 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, increased 23% to 133 million square feet. *(See tables 6 and 7.)*

World Review

Estimated world production of crude gypsum remained at 108 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. *(See table 8.)*

Canada.—Acting on complaints that U.S. gypsum wallboard was being dumped on the Canadian market, Canada's Customs Department issued a preliminary determination that dumping had occurred. The final determination was to be made within 90 days, and within 120 days the Canadian International Eastern Tribunal was to rule on whether dumping injured Canadian production. At yearend, those determinations were still pending.[2]

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 3.40 billion square feet, a slight increase compared with that of the previous year.

Denmark.—Knauf AG, a German construction materials firm, purchased Danogips, Europe's fourth largest gypsum wallboard producer. The purchase included two wallboard plants in Denmark and one in Sweden with a combined capacity of about 600 million square feet per year.[3]

Qatar.—A contract was awarded to construct a gypsum wallboard plant for Qatar Saudi Gypsum Industries, a joint venture of Qatar Industrial Manufacturing Co., Saudi Arabia's National Gypsum Co., and the Qatar National Cement Co. Construction was to begin by yearend.[4]

Saudi Arabia.—National Gypsum Co. announced plans to double the capacity of its Yanbu plant.[5]

Thailand.—Thai Gypsum Product Co. Ltd. opened its Laem Chabang gypsum wallboard facility at Chon Buri. Advanced technology and equipment developed by United States Gypsum Co. was utilized under an agreement between the two companies. The facility is the first in Thailand to use a computer-aided wallboard manufacturing system.[6]

Turkmenistan.—A new gypsum operation began production in Gaurdak, Chardzhou Oblast.[7]

United Kingdom.—British Gypsum, a subsidiary of BPB Industries PLC, was building a new 660,000-ton-per-year gypsum processing plant at Barrow Upon Soar, near Loughborough. Completion was expected in mid-1992. A new mine at the site was already in production using a continuous mining machine for excavation.

Redland PLC was working to double the capacity of its wallboard plant at Portbury, near Bristol. Construction was to be completed by yearend with production starting in 1993.

Knauf UK announced plans to build a 55,000-ton-per-year plaster plant at its wallboard facility at Immingham in Humberside.[8]

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 the manufacture of portland cement. The decline in construction activity that depressed demand for gypsum products over the past several years appears to have ended. Gypsum product demand increased in 1992, and a slow, but steady, recovery is expected to continue over the next few years.

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[1]Engineering News Record. Dec. 21, 1992, p. 45.
[2]The Wall Street Journal. Sept. 23, 1992, p. A4.
[3]Industrial Minerals (London). No. 293, Feb. 1992, p. 9.
[4]Page 62 of work cited in footnote 3.
[5]Industrial Minerals (London). No. 299, Aug. 1992, p. 71.
[6]———. No. 305, Feb. 1993, p. 19.
[7]———. No. 296, May 1992, p. 150.
[8]Harries-Ries, K. Industrial Minerals of the UK. Ind. Miner. (London), No. 293, Feb. 1992, pp. 21-37.

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TABLE 1
SALIENT GYPSUM STATISTICS

(Thousand short tons and thousand dollars)

	1988	1989	1990	1991	1992
United States:					
Active mines and plants[1]	112	112	106	112	109
Crude:					
Mined	16,390	17,624	16,406	15,456	16,269
Value	$109,205	$128,448	$99,567	$94,199	$100,583
Imports for consumption	9,679	9,304	8,726	7,633	7,915
Byproduct gypsum sales	733	725	735	681	695
Calcined:					
Produced	17,274	17,893	17,553	15,358	16,610
Value	$313,251	$285,659	$278,607	$240,663	$249,846
Products sold (value)	$2,090,786	[2]$1,926,676	[2]$1,712,848	[2]$1,348,714	[2]$1,348,648
Exports (value)	$42,789	$60,311	$84,452	$85,613	$96,983
Imports for consumption (value)	$158,169	$111,012	$110,205	$88,141	$96,036
World: Production	r111,654	r113,258	r110,481	r107,797	107,796

rRevised.
[1]Each mine, calcining plant, or combination mine and plant is counted as one establishment; includes plants that sold byproduct gypsum.
[2]Does not include value of plasters sold.

TABLE 2
CRUDE GYPSUM MINED IN THE UNITED STATES, BY STATE

State	1991			1992		
	Active mines	Quantity (thousand short tons)	Value (thousands)	Active mines	Quantity (thousand short tons)	Value (thousands)
Arizona and New Mexico	6	648	$4,874	6	767	$5,606
Arkansas, Kansas, Louisiana	5	1,482	10,909	5	1,452	10,261
California, Nevada, Utah	13	2,903	14,923	13	2,930	12,903
Colorado, South Dakota, Wyoming	7	536	3,670	5	732	4,909
Indiana, New York, Ohio, Virginia	5	2,040	12,323	5	2,032	16,553
Iowa	6	2,162	12,285	6	2,193	11,626
Michigan	5	1,721	13,052	5	1,770	13,889
Oklahoma	8	2,356	12,925	8	2,603	14,915
Texas	6	1,609	9,240	5	1,790	9,920
Total[1]	61	15,456	94,199	58	16,269	100,583
Total thousand metric tons	XX	14,021	XX	XX	14,759	XX

XX Not applicable.
[1]Data may not add to totals shown because of independent rounding.

TABLE 3
CALCINED GYPSUM PRODUCED IN THE UNITED STATES, BY STATE

State	1991			1992		
	Active plants	Quantity (thousand short tons)	Value (thousands)	Active plants	Quantity (thousand short tons)	Value (thousands)
Arizona, Colorado, New Mexico, Utah	5	658	$5,112	5	813	$5,895
Arkansas, Louisiana, Oklahoma	7	1,596	21,442	7	1,782	24,802
California	6	1,620	21,810	6	1,669	25,366
Delaware, Maryland, North Carolina, Virginia	6	1,485	30,621	6	1,612	31,427
Florida	3	1,162	23,652	3	1,225	10,818
Georgia	3	549	8,495	3	641	9,737
Illinois, Indiana, Kansas	6	1,270	18,835	6	1,385	20,762
Iowa	5	1,420	19,240	5	1,500	20,529
Massachusetts, New Hampshire, New Jersey	5	887	17,083	5	1,013	19,064
Michigan	4	653	12,395	4	628	11,997
Nevada	4	989	13,330	4	1,077	12,539
New York	4	972	18,445	4	1,013	20,435
Ohio	3	359	6,446	3	372	6,791
Texas	6	1,122	13,623	5	1,242	16,185
Washington, and Wyoming	4	616	10,133	4	639	13,498
Total[1]	71	15,358	240,663	70	16,610	249,846
Total thousand metric tons	XX	13,933	XX	XX	15,068	XX

XX Not applicable.
[1]Data 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	1991		1992	
	Quantity	Value	Quantity	Value
Uncalcined:				
Portland cement	3,272	34,647	3,331	35,049
Agriculture and miscellaneous[1]	1,890	31,763	2,936	29,681
Total	5,162	66,410	6,267	64,731
Total thousand metric tons	4,683	XX	5,685	XX
Calcined:				
Plasters	W	W	W	W
Prefabricated products[2]	16,697	1,282,305	18,330	1,283,917
Total calcined[3]	16,697	1,282,305	18,330	1,283,917
Total calcined thousand metric tons[3]	15,147	XX	16,629	XX
Grand total[3]	21,859	[4]1,348,714	24,597	1,348,648
Grand total thousand metric tons[3]	19,830	XX	22,314	XX

W Withheld to avoid disclosing company proprietary data. XX Not applicable.
[1]Includes byproduct gypsum.
[2]Includes weight of paper, metal, or other materials and some byproduct gypsum.
[3]Data does not include plasters.
[4]Data do not add to total shown because of independent rounding.

TABLE 5

PREFABRICATED GYPSUM PRODUCTS SOLD OR USED IN THE UNITED STATES

Product	1991			1992		
	Thousand square feet	Thousand short tons[1]	Value (thousands)	Thousand square feet	Thousand short tons[1]	Value (thousands)
Lath:						
3/8 inch	11,400	9	$1,995	10,400	8	$1,841
1/2 inch	300	(2)	43	300	(2)	45
Other	80	(2)	6	—	—	—
Total	11,780	9	2,044	10,700	8	1,886
Total thousand metric tons	XX	8	XX	XX	7	XX
Veneer base	385,755	400	29,002	397,350	415	30,185
Sheathing	184,947	178	22,124	182,822	179	21,541
Regular gypsumboard:						
3/8 inch	621,924	517	53,861	609,364	516	45,176
1/2 inch	8,861,284	7,928	550,391	10,024,439	8,992	533,923
5/8 inch	1,389,452	1,450	60,625	1,273,671	1,346	55,432
1 inch	92,863	104	19,216	158,482	168	21,847
Other[3]	123,564	105	14,243	142,242	151	16,151
Total[4]	11,089,087	10,103	698,336	12,208,198	11,173	672,529
Total thousand metric tons	XX	9,165	XX	XX	10,136	XX
Type X gypsumboard	4,554,542	4,838	372,957	4,899,560	5,261	392,447
Predecorated wallboard	94,100	91	28,840	98,580	94	28,252
5/16-inch mobile home board	634,754	489	54,851	790,567	581	65,250
Water-/moisture-resistant board	514,100	499	60,477	566,033	556	63,595
Other	95,626	91	13,673	54,362	61	8,233
Grand total[4]	17,564,691	16,697	1,282,305	19,208,172	18,330	1,283,917
Grand total thousand metric tons	XX	15,147	XX	XX	16,629	XX

XX Not applicable.

[1]Includes weight of paper, metal, or other material.

[2]Less than 1/2 unit.

[3]Includes 1/4-, 7/16-, and 3/4-inch gypsumboard.

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

TABLE 6

IMPORTS FOR CONSUMPTION OF CRUDE GYPSUM, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1991		1992	
	Quantity	Value	Quantity	Value
Australia	34	298	22	189
Bahamas, The	(1)	42	—	—
Belgium	(1)	2	—	—
Canada[2]	5,379	38,631	5,549	38,913
China	2	212	32	437
Dominican Republic	(1)	13	(1)	10
France	(1)	2	(1)	66
Germany	(1)	15	—	—
Jamaica	56	399	54	376
Japan	(1)	15	(1)	3
Mexico	1,738	8,809	1,926	9,659
Morocco	12	74	—	—
Netherlands	—	—	(1)	4
Spain	411	3,508	331	3,213
Taiwan	—	—	(1)	2
United Kingdom	1	51	1	101
Total[3]	7,633	52,070	7,915	52,972
Total thousand metric tons	6,925	XX	7,180	XX

XX Not applicable.
[1]Less than 1/2 unit.
[2]Includes anhydrite.
[3]Data 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:								
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
1992	108	3,946	151	22,303	151	39,177	31,557	96,983
Imports for consumption:								
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
1992	7,915	52,972	7	660	106	8,803	33,600	96,036

NA Not available.

[1]Import and export data for 1989-92 are for "Gypsum; anhydrite," Harmonized Tariff Schedule 2520.10.0000. Data for 1988 are for "Plaster rock or gypsum: Not ground and not wholly or partly calcined," TSUS 512.21.00. The two categories might not be comparable.

[2]Import and export data for 1989-92 are for "Plasters," Harmonized Tariff Schedule 2520.20.0000. Data for 1988 are for "Plaster rock or gypsum: Ground, wholly or partly calcined, or both," TSUS 512.24.00. The two categories might not be comparable.

[3]Import and export data for 1989-92 are for "Boards, sheets, panels, tiles and similar articles, not ornamented: Faced or reinforced with paper or paperboard only," Harmonized Tariff Schedule 6809.11.0000. Data for 1988 are for "Gypsum or plaster building boards and lath," TSUS 245.7000. The two categories might not be comparable.

[4]Import and export data for 1989-92 are for "Boards, sheets panels, tiles and similar articles, not ornamented: other," Harmonized Tariff Schedule 6809.19.0000 and "Other articles," Harmonized Tariff Schedule 6809.90.0000. Data for 1988 are for "Cement of gypsum," TSUS 512.31 and 512.35, "Articles n.s.p.f. of Plaster of Paris," TSUS 512.4100, and "Alabaster articles, n.s.p.f.," TSUS 513.94. Data for 1989-92 might not be comparable with that of previous years.

[5]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 8

GYPSUM: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country	1988	1989	1990	1991	1992e
Afghanistan e	3	3	3	3	3
Algeria e	303	303	276	2168	165
Angola e	63	63	63	63	63
Argentina	573	444	e440	e495	475
Australia e	21,801	1,980	1,980	2,205	2,205
Austria 3	796	r888	r829	r722	720
Bolivia e	(4)	(4)	(4)	(4)	(4)
Bosnia and Herzegovina 5	—	—	—	—	165
Brazil	r869	r949	r908	r1,066	1,100
Bulgaria	442	497	545	e495	495
Burma 6	35	35	r36	e34	40
Canada 3	10,485	r9,017	r8,794	r7,529	27,776
Chile	348	306	280	370	370
China e	8,900	r9,900	r11,200	r11,600	12,100
Colombia	338	610	e550	r704	660
Croatia 5	—	—	—	—	83
Cuba e	145	145	r145	r145	140
Cyprus	36	r e37	41	r e41	41
Czechoslovakia	853	877	787	r688	660
Dominican Republic	169	189	86	r130	132
Ecuador e	55	253	r35	26	26
Egypt	e1,200	1,443	r1,410	r1,365	1,300
El Salvador e	5	5	5	r6	6
Ethiopia e 7 8	2	2	2	22	2
France 3	6,204	6,266	6,389	r e6,200	6,300
Germany:					
Eastern states	r3,029	r2,952	r e2,535	—	—
Western states (marketable) 3	r2,554	r2,426	r2,394	—	—
Total	r5,583	r5,378	r e4,929	r e4,642	4,740
Greece	r660	r596	r496	r e500	440
Guatemala	38	63	72	r57	57
Honduras e	25	r30	r30	r30	30
Hungary 3	130	125	123	r e125	110
India	1,570	1,697	1,827	1,712	1,710
Iran 3 9	8,430	8,662	8,514	r8,874	8,800
Iraq e 10	390	500	420	210	420
Ireland	359	346	434	e360	330
Israel e	234	34	42	r 228	28
Italy e	1,430	1,380	1,380	1,325	1,325
Jamaica	160	86	91	r150	110
Japan e	6,900	6,900	7,000	r6,000	6,000
Jordan	94	146	102	r61	60
Kenya 3	42	40	e40	e40	40

See footnotes at end of table.

TABLE 8—Continued

GYPSUM: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country	1988	1989	1990	1991	1992e
Laos	88	115	r58	r85	2 88
Lebanone	2	2	2	2	2
Libyae	200	200	200	200	200
Luxembourge	(4)	(4)	(4)	(4)	(4)
Macedonia[5]	—	—	—	—	55
Malie	1	1	1	1	1
Mauritaniae	7	7	9	2 3	3
Mexico	5,269	5,942	5,990	e6,100	6,100
Mongoliae	35	35	35	30	30
Moroccoe	500	500	500	500	500
Nicaragua	e8	13	15	e18	18
Nigere	3	3	r1	r 2 1	1
Pakistan	413	515	527	r575	550
Paraguay	4	5	5	5	5
Perue	165	r175	165	165	175
Philippinese	r130	r130	r130	r35	35
Poland[3]	1,209	1,249	832	e830	770
Portugale	2 373	330	330	330	330
Romaniae	1,760	1,545	880	660	550
Saudi Arabiae	413	413	413	413	413
Serbia and Montenegro[5]	—	—	—	—	44
Sierra Leonee	4	4	4	4	4
Slovenia[5]	—	—	—	—	166
Somaliae	4	4	3	1	2
South Africa, Republic of	410	448	431	463	2 368
Spaine	2 8,233	6,060	5,500	5,500	5,500
Sudan[3]	6	11	e6	r e8	11
Switzerlande	250	250	250	250	250
Syria	197	e198	193	e193	193
Taiwan	3	4	2	r4	4
Tanzania[3]	22	6	r40	r39	39
Thailand	5,014	6,038	6,342	7,933	7,700
Tunisiae	110	110	110	110	110
Turkey	255	r236	e250	e250	250
U.S.S.R.[11]	5,404	5,401	4,960	e4,400	3,860
United Arab Emiratese	93	96	98	105	105
United Kingdome 3	4,080	4,400	4,400	r3,900	3,300
United States[12]	16,390	17,624	16,406	15,456	2 16,269
Uruguaye	2 160	110	160	160	160
Venezuela	244	366	222	r269	275
Vietname	30	30	30	35	35
Yemen, Republic of	66	69	73	r83	83

See footnotes at end of table.

TABLE 8—Continued

GYPSUM: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country	1988	1989	1990	1991	1992[e]
Yugoslavia[13]	612	601	589	495	—
Zambia[e 10]	17	17	r15	r15	15
Total	r111,654	r113,258	r110,481	r107,797	107,796
Total thousand metric tons	r101,291	r102,746	r100,227	r97,792	97,791

[e]Estimated. [r]Revised.

[1]Table includes data available through July 12, 1993.

[2]Reported figure.

[3]Includes anhydrite.

[4]Less than 1/2 unit.

[5]Formerly part of Yugoslavia; data were not reported separately until 1992.

[6]Data are for years beginning Apr. 1 of that stated.

[7]Data are for years ending July 7 of that stated. Reported in cubic meters and estimated at mean weight of 1.8 tons per cubic meter.

[8]Probably 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).

[9]Data are for years beginning Mar. 21 of that stated.

[10]For cement production only. Information is insufficient to formulate reliable estimates for output for other uses (plaster, mortar, etc.)

[11]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

[12]Excludes byproduct gypsum.

[13]Dissolved in Apr. 1992.

FIGURE 1
SUPPLY OF CRUDE GYPSUM IN THE UNITED STATES

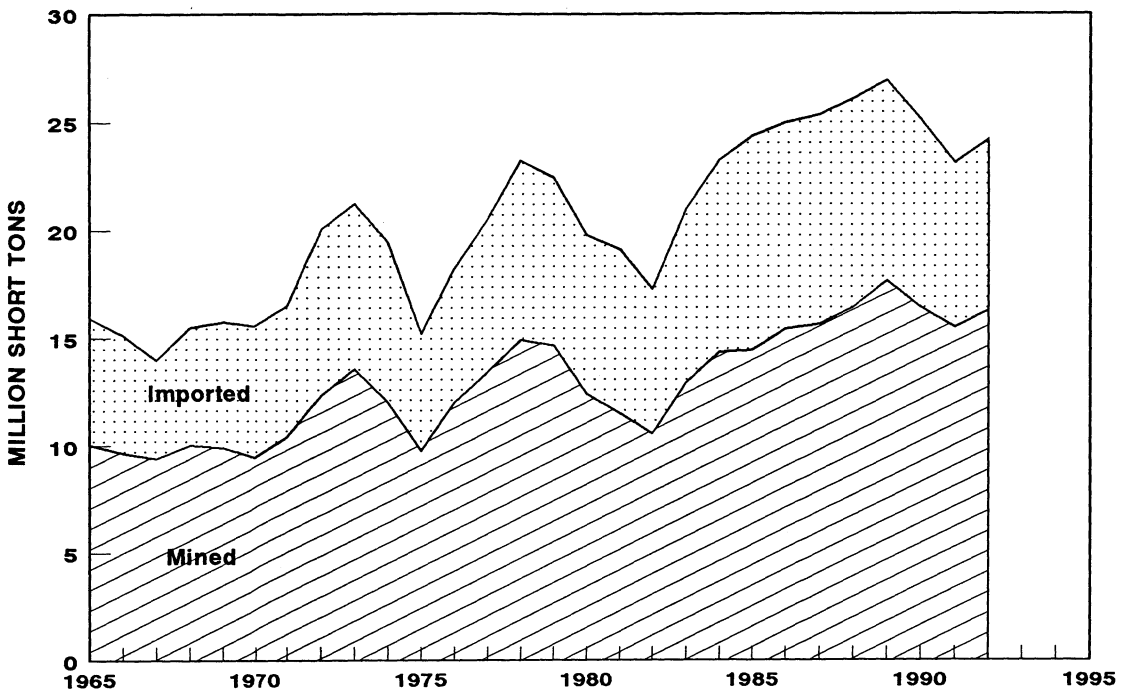
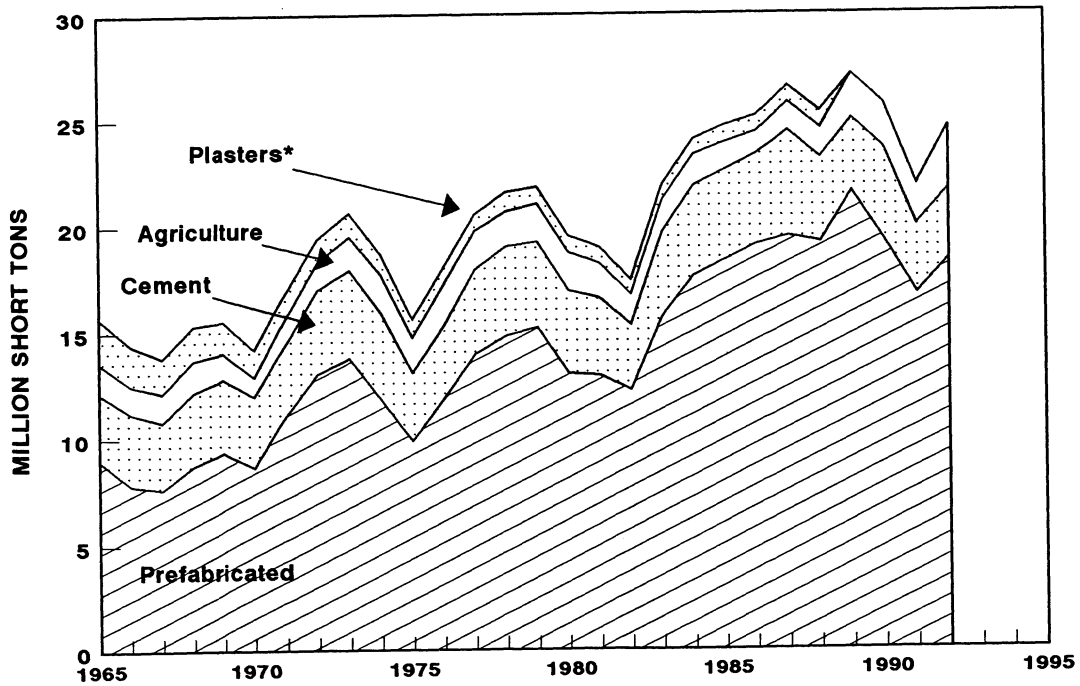


FIGURE 2
SALES OF GYPSUM PRODUCTS, BY USE



*Data withheld since 1989

HELIUM

By William D. Leachman

Mr. Leachman, a chemical engineer with 39 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 63.7 million cubic meters [2,297 million cubic feet (MMcf)] in 1992.[1] Grade-A helium exports by private producers were 30.7 million cubic meters (1,106 MMcf), for total sales of 94.4 million cubic meters (3,403 MMcf) of U.S. helium. The Bureau's price for Grade-A helium, f.o.b. plant, was $1.983 per cubic meter [$55.00 per thousand cubic feet (Mcf)] and bulk liquid helium was $2.253 per cubic meter ($62.50 per Mcf) on January 1, 1992, with additional costs for container services and rent. On November 1, 1992, the bulk liquid helium price was raised to $2.379 per cubic meter ($66.00 per Mcf). Private industry also increased its helium prices last year, but the prices are lower 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 near Amarillo, TX, 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. The present Federal helium demand is supplied solely by the Bureau's Exell Helium Plant, 56 kilometers (35 miles) north of Amarillo.

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 an 8-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, 1992, the latest figures available, are estimated to be 13.0 billion cubic meters [467 billion cubic feet (Bcf)]. The total identified helium resources are about 0.1 billion cubic meters (4 Bcf) more than those reported in 1991. The resources include measured reserves and indicated resources estimated at 6.9 billion cubic meters (248 Bcf) and 0.9 billion cubic meters (32 Bcf), respectively, in natural gas with a minimum helium content of 0.3%. A slight increase in the measured reserves of helium is reported due to ongoing evaluations of the Nation's depleting helium resources. The measured reserves included 1.0 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 1.2 billion cubic meters (44 Bcf). Indicated helium resources in natural gas with a helium content of less than 0.3% are estimated to be 4.0 billion cubic meters (143 Bcf). Approximately 4.5 billion cubic meters (163 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 85% of these reserves are 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 206 natural gas samples from 20 States and 5 foreign countries during 1992 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 most energetic 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). The SSC magnets will be similar to the magnets used at Fermi, which have been proven and tested in operation. When completed, the SSC will have about 20 times the energy 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 film "Hunt for Red October." Researchers at Argonne used the world's largest helium-cooled superconducting dipole magnet to study this 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 diagnoses 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 uses of the new high-temperature (about -184 °C or -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 in addition to 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) fiber-optic production, where an ultrapure inert 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, results in 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 proposed 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. No action was taken on this legislation.

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 1992, 13 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 6.7%, while sales increased about 7.0% in 1992. 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, Oklahoma, Texas, and Wyoming. Seven private plants and the Bureau's plant purified helium this year. Pressure-swing adsorption is used for helium purification at all seven of the private helium plants and at the Bureau's plant. The Bureau also uses cryogenic purification for backup. The Bureau and six 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; Exxon Co., U.S.A., Shute Creek, WY; Kansas Refined Helium Co., Otis, KS; and Praxair, Inc., Bushton and Ulysses, KS. Nitrotec's helium plant near Burlington, CO, produces Grade-A helium but does not liquefy it. *(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. *(See figure 3.)* The Pacific and Gulf Coast States were the principal areas of helium consumption.

Bureau sales to Federal agencies and their contractors totaled 8.626 million cubic meters (311 MMcf) in 1992, a decrease of about 8% when compared with last year's sales. This decrease was largely due to the helium price increases implemented during 1991 and reduced SDI purchases 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.

Stocks

The volume of helium stored in the U.S. Bureau of Mines helium conservation storage system, including the conservation pipeline network and Cliffside Field, totaled 0.94 billion cubic meters (33.8 Bcf) at yearend. The storage system contains crude helium purchased under contract by the Bureau from 1962 to 1973 and privately owned helium stored under contract. Excess private helium is extracted from natural gas supplying fuel markets in the winter and stored by the Bureau under contract. This privately owned crude helium is returned to the owners as needed for purification to supply private demand. During 1992, 25.3 million cubic meters (913 MMcf) of private helium was delivered to the Bureau's helium conservation storage system and 18.4 million cubic meters (663 MMcf) was withdrawn for a net increase of 6.9 million cubic meters (250 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 Bureau price for Grade-A helium, f.o.b. plant, was $1.983 per cubic meter ($55.00 per Mcf) and bulk liquid helium was $2.253 per cubic meter ($62.50 per Mcf) on January 1, 1992, with additional costs for container services and rent. On November 1, 1992, the bulk liquid helium price was raised to $2.379 per cubic meter ($66.00 per Mcf). Private

industry also increased its helium prices last year, but lagged behind the Bureau's.

Foreign Trade

Exports of Grade-A helium, all by private industry, increased by 13% in 1992 to 30.7 million cubic meters (1,106 MMcf). *(See table 3).* About 47% of the exported helium was shipped to Europe. Belgium-Luxembourg, France, and the United Kingdom, collectively, received about 88% of the European helium imports. About 37% of the U.S. helium exports went to Asia, with Japan receiving about 87%. Other exports were as follows: about 7% to North America; about 2% each to Australia-New Zealand, the Middle East, and South America; 1% to Central America; and less than 1% each to Africa and the Caribbean. The shipments of large volumes of helium to Western Europe were attributed to helium uses in cryogenic research and superconducting applications. Significant volumes were also used in breathing mixtures for diving, welding, and as a lifting gas. Although no helium was imported by the United States in 1992, import tariffs on helium remained at the 3.7% rate for most favored nations established on January 1, 1987. The non-most-favored-nation tariff also remained unchanged at 25%. No changes in import tariffs are scheduled at this time.

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 Russia. The remainder was produced in small plants in China and India. *(See table 5.)*

OUTLOOK

Until recently, all superconductors required liquid helium (-269 °C or -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 or -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 1988, the market for U.S.-produced helium has grown at an average annual rate of 7.2%. Private industry's market has been growing at 8.2% per year, while the Federal market has dropped 23% since prices were increased in 1991. In 1992, private industry supplied about 86% of the domestic demand while the Bureau supplied the remaining 14%. Private industry supplies all of the U.S. helium exports. The foreign market made up about 33% of U.S. helium sales in 1992 and has grown at an average rate of almost 14% per year since 1988.

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.

[1]All metric helium volumes herein reported are at 101.325 kilopascals absolute (14.696 psia) and 15 °C (59 °F). Helium volumes, reported in parenthesis following metric units, are measured at 14.7 psia and 70 °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 cubic feet at 14.7 psia and 70 °F.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Helium. Ch. in Commodity Annual Report, annual.

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Information Circular 9301, Analyses of Natural Gases, 1986-1990, by J. E. Hamak and S. M. Sigler.

Information Circular 9318, Analyses of Natural Gases, 1991, by J. E. Hamak and B. D. Gage.

Information Circular 9342, Helium Resources of the United States, 1991, by J. E. Hamak and B. D. Gage.

TABLE 1

OWNERSHIP AND LOCATION OF HELIUM EXTRACTION PLANTS IN THE UNITED STATES IN 1992

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	Deactivated.
Nitrotec	Burlington, CO	Grade-A helium.
Trident NGL, Inc.	Ulysses, KS	Crude helium.
Phillips Petroleum Co.	Dumas, TX	Do.
Do.	Hansford County, TX	Do.
Praxaire, Inc.	Bushton, KS	Grade-A helium.[1]
Do.	Elkhart, KS	Deactivated.
Do.	Ulysses, KS	Grade-A helium.[1]

[1]Including liquefaction.
[2]Output is piped to Ulysses, KS, for purification.

TABLE 2

HELIUM RECOVERY IN THE UNITED STATES[1]

(Thousand cubic meters)

	1988	1989	1990	1991	1992
Crude helium:					
U.S. Bureau of Mines total storage	(9,969)	(10,471)	(12,837)	(9,551)	(9,359)
Private industry:					
Stored by U.S. Bureau of Mines	17,495	15,176	14,064	26,580	25,319
Withdrawn	(15,311)	(18,120)	(21,265)	(18,105)	17,874
Total private industry storage	2,184	(2,943)	(7,201)	8,475	7,445
Total crude helium	(7,785)	(13,414)	(20,038)	(1,076)	(1,914)
Stored private crude helium withdrawn from storage and purified by the U.S. Bureau of Mines for redelivery to industry	(331)	(152)	(178)	(613)	(510)
Grade-A helium:					
U.S. Bureau of Mines sold	8,791	9,712	11,170	9,399	8,630
Private industry sold	62,602	70,153	73,665	78,702	85,762
Total sold	71,394	79,865	84,835	88,101	94,392
Total stored	(8,115)	(13,566)	(20,216)	(1,689)	(2,424)
Grand total recovery	63,278	66,299	64,619	86,412	91,968

[1]Negative numbers are enclosed in parenthesis ( ) to denote net withdrawal from the Bureau's underground storage facility, a partially depleted natural gas reservoir in Cliffside Field near Amarillo, TX.

TABLE 3

TOTAL SALES OF GRADE-A HELIUM PRODUCED IN THE UNITED STATES

(Million cubic meters)

Year	Volume		
	Domestic sales	Exports[1]	Total sales
1988	53.0	18.4	71.4
1989	57.8	22.1	79.9
1990	60.1	24.7	84.8
1991	61.0	27.1	88.1
1992	63.7	30.7	94.4

[1]Source: Bureau of the Census.

TABLE 5

WORLD GRADE-A HELIUM PRODUCTION CAPACITY, DECEMBER 31, 1992

(Million cubic meters)

	Capacity
United States	[1]106
Rest of world[e]	11
Total[e]	117

[e]Estimated.
[1]Includes capacity of plants on standby as well as operating plants.

TABLE 4

SUMMARY OF U.S. BUREAU OF MINES HELIUM CONSERVATION STORAGE SYSTEM OPERATIONS[1]

(Thousand cubic meters)

	1990	1991	1992
Helium in conservation storage system at beginning 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	952,609
Input to system:			
Net deliveries from U.S. Bureau of Mines plants[2]	(12,837)	(9,551)	(9,359)
Stored for private producers under contract	14,064	26,580	25,319
Total	1,227	17,029	15,960
Redelivery of helium stored for private producers under contract[2]	(21,443)	(18,718)	(18,384)
Net addition to system[2]	(20,216)	(1,689)	(2,424)
Helium in conservation storage system at end of period:			
Stored under U.S. Bureau of Mines conservation program	912,999	903,448	894,089
Stored for private producers under contract	41,300	49,161	56,096
Total	954,299	952,609	950,185

[1]Crude 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.
[2]Numbers in parentheses indicate net withdrawal from storage.

FIGURE 1

HELIUM RECOVERY IN THE UNITED STATES

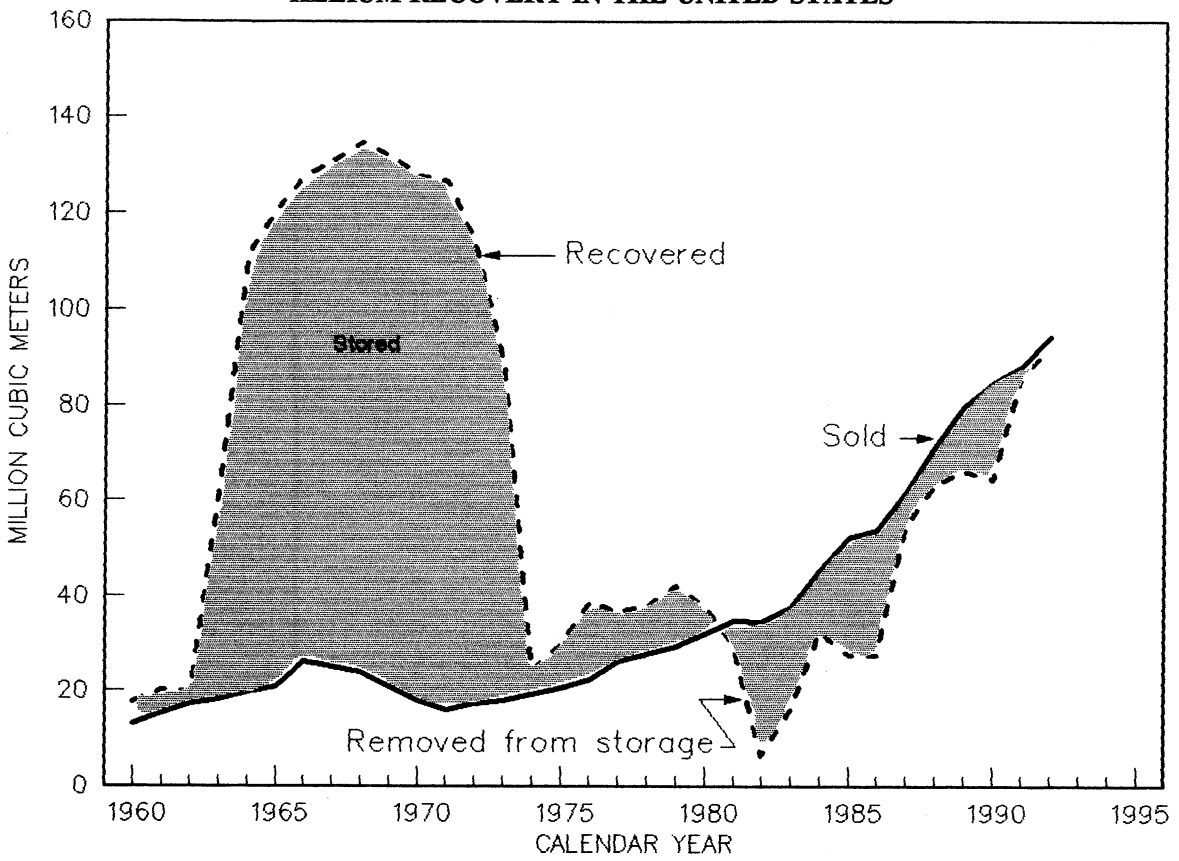


FIGURE 2

MAJOR U.S. HELIUM-BEARING NATURAL GAS FIELDS

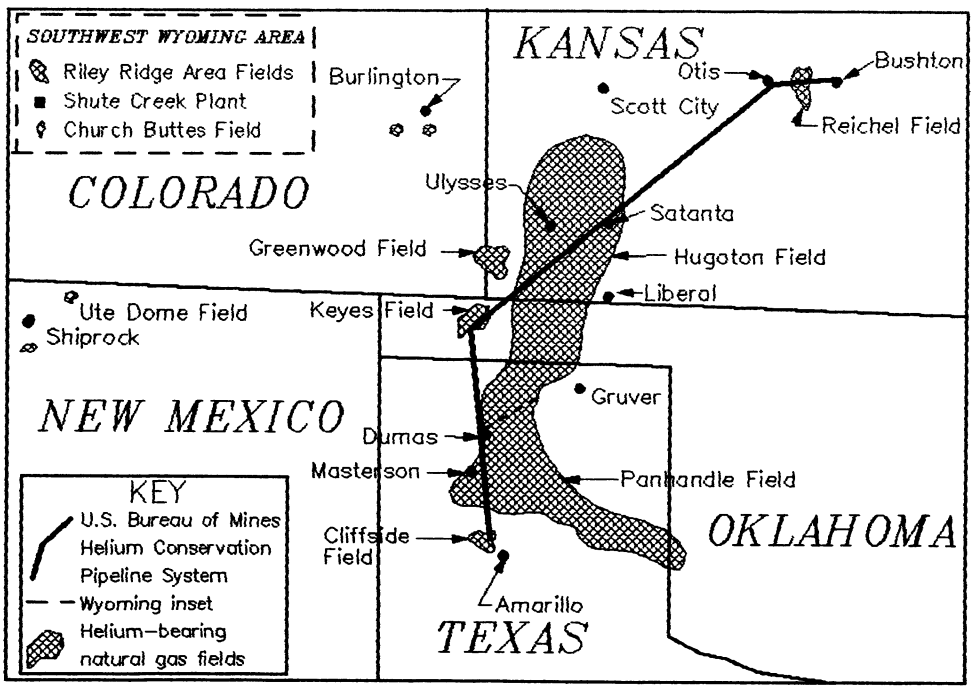
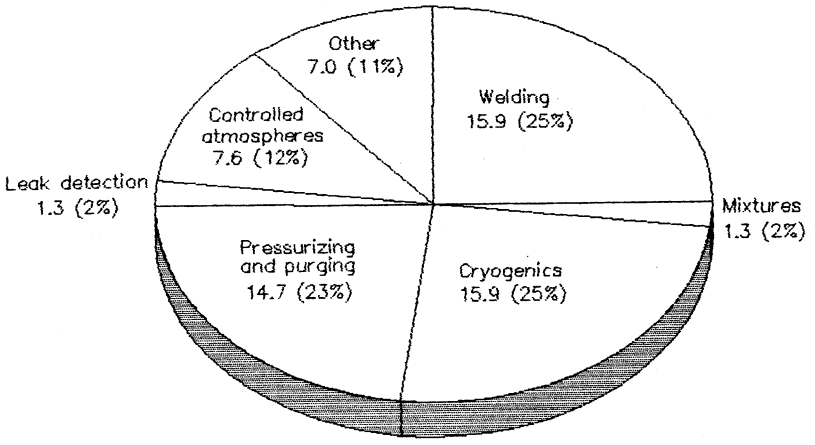


FIGURE 3

ESTIMATED HELIUM CONSUMPTION, BY END USE, IN THE UNITED STATES IN 1992

(Million cubic meters)



Estimated total helium used
(63.7 million cubic meters)

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 14 years. Domestic survey data were prepared by Tonya Hardin, statistical assistant; and international data tables were prepared by Jeremy Tidwell, international data coordinator.

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 6. *(See tables 1 and 6.)*

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 ($2CaO \cdot I_2O_5 \cdot CrO_3$) 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 Gujangon 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 where the iodine is absorbed by a solution of hydriodic acid. The iodine settles, is filtered, and is 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 readily in radiopaque media, animal feeds, catalysts, and stabilizers, shortages tend to cause the accumulation of inventories to ensure an adequate supply. An adequate supply tends to lower and stabilize the price.

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 enters the United States duty free. Calcium and cuprous iodine has a 25% ad valorem duty for non-most-favored-nation (MFN) status. Potassium iodide has duties of 2.8% ad valorem for MFN status and 7.5% ad valorem for non-MFN 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 to 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 U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), proposed in the Federal Register June 12 to amend its existing air contaminant standards that set permissible exposure limits (PEL's) for the maritime, construction, and agriculture industry sectors. Only employees of farms with more than 10 employees are covered under OSHA standards. Included in the proposed PEL's are iodoform and methyl iodide.

South Carolina and Virginia were granted exemptions for the use of iprodione on apples. The provisions included a maximum application area of 809 hectares (2,000 acres) a maximum of three applications made at 2- to 3- week intervals, a preharvest interval of 30 days, and an expiration date of January 1, 1993.[1]

Strategic Considerations

The National Defense Stockpile contained 6.1 million pounds of crude iodine. The stockpile goal for iodine was reduced to zero with the passage of Public Law 102-484 on October 23, 1992. The Defense Logistics Agency (DLA) of the U.S. Department of Defense sold 11,340 kilograms (kg) of excess iodine valued at $83,500 ($3.34 per pound) during fiscal year 1991, and no iodine was disposed during fiscal year 1992, although Congress authorized 102,058 kg. 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, 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 per year.

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.

In the mid-1980's, drug companies developed a new form of the iodine dye that is injected into patients so doctors can view the functioning of coronary arteries or kidneys on an X-ray screen. Fewer patients get adverse reactions from the new dye, but the price is 10 to 15 times higher. Some health plans, pressured to hold down premium increases, approved a guideline strongly encouraging use of the old, less expensive version, except for high-risk patients. The high-risk group of patients would experience severe but nonfatal reactions, such as vomiting. It was estimated that 40 additional bad reactions per year among the southern California region's 2.3 million members would save an estimated $3.5 million annually.[2]

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.

Tall oil capacity increased as capacity was expanded to 920,000 metric 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. Demand through the 1990's for tall oil rosin derivatives is expected to increase 3% per year, while supply will increase 1% or less. The adhesives, ink, and paper sizing markets make up 80% of the demand. Tall oil rosins will not be used for low-value applications.[3]

Deepwater Iodides announced plans for the construction of a $3.7 million manufacturing and distribution facility at Woodward, OK. Two separate buildings will be constructed. One will be the production plant and the other the office, warehouse, and laboratory. The plant will make high-purity organic iodine derivatives for the pharmaceutical industry. The facility will occupy a 6-hectares site at Woodward Industrial Airpark. The company changed its name from Deepwater Inc. last year to more accurately reflect its business.

Producers sold $86.9 million of iodophors for medical, veterinary, and food-processing applications. The two main classes of iodophors are povidone iodine, manufactured from polyvinylpyrrolidone and utilized in human skin disinfectants, and the nonionic detergent-iodine combinations, utilizing primarily nonoxynol and the poloxamers. Iodophors are highly self-stable, substantially free of the corrosive effects of noncomplexed-iodine concentrations, and relatively nonirritating to human skin. One of the world's largest producers of nonionic detergent iodines is West Agro, Inc.[4]

Angus Chemical Co. was the only producer of diiodomethyl-p-tolylsulfone, a biocide, used in the control of fungi, mildew, and algae. Added in the pigment-dispersion operation, the preservative provides superior protection against mildew formation of latex paint films. Typical applications include products for the lumber, construction, home improvement, textile, and automotive industries. *(See table 2.)*

Prices

The average declared c.i.f. value for imported crude iodine was $9.03 per kg ($4.09 per pound). The average declared c.i.f. value for imported crude iodine from Japan averaged $9.58 per kg ($4.35 per pound). The average declared c.i.f. value for iodine imported from Chile was $8.52 per kg ($3.86 per pound). Quoted yearend U.S. prices for iodine and its primary compounds are shown in table 3. *(See table 3.)*

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.

Calabrian Corp. and Mitsubishi International Corp. formed a joint venture

for the domestic sale of crude iodine produced by Ise Chemicals Corp. of Tokyo. The new company, called Mical Specialty Chemicals Inc., will be located in New Jersey. *(See tables 4 and 5.)*

World Review

Canada.—Brines with iodine enrichment are confined mainly to shallow formations of Cretaceous age. Contents generally are in the range of 40 to 50 ppm. These compositions are below current commercial production limits.[5]

Chile.—Sociedad Química y Minera de Chile (SQM, formerly known as SOQUIMICH) was the largest producer of iodine in Chile. During 1991, SQM formed two independent operating divisions, SQM Fertilizer and SQM-Iodine. SQM-Iodine will be responsible for marketing crude iodine and also iodine salts that SQM recently began manufacturing. Installed capacity was reported at 6,000 tons per year, although current production was about 4,000 tons per year. SQM operates 10 iodine plants in Chile: one at Maria Elena, two at Coya Sur, and three at Pedro de Valdiva with satellite plants at Araucamna, Ossa, and Puelma. SQM also announced plans to be certified under the International Organization for Standardization 9000 program or 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. During 1991 SQM sales were $140 million, but its new profits slumped to $4.0 million compared with $14 million during 1990. The slump in earning had been attributed to a halving of iodine prices over the past 3 years from $18 per kg to less than $9 per kg. As a result of the poor performance, the work force agreed to a 5% pay reduction. During 1992, iodine shipments rose, but the price dropped again.[6]

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 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 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 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 tons of 99.5% to 100.5% iodine, with mineral reserves of 48,000 tons of iodine in situ. The company also owns mineral rights at other locations in the first and second regions of Chile.

Mineral Yolanda was seeking a $60 million investment to finance the Yolanda Project, also known as the Taltal Project. The project is wholly owned by Kap Resources Ltd., Vancouver, Canada. The project planned to produce 930 tons per year of iodine and 300,000 tons per year of sodium nitrate. The mineral salts or caliche will be leached with seawater to dissolve the salts. The solution will be processed to extract the iodine. The remaining solution will be evaporated in solar ponds to concentrate the nitrate salts. Production was expected to commence by 1994.[7]

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 1992. 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 6.)*

Current Research

An experimental transparent panel using negatively charged iodine could one day transform ordinary windows into see-through solar cells. The panels are made with titanium and tin conductors with an electrolyte solution of iodine. The conversion of light to electricity ranges from 10% to 15%, which is more efficient than the amorphous silicon solar cells commonly found in calculators. The panels are projected to cost about one-fifth of amorphous solar cells.[8]

Researchers have used soluble conducting polymers doped with iodine to make a flexible light-emitting diode that works when bent. This is a significant step forward to semiconductor technology based on organic materials, which are easier to process and fabricate into different shapes and offer mechanical properties that inorganic semiconductors cannot match.[9]

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.

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[2]Faltermayer, E. A Health Plan That Can Work. Fortune, v. 127, No. 12, 1993, p. 95.
[3]Chemical Marketing Reporter. Tall Oil Rosin Jump. V. 241, No. 25, 1992, p. 5.
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[5]Hora, Z. D. Industrial Minerals of Western Canada. Ind. Miner. (London), No. 296, 1992, p. 60.
[6]Mining Journal. SQM Acquires AMAX stake in MINSAL. V. 319, No. 8200, p. 355.
[7]Industrial Minerals (London). Chile: Yolanda Iodine/Nitrate Progress. No. 298, 1992, p. 10.
[8]Popular Science. "Electric" Windows. V. 241, No. 6, 1992, p. 81.
[9]Dagani, R. Flexible Light-Emitting Diode Developed From Conducting Polymers. Chem. & Eng. News, v. 70, No. 26, 1992, pp. 27-28.

OTHER SOURCES OF INFORMATION

Iodine. Ch. in Mineral Facts and Problems, 1985.
Iodine. Ch. in Minerals Yearbook, annual.

TABLE 1
SALIENT IODINE STATISTICS

(Thousand kilograms and thousand dollars)

	1988	1989	1990	1991	1992
United States:					
Production	1,015	1,508	1,973	1,999	1,995
Imports for consumption[1]	3,300	3,326	3,168	3,555	3,745
Exports[1]	NA	NA	2,100	r1,317	1,807
Consumption:[2]					
Apparent	4,315	4,834	3,041	r4,327	3,933
Reported	2,900	2,900	3,100	3,200	3,400
Price, average c.i.f. value, dollars per kilogram	$17.46	$19.50	$13.78	$10.16	$9.03
World: Production	r14,915	r16,254	r17,014	r17,537	e16,930

eEstimated. rRevised. NA Not available.
[1]Bureau of the Census.
[2]Calculated by production plus imports minus exports.

TABLE 2
U.S. CONSUMPTION OF CRUDE IODINE, BY PRODUCT

Product	1991		1992	
	Number of plants	Consumption (thousand kilograms)	Number of plants	Consumption (thousand kilograms)
Reported consumption:				
Resublimed iodine	9	127	9	148
Hydriodic acid	1	W	3	107
Calcium iodate	(1)	(1)	(1)	(1)
Calcium iodide	3	113	3	125
Cuprous iodide	3	24	3	62
Potassium iodide	5	643	4	530
Potassium iodate	3	42	3	40
Sodium iodide	6	66	6	94
Other inorganic compounds	16	1,191	17	1,219
Ethylenediamine dihydroiodide	4	494	4	559
Other organic compounds	6	476	8	516
Total	[2]29	3,176	[2]27	3,400
Apparent consumption	XX	5.2	XX	5.3

W Withheld to avoid disclosing company proprietary data; included with "Other inorganic compounds." XX Not applicable.
[1]Included with calcium iodide.
[2]Nonadditive total because some plants produce more than one product.

TABLE 3

YEAREND 1992 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
Iodine, crude, drums	10.00- 11.00	4.75- 5.21
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

[1]Conditions of final preparation, transportation, quantities, and qualities not stated are subject to negotiations and/or somewhat different price quotations.

Source: Chemical Marketing Reporter. V. 242, No. 26, Dec. 28, 1992, pp. 22-30.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF CRUDE IODINE, BY TYPE AND COUNTRY

(Thousand kilograms and thousand dollars)

Country	1991		1992	
	Quantity	Value[1]	Quantity	Value[1]
Iodine, crude:				
Chile	1,798	18,653	1,963	16,723
Germany	(2)	(2)	—	—
Italy	(2)	(2)	—	—
Japan	1,705	16,863	1,689	16,188
Netherlands	(2)	(2)	—	—
United Kingdom	(2)	(2)	—	—
Total	3,503	r35,516	3,652	32,911
Iodine, potassium:				
Canada	2	26	15	166
Chile	—	—	6	58
Germany	(3)	5	2	23
India	37	400	40	389
Italy	9	26	11	44
Mexico	—	—	17	212
Netherlands	(3)	7	—	—
Switzerland	2	8	—	—
United Kingdom	2	30	—	—
Total[4]	52	502	93	891
Grand total	3,555	r36,018	3,745	33,802

rRevised.
[1]Declared c.i.f. valuation.
[2]Revised to zero.
[3]Less than 1/2 unit.
[4]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census, as adjusted by the U.S. Bureau of Mines.

TABLE 5
U.S. EXPORTS OF CRUDE IODINE, BY TYPE AND COUNTRY

(Thousand kilograms and thousand dollars)

Country	1991		1992	
	Quantity	Value[1]	Quantity	Value[1]
Iodine, crude/resublimed:				
Belgium	—	—	13	52
Canada	66	981	94	966
China	34	344	—	—
Dominican Republic	(2)	(2)	—	—
Germany	455	5,019	567	4,925
Hong Kong	—	—	15	175
India	17	165	—	—
Japan	281	2,795	428	4,664
Mexico	204	4,526	350	2,819
Taiwan	22	258	59	106
United Kingdom	95	1,144	67	889
Venezuela	10	84	—	—
Other[3]	28	435	32	543
Total[4]	r1,213	r15,751	1,625	15,139
Iodide, potassium:				
Canada	30	26	76	67
China	—	—	18	58
Colombia	—	—	36	42
Mexico	17	48	1	2
Netherlands	25	127	—	—
Spain	1	3	11	55
Sweden	—	—	18	20
Taiwan	14	23	—	—
Other[5]	r18	r171	24	159
Total[4]	105	398	182	402
Grand total[4]	r1,317	r16,149	1,807	15,541

rRevised.
[1]Declared c.i.f. valuation.
[2]Revised to zero.
[3]Includes United Arab Emirates (1991), Australia, The Bahamas, Ecuador (1992), El Salvador (1992), France (1991), Ghana, Indonesia (1992), Ireland (1991), Italy, the Republic of Korea (1991), Kuwait (1992), New Zealand (1992), Panama (1991), Peru, Philippines (1992), Spain (1991), and Turkey (1992).
[4]Data may not add to totals shown because of independent rounding.
[5]Includes Belgium (1992), Brazil (1992), Chile, Finland (1992), Hong Kong, Ireland (1992), the Republic of Korea, Mexico (1992), Norway (1992), Saudi Arabia, the Republic of South Africa (1992), and Thailand (1992).

Source: Bureau of the Census.

TABLE 6

CRUDE IODINE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand kilograms)

Country[2]	1988	1989	1990	1991	1992[e]
Chile	r3,939	r4,640	r5,000	r5,700	r5,600
China[e]	500	500	500	500	500
Indonesia	10	14	60	r36	35
Japan	7,451	7,592	7,581	r7,502	7,300
U.S.S.R.[e 2]	2,000	2,000	1,900	1,800	1,500
United States	1,015	1,508	1,973	1,999	[3]1,995
Total	r14,915	r16,254	r17,014	r17,537	16,930

[e]Estimated. [r]Revised.

[1]Table includes data available through June 14, 1993.

[2]Dissolved in Dec. 1991. This commodity is believed to be produced in Azerbaijan and Turkmenistan; however, information is inadequate to formulate reliable estimates of individual country production.

[3]Reported figure.

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 Coordination. The world production table was prepared by Douglas R. Rhoten, International Data Section.

Iron ore is essential to the economy and national security of the United States. As the basic raw material from which iron and steel is made, its supply is critical to any industrial country. Scrap is used as a supplement in steelmaking, but is limited as a major feed material because there is a limited quantity of high-quality scrap.

In 1992, China became the world's largest producer and consumer of iron ore. Iron ore production fell in all major producing countries and regions with the exception of China. World pig iron production, the best indicator of iron ore consumption, fell slightly during the year. Production in the United States posted a moderate gain, while production in China rose by 15%. Pig iron production in China slightly exceeded that of Japan to make China the world's largest iron ore consumer. Australia and Brazil continued to be the leading exporters of iron ore with a combined total of close to 60% of the world total.

Domestic iron ore production and shipments fell slightly from 1991 levels. Total reported consumption, however, increased by 16% and stocks fell accordingly. The increase in consumption was the result of a 6% increase in raw steel production.

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 47 addressees to whom the 1066-A form was sent, 25 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] Initially, 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 million metric tons (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

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 increased imports of steel and 2 deep recessions from which the iron ore and steel industries have not yet fully recovered.

Size and Organization.—In 1992, iron ore was produced by 20 companies operating 20 mines, 16 concentration plants, and 10 pelletizing plants. The mines included 19 open pits and 1 underground operation. Virtually all ore was concentrated before shipment, and about 98% 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 1992, 80% of domestic production came from mines owned by U.S. steel companies. 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. 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 Auxiliar de Empresas de Mineracao (CAEMI) of Brazil (25%).

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 [$(Ca,Mg)CO_3$] to the iron ore concentrate during the balling stage. Sufficient fluxstone is added to raise the ratio of $(CaO+MgO)/(SiO_2+ Al_2O_3)$ in the pellet to above 0.6. The most common ratio is about 1. Fluxed pellets comprised 56.6% of total U.S. pellet production in 1992 compared with 56.3 in 1991. 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 1992. At least 45 other countries mined crude ore during the year. The leading producer was Brazil, which accounted for about 19% of world output in terms of metal content, followed by Australia with 14% and China with 13%. Trends in world mine production since 1988 are shown on a country basis in table 19.

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 also has 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 former 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 (km^2). 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 former 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 Ukraine. 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 also are 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 pyrometasomatic 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.

Pyrometasomatic 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

The construction of a plant to determine the technical and economic feasibility of the HIsmelt Direct Smelting Process was about 75% complete at yearend. The project was to be managed by HIsmelt Corp. Pty. Ltd., a 50-50 joint venture between CRA Ltd., Australia's largest mining company, and Midrex Corp., based in Charlotte, NC. The facility, at Kwinana, 40 kilometers (km) south of Perth, Western Australia, was expected to cost more than US$100 million. The HIsmelt process converts iron ore fines directly into metal using coal rather than coke, as is used in conventional blast furnace technology. The purpose of the plant was to confirm that the process would (1) produce hot metal suitable for making high-quality steel from a wide range of iron ore fines, (2) use a variety of coals with an energy consumption comparable to that of an efficient blast furnace, (3) be capable of being scaled up to be competitive at a capacity of 0.5 to 1.0 million metric tons per year (Mmt/yr), and (4) meet future emission standards.

The heart of the new complex will be a 0.1-Mmt/yr prototype smelt reduction vessel (SRV), which is scheduled to startup in mid-1993. The capacity of a commercial-sized plant is considered to be 0.5 to 1.0 Mmt/yr. The process is a single-stage process that involves the direct smelting of iron ore in a closed molten bath reactor. Coal is injected into the iron bath to maximize recovery of the carbon and to generate bath turbulence. The ore is preheated and prereduced in a circulating fluidized bed prior to injection into the horizontal SRV. Hot air is supplied to the top of the SRV to post

combust the generated CO. The hot metal and slag tapped from the SRV are transported to the pig caster and the slag pens. If the full-scale pilot plant tests at Kwinana are successful, several U.S. companies may follow suit.

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 1992, 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, and pelletizing plants and in repair and maintenance shops, but do not include 827 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 affect 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 3.2% higher than that of 1991.

Transportation.—In 1990, the U.S. Army Corps of Engineers published a Notice of Proposed Rulemaking to set the closing for the Soo locks at Sault Ste. Marie, MI, at January 15, rather than the variable closing time that previously had been in effect. The Corps had studied the environmental impacts of an extended navigation season through the St. Marys River for a decade and could find no significant adverse effects. After a period of public comment, which produced no evidence to the contrary, the January 15 closing date became official as of the 1992 navigation season.

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 tons 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 tons 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. 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 tons. 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/hr of pellets and has a stockpiling capacity of 860,000 tons of pellets and 1.06 Mmt of coal.[8]

U.S. coastal ports are still limited to incoming cargoes of 65,000 tons or less. Hunterston, Rotterdam, Taranto, and several other ports in Western Europe can now accommodate iron ore cargoes of 150,000 to 300,000 tons. 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 tons 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 Docefjord, another vessel capable of carrying more than 300,000 tons of ore, were built in 1986, primarily for trade between Brazil and Japan. In Japan, cargoes of 200,000 to 260,000 tons 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 have 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. A 20-centimeter (cm) (8-inch), 87-km line from La Perla is connected to a 36-cm (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. 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 also have been built in Brazil and India since 1977, and others are operating in Argentina, Australia, New Zealand, and Peru.

ANNUAL REVIEW

Legislation and Government Programs

Voluntary Restraint Agreements (VRA's) on steel imports expired on March 31. Under the VRA's, steel-producing nations had agreed to limit steel exports to the United States in return for withdrawal of charges by U.S steel companies that the imports were a cause of injury to the U.S. steel industry. In June, U.S. steelmakers filed new complaints with the International Trade Commission (ITC) against 21 nations, alleging injury to the U.S. industry as a result of illegal subsidies and sales at less than face value. The ITC issued an initial decision affirming the claims of injury against a number of these nations. Effective December 7, importers were required to provide funds or bonds to cover countervailing duties, pending a final decision in 1993.

Production

Domestic iron ore production showed a 2% drop in 1992, down from 56.8 Mmt in 1991 to 55.6 Mmt. Productivity for usable ore in the Lake Superior District was greater than that of 1991.

Iron ore was produced by 19 open pit mines and 1 underground mine. Sixteen 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, 1992, was estimated at 82 Mmt/yr, of which 81 Mmt was pellets. Total output of usable ore was equivalent to about 68% of installed production capacity, down from 69% in 1991. An average of 3.3 tons of crude ore was mined in 1992 for each ton of usable ore produced, a slight increase from that of 1991. 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 54.2 Mmt, 98% of usable ore output. The average iron content of usable ore produced was 63.4%. Shipments from U.S. loading docks on the upper Great Lakes totaled 58.3 Mmt in 1992 compared with 55.9 Mmt in 1991.

Michigan.—Michigan accounted for 25% of the national output of usable ore in 1992. 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 6.8 Mmt of pellets produced from magnetite concentrate. Tilden shipped 2.2 Mmt of magnetite pellets and 2.3 Mmt of hematite pellets, for a total of 4.5 Mmt. Production of usable ore was up 10% from the 1991 figure of 12.6 Mmt. Production of pellets totaled 12.2 Mmt, of which 6.8 Mmt was produced at the Empire plant and 5.4 Mmt was produced 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 74% of the national output of usable ore in 1992. All of the State's production came from open pit mines on the Mesabi Range. Production of pellets totaled 40.4 Mmt, equivalent to about 84% of installed production capacity of the State's seven taconite plants.

The year 1992 marked the centennial of the iron ore shipments from the Mesabi iron range. In October 1892, ore shipments commenced from the Mountain Iron Mine, the first mine on the range. Shipments have totaled about 3.7 billion tons.

CCI ceased iron ore shipments to Sharon Steel Corp. after the steelmaker idled its blast furnace in November because of financial problems. Shipments to Sharon accounted for about 11% of CCI's operating revenues. Sharon Steel

remained closed at yearend.

Cyprus Northshore Mining Corp. closed its Babbitt Mine and Silver Bay processing plant in early June as the result of a weak market. The shutdown, which resulted in the laying off of 328 employees, was expected to last for 23 weeks. However, even though the iron ore market remained soft, a small increase in sales enabled Cyprus to restart its operations in September rather than later in the year.

LTV Steel Mining Co. resumed operations on August 23, after a 6-week shutdown to reduce pellet inventories. Of the company's 1,600 employees, 1,450 were affected.

Effective January 1, 1992, Wheeling-Pittsburgh Steel Corp. increased its ownership interest in the Empire Iron Mining Partnership to 12.5% by acquiring 2.5% from CCI.

In September, Armco Steel Co. LP reduced its requirements for iron ore pellets from Eveleth Mines at Eveleth, MN, for the balance of the year. Following tests run with 100% fluxed pellets in a blast furnace at its Ashland, KY, plant, Armco determined that its feed mix could be changed. The company began receiving fluxed pellets from Northshore Mining Co. at Silver Bay, MN, and from Cia. Vale do Rio Doce (CVRD), in Brazil. The Cyprus Northshore pellets were delivered in self-unloaders to the Torco dock in Toledo, OH, with rail delivery to the Ashland and Middletown, OH, steel plants. The CVRD pellets were loaded onto barges at New Orleans for shipment up the Mississippi and Ohio Rivers. As the result of the reduction, Eveleth announced that its 1992 production schedule was reduced by 9% to 3.6 Mmt. Armco decided to obtain its remaining 1992 iron ore requirements from sources other than Eveleth because of Eveleth's high costs.

At Mountain Iron, the Minntac Mine closed its No. 3 pelletizing line, the smallest of five, as the result of a weak market. The line closed in early October and remained closed through yearend. The plant, which is the largest of the Iron Range's seven taconite companies, produced taconite pellets for USX Corp.'s U.S Steel Group and others.

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. 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. 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.

Other States.—Two California mines produced iron ore during the year—the Baxter and the Beck. The bulk of the shipments went to cement plants in the Los Angeles basin.

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 1992.

Consumption and Uses

The U.S. steel industry accounted for 98.6% of domestic iron ore consumption in 1992. The steel industry experienced a slight increase over the previous 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 6%.

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 38.0% of total steelmaking in 1992. This was the largest share for electric arc furnace steelmaking in the United States.

Consumption of iron ore was 7.7% higher than the figure for 1991. Consumption for ironmaking and steelmaking totaled 68.9 Mmt. Monthly consumption of pellets, direct-shipping ore, and merchant sinter by the industry averaged 5.71 Mmt compared with 5.31 Mmt in 1991. Reported consumption of iron ore for manufacture of cement, heavy-medium materials, animal feed, ballast, ferrites, pigments, and other nonsteel products was 976,000 tons.

U.S. production of hot metal and pig iron totaled 47.0 Mmt, a 6.5% increase from that of 1991. During 1992, the number of blast furnaces in operation ranged from 41 to 44.

Consumption of iron ore and all types of agglomerates reported to the AISI by integrated producers of iron and steel totaled 73.7 Mmt. This included 60.2 Mmt of pellets; 11.4 Mmt of sinter, briquettes, etc.; and 2.1 Mmt of natural coarse ore. Of the primary ore consumed, 79% was of domestic origin, 10% came from Canada, and 11% 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, 2.4 Mmt of ferrous scrap was consumed in blast furnaces in 1992.

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 and 1991, but has since continued downward. At yearend, total industry stocks were 21.3 Mmt. Furnace yard stocks stood at 16.1 Mmt and included 11.9 Mmt of domestic ores, 1.9 Mmt of Canadian ores, and 2.2 Mmt of foreign ores. Mine stocks at yearend were 35% lower than those of 1991.

Stocks of unagglomerated concentrates reported at pelletizing plants totaled 1.9 Mmt at yearend, an increase of 3% from that of 1991. 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

Great Lakes shipping continued to play a key role in the competitiveness of the U.S. iron ore industry. The Corps of Engineers kept the Soo locks open until January 10, 1993. Ore shipments from Escanaba on Lake Michigan began on March 11. The 1992 navigation season lasted 315 days. Iron ore shipments on the Great Lakes totaled 60.9 Mmt compared with 58.3 Mmt in 1991.

The fleet operated 57 of its 66 serviceable vessels, with the 57 vessels accounting for 94% of carrying capacity. Since 1980, the number of U.S.-flag vessels on the Great Lakes has dropped from about 140 to 61. At the same time, the average carrying capacity has risen from 20,900 tons to 25,900 tons. Of the 66 vessels, 6 were cement carriers and 3 were self-propelled tankers.

Prices

Internationally, price reductions were forced on iron ore producers for the second consecutive year. Steelmakers insisted on lower prices because steel prices were down for the fourth consecutive year. According to the Bureau of Labor Statistics, the Producer Price Index for Steel Mill Products fell from 114.52 in 1989 to 106.38 in 1992, a decline of 7%. The decreases of the past 2 years followed several years of increases that progress had been made in reversing a long trend of declines in iron ore prices, particularly in terms of inflation adjustment.

Most iron ore prices are negotiated between buyer and seller. About 80% of domestic ore is produced by captive mines (mines producing for company smelters) and therefore does not reach the open market. The average f.o.b. mine value of usable ore shipped in 1992 was $31.18 per ton, 5.7% higher than 1991. This average value was based primarily on producers' statements and should approximate the average commercial selling price less the cost of mine-to-market transportation.

In Japan, prices for lump ore were down about 6%; fines, about 5%. Very few published prices for domestically produced pellets changed in 1992. Oglebay Norton was both still quoting a price of $0.7245 per *long ton unit* (ltu) of iron, natural, for its standard grades of Lake Superior pellets. An 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 price for Minntac acid pellets was left at $0.3744 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 1991 and were as follows, per ton: at Georgetown, SC, $125.00 to $135.00; at Contrecoeur, Quebec, $115.00; and at Point Lisas, Trinidad and Tobago, $120.00.

Foreign Trade

U.S. exports of iron ore were 25% higher than those of 1991. 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 fell 6% to 12.5 Mmt.

Net imports for 1992 were 44% below the average of the previous 4 years and were equivalent to 10% of U.S. ore consumption. Canada's share of net imports was 55%; Brazil's share was 20%.

World Review

At least 55 countries mined iron ore during the year, producing a total of 929.8 Mmt. China was the largest producer, with an output of 194 Mmt. World production of pig iron, which directly reflects ore consumption, decreased by 1.7% to 498 Mmt. World DRI production rose by 7.9% to 20.9 tons.

For the second consecutive year Australia was the leading exporter of iron ore, shipping 106.6 Mmt to world markets, followed closely by Brazil, which exported 106.0 Mmt. Together, the two countries accounted for 57.8% of exports in 1992. The next largest exporter was India, at 7.8%. Total exports were 367.5 Mmt, down from 398.8 Mmt in 1991. Australia's principal customer, Japan, accounted for about one-half of its exports. Brazil's primary customers were the European Community (EC) and Japan.

Integrated iron ore operations have become extremely complex and are so large as to 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 also could make diversion feasible. Table 21 shows world pelletizing capability at the close of 1992. The data represent the rated capacities of 82 plants in 26 countries. A significant part of the data was published by the Trust Fund Project on Iron Ore Information in 1992. 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 21 also excludes sintering plants.

Australia.—BHP Iron Ore Ltd. opened its Yandi Mine in March with an initial production capacity of 5 Mmt/yr. Capacity was being doubled to 10 Mmt/yr through the installation of additional

crushing and screening equipment, which began in 1992 and was expected to be completed in 1993.

Robe River Iron Associates produced and shipped more than 20 Mmt of ore for the third consecutive year, but failed to achieve the record breaking levels of 1991. The company began mining the Mesa J deposit at Pannawonica at midyear. This event, combined with infrastructure improvements completed during the year, raised Robe River's nominal production capacity to 35 Mmt/yr. In the long term, the company intended to increase output to 50 Mmt/yr. Proven reserves at the J deposit were estimated at 600 Mmt and were likely to be closer to 800 Mmt.

Hamersley Iron Pty. Ltd. reached record production levels for the fourth consecutive year. Shipments for the year, on the other hand, declined as the result of drop in demand and a month-long strike during which the company declared a force majeure. Fourth quarter shipments dropped by 16% from the same period in 1991. Production from the Brockman No. 2 Detritals Mine, which began operating in June, contributed to the record result. The Brockman, 55 km northwest of Hamersley's main mine at Tom Price, was a small deposit, with only 20 Mmt of salable ore and expected life of 5 years. Like the Paraburdoo and Channar Mines and the Marandoo deposit, the Brockman was to be used to extend the life of the Tom Price Mine. After more than 27 months of negotiations, Hamersley gained approval in October from the Western Australian Ministry for the Environment for the development of the Marandoo deposit. The project was delayed because of environmental concerns and a dispute with Aboriginal interests regarding sacred sites. Development work on the deposit began late in the year with commissioning expected in 1995. The deposit was estimated to contain about 400 Mmt of high-grade ore. The Marandoo, 35 km east of Mount Tom Price, was expected to produce between 10 and 15 Mmt/yr beginning in early 1994.

Brazil.—Samarco Mineracao S.A. signed a contract for a $15 million loan from a group of Japanese companies to help finance its expansion plans. The group was led by Kobe Steel, one of the primary consumers of Samarco ore. Under the terms of the agreement, Samarco was to double its sales to Kobe to about 1 Mmt/yr. The projects included the construction of a pipeline and expansion of the company's pellet plant and was expected to increase Samarco's production capacity from 8.5 to 10 Mmt/yr.

Canada.—The two largest producers, Iron Ore Co. of Canada and Quebec Cartier Mining Co., experienced a drop in sales as the result of declining steel production in Europe, their primary market.

China.—In recent years, China's economy and industrial base have grown at a very rapid rate. To support this growth China has made enormous strides in increasing its iron ore production and consumption, and in 1992, became the world's largest producer and consumer of iron ore. In terms of Fe content, however, China was the world's third largest producer. Over the 10-year period 1983-92, China increased its iron ore production by 71% compared with a production growth rate of 7% for the rest of the world. For the same period, China's pig iron production rate grew 96%, compared with 3% for the rest of the world.

During 1992, China was planning the construction of at least three steel mills, each with a production capacity of 10 Mmt/yr. As a consequence, the country was seeking additional supplies of iron ore. As well as constructing eight new mines, China was considering expansions of the Nanfen Mine near Benxi, the Jian Chan near Taiyuan, and the Shuichang near Beijing. Late in the year, Anshan Steel signed a preliminary contract with United States and Canadian equipment manufacturers for large trucks, electric shovels, and slurry pipe machinery for the transport of concentrates. The equipment was expected to be used in the Qidashan Mine, which was to expand from a production capacity of 7 Mmt/yr to 15 Mmt/yr by 1995. Even with this level of effort, China was forced to look abroad for supplies of iron ore. Their imports of iron ore, primarily from Australia, have increased steadily, rising from 3.9 Mmt in 1983 to 25.2 Mmt in 1992. China was taking a number of steps to increase its imports. In December, the Capital Steel Corp. of Beijing purchased an iron mine in Peru (see Peru section). Capital Steel, also known by its Chinese name of Shougang Corp., was China's fourth largest steel producer. Most of China's efforts in seeking iron ore abroad centered on Australia. China was a partner with the Western Australia Government in the Western Australia-China Economy and Research Fund, which provided money for studying the feasibility of construction of a DRI plant in Western Australia. China also owned 40% of the Channar Mine in Western Australia.

France.—Lormines, the Usinor Sacilor iron mining subsidiary, reached an agreement with unions on closing the group's three iron mines in Lorraine. The Mairy-Maiville closed in June, while the other two, Moyeuvre and Roncourt, were scheduled to close before the end of 1994. The reasons for the closures were metallurgical more than economic. The ore was low grade, at 32% Fe, and low quality because of its high arsenic and phosphorus contents. After the mines close, French iron ore production will have fallen to less than 3 Mmt/yr, all from Arbed S.A.'s two mines in Lorraine.

India.—The Indian Government was intent on increasing domestic steel production. To this end, the Government removed restrictions on licenses and prices and announced that it would not allow any new contracts for increased exports of iron ore. The State-owned steel producer, Steel Authority of India Ltd. (SAIL), set a target of investing $11 billion over 15 years to expand production from existing plants. Its plan

calls for increasing production from 9.9 Mmt in 1991-92 to 18.9 Mmt in the year 2004-05. The Indian Steel Ministry set a goal of expanding overall steel production to 67 Mmt/yr by the year 2010 compared with 17 Mmt/yr in 1992. To supply part of the additional iron ore that will be needed, plans were made to double production to 18 Mmt/yr at the Bailadila Mine in Madhya Pradesh.

Iran.—Three 640,000-mt/yr Midrex Direct Reduction Corp. DRI modules became operational at the National Iranian Steel Corp.'s. (Nisco) facility in Mobarakeh. Two more were scheduled to come on-line in 1993, which would bring the complex's total DRI capacity to 3.2 Mmt/yr. Nisco, with technical help from Kobe Steel of Japan, was developing a large iron deposit at Chador Nalu in central Iran. The mine was expected to begin operation in 1995, with production of 5 Mmt/yr. Reserves at the deposit were estimated at 330 Mmt, grading 58% Fe. Kobe Steel was also involved in conducting a feasibility study to construct a DRI plant on Qeshm Island in the Strait of Hormuz.

Korea, Republic of.—Pohang Iron and Steel Co. (Posco) signed a contract to buy a Corex ironmaking unit from Voest-Alpine Industrieanlagenbau (VIA). The plant was expected to produce 600,000 to 700,000 mt/yr. Posco was the first customer to order the Corex technology after the Republic of South Africa.

Mauritania.—Five iron and steel companies, two each from Egypt and Algeria and one from Mauritania, signed an agreement to build an iron ore pelletizing plant in the country. Pending the results of a feasibility study, a deposit at Aouj Centere, 30 km north of F'Derik, was to be developed to feed the plant. Reserves at the deposit were estimated at 220 Mmt.

Peru.—The Peruvian Government succeeded in privatizing its state-owned iron ore producer. On December 1, 1992, Empresa Minera del Hierro del Peru (Hierro Peru) was sold to the Capital Steel Corp. of Beijing. Hierro Peru owned and operated the Marcona Mine. Capital Steel was China's fourth largest steel producer.

Under the contract, Capital Steel agreed to pay $120 million in cash, invest $150 over the next 3 years, and assume $42 million of Hierro's debt for a total of $312 million.

Sweden.—State-owned producer Luossavaara-Kiirunavaara A.B. (LKAB) planned to increase pellet production capacity at Kiruna, its principal mine. The 4-Mmt/yr plant was expected to come on-stream early in 1995 and was expected to make LKAB the world's largest pellet producer, with a total capacity of 15 Mmt/yr.

Trinidad and Tobago.—Nucor Steel Corp., a minimill operator, announced plans to build a plant in Trinidad and Tobago to produce iron carbide, a form of DRI. The Charlotte, NC, based company was to build a 320,000-mt/yr plant at a cost of $60 million; the plant's size could be quadrupled if it proved to be successful. Nucor was to use the process developed by Iron Carbide Holdings Ltd. and anticipated beginning construction of the plant early in 1993; production was expected to begin in late 1994. Feed for the plant was to be 500,000 mt/yr of Brazilian fines, which was expected to give them a cost advantage over pellets. Initially, the iron carbide was to be used in Nucor's flat-rolled sheet mills in Crawfordsville, IN, and Hickman, AR.

Ukraine.—Prospects for finishing the large, joint-venture iron ore beneficiation plant project at Dolinska appeared to be dead. The joint-venture partners and their respective shares of the project were the former U.S.S.R., about 50%; Romania, 27%; Czechoslovakia, 14%; with the balance going to the former German Democratic Republic and Bulgaria. Plans for the project were to construct a 13-Mmt/yr pelletizing plant at Dolinska, about 60 km from Krivoy Rog in the southern part of the country. Work on the joint venture began in 1986 and was scheduled for completion in 1992, but, at the end of the year was no more than one-half finished. With the dissolution of the U.S.S.R. and the unification of Germany, attitudes toward the project began to change. Germany, Russia, and the Czech and Slovak Republics indicated that they were not interested in completing the facility for various reasons, including changes in national priorities, escalating construction costs, and doubts about the quality of the ore.

Venezuela.—CVG Ferrominera del Orinoco CA (Ferrominera) launched an ambitious expansion program that, among other things, could nearly double its production capacity from 23 Mmt/yr to 40 Mmt/yr by the year 2000. As part of this program, the state-owned company began construction on a 3.3-Mmt/yr pellet plant at Peurto Ordaz, which was expected to begin operation at the end of 1994. Kobe Steel, a Japanese steelmaker, was also considering putting a pellet plant at the site in a joint project with Ferrominera, with construction beginning in 1993. Ferrominera and Kobe were also studying the possibilities of locating an 8-Mmt/yr concentrates plant at the mine site. Laboratory studies took place in Canada, Japan, and the United States, and a pilot plant was expected to begin operating in early 1993, to run for 2 years. The concentrates were expected to contain 68% iron. The cost of the project was projected to be $1.3 billion. Ferrominera reportedly had proven reserves estimated at 1,900 Mmt grading 60% iron. Probable and possible reserves were estimated to be 11,700 Mmt grading 44% iron.

OUTLOOK

The domestic iron ore industry is totally dependent on the 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 chapter. Only 9% of the iron ore shipped

in 1992 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. The U.S. steel industry is concentrating on making high-value, quality steels, not increasing output. Domestic blast furnace production in the year 2000 is expected to be no more than 50 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. The hope for the domestic iron ore industry is that one or more of the new direct processes, COREX, DIOS, AISI, HIsmelt, carbide, etc., will prove to be economic for lake producers.

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 variety 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 1992, China became the world's largest producer and consumer of iron ore. Iron ore production fell in all major producing countries and regions with the exception of China. World pig iron production, the best indicator of iron ore consumption, fell slightly during the year. Production in the United States posted a moderate gain, while production in China rose by 15%. Pig iron production in China slightly exceeded that of Japan to make China the world's largest iron ore consumer. Australia and Brazil continued to be the leading exporters of iron ore with a combined total of close to 60% of the world total.

In contrast to the United States, demand for iron ore in other parts of the world is expected to escalate, particularly in Asia. China became the world's largest producer and consumer of iron ore in 1992 (see section on China). From 1983 through 1992, pig iron production in China increased 96%, while in the rest of the world, the growth was 3%. Looking at Asia as a whole, production grew at 43% during the same period, whereas production in the rest of the world fell by 3%. India's growth was 65% and that of Taiwan was 55%. The most spectacular increase, at 140%, occurred in the Republic of Korea. The situation in Japan means greater consumption of iron ore elsewhere. The growth rate in that country has been flat and that is expected to continue, but Japan has been using more steel domestically. In the years from 1981 through 1991, in terms of its share of the world market, Japan's imports of semifinished and finished steel products rose from 1% to 6%. For the same period, its exports of these steel products fell from 20% to 10%, while apparent consumption rose from 11% to 15%. Given these data, it seems unlikely that Japanese steel exports will increase in the near term. The shortfall will have to be made up by higher steel production elsewhere and, consequently, higher iron ore consumption.

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.

The increase in consumption in Asia is expected to benefit Australia, primarily. Australia and Brazil are the two leading exporters of iron ore; each accounts for about 30% of the world total, and no other exporter comes close to that level. Of the two, Australia seems to be better placed to take advantage of growth of iron ore consumption in Asia because of Australia's proximity and the consequent lower freight rates.

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[4]Chamosite is a yellow-green to greenish-gray iron-rich alumino-silicate that forms ooliths 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 [$Mg_6Si_4O_{10}(OH)_8$]. Chamosite is a major constituent of the Jurassic ironstones of the English Midlands.

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TABLE 1
SALIENT IRON ORE STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1988	1989	1990	1991	1992
United States:					
Iron ore (usable,[1] less than 5% manganese):					
Production	57,515	59,032	56,408	56,761	55,593
Shipments	57,113	58,299	57,010	56,775	55,569
Value	$1,716,661	$1,939,873	$1,740,925	$1,674,100	$1,732,416
Average value at mines, dollars per ton	30.06	33.27	30.54	29.49	31.18
Exports	5,285	5,365	3,199	4,045	5,055
Value	$193,796	$192,796	$124,076	$156,242	$186,864
Imports for consumption	20,183	19,596	18,054	r13,335	12,504
Value	$484,543	$522,262	$559,525	r$436,777	$395,791
Consumption (iron ore and agglomerates)	[2]83,694	[2]80,447	76,855	r66,366	75,067
Stocks, Dec. 31:					
At mines[3]	2,957	3,800	3,386	3,421	2,214
At consuming plants	18,005	15,730	15,911	17,612	16,093
At U.S. docks[4]	2,537	2,171	2,273	2,981	2,981
Total[5]	23,499	21,701	21,570	24,014	21,288
Manganiferous iron ore (5% to 35% manganese):					
Shipments	W	W	W	W	W
World: Production	r967,218	r998,651	r982,229	r956,224	e929,754

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.

[1]Direct-shipping ore, concentrates, agglomerates, and byproduct ore.

[2]Consumption data for 1988 and 1989 are not entirely comparable with those of previous years owing to changes in data collection.

[3]Excludes byproduct ore.

[4]Transfer and/or receiving docks of Lower Lake ports.

[5]Sum 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 1992, 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	2,666	4,313	42,131	13,947	8,659	62.5	9.77	3.23	2.01
Minnesota	5,286	10,893	141,352	41,071	26,264	63.7	12.98	3.77	2.41
Total or average	7,952	15,206	183,483	55,018	34,923	63.4	12.07	3.62	2.30
Other States[1]	108	232	1,128	575	328	53.7	4.87	2.48	1.42
Grand total or average	8,060	15,438	184,611	55,593	35,251	63.4	11.96	3.60	2.28

[1]Includes California, Missouri, Montana, New Mexico, South Dakota, Texas, and Utah.

TABLE 3

CRUDE IRON ORE[1] MINED IN THE UNITED STATES IN 1992, 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	42,131	—	42,131
Minnesota	9	141,352	—	141,352
Total	11	183,483	—	183,483
Other States:				
Missouri	1	—	457	457
Other[2]	8	671	—	671
Total	9	671	457	1,128
Grand total	20	184,153	457	184,611

[1]Excludes byproduct ore.
[2]Includes California, Montana, New Mexico, South Dakota, Texas, and Utah.
[3]Data do not add to total shown because of independent rounding.

TABLE 4

USABLE IRON ORE PRODUCED IN THE UNITED STATES IN 1992, 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[2]
Lake Superior:				
Michigan	161	—	13,786	13,947
Minnesota	310	340	40,421	41,071
Total[2]	470	340	54,207	55,018
Other States:				
Missouri	—	257	8	265
Other[3]	309	1	—	310
Total	309	258	8	575
Grand total[2]	780	598	54,215	55,593

[1]Data may include pellet chips and screenings.
[2]Data do not add to total shown because of independent rounding.
[3]Includes California, Montana, New Mexico, South Dakota, Texas, and Utah.

TABLE 5

SHIPMENTS OF USABLE IRON ORE[1] FROM MINES IN THE UNITED STATES IN 1992

(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	—	—	12,881	12,881	62.5	W
Minnesota	305	368	41,675	42,348	63.7	$1,180,563
Total reportable or average[2]	305	368	54,557	55,230	63.4	1,180,563
Other States:						
Missouri	—	—	19	19	67.2	W
Other[3]	320	—	—	320	52.9	5,421
Total reportable or average[3]	320	—	19	339	53.7	5,421
Total withheld	—	—	—	—	—	546,432
Grand total or average	625	368	[2]54,576	55,569	63.4	1,732,416

W Withheld to avoid disclosing company proprietary data; included in "Total withheld."
[1]Includes byproduct ore.
[2]Data do not add to total shown because of independent rounding.
[3]Includes Arizona, California, Montana, New Mexico, South Dakota, Texas, and Utah.

TABLE 6

CONSUMPTION OF IRON ORE[1] 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		
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	r56,169
1987	44,004	710	—	8,686	7,651	61,051
1988	51,048	1,242	—	9,453	10,122	r71,865
1989	51,845	1,710	—	7,473	12,034	73,062
1990	r54,340	1,516	—	8,257	9,571	73,685
1991	47,945	r659	—	7,229	7,828	r63,661
1992	53,786	482	—	6,861	7,425	r68,555

rRevised.
[1]Excludes dust, mill scale, and other revert iron-bearing materials added to sinter.
[2]Data may not add to totals shown because of independent rounding.

Source: American Iron Ore Association.

TABLE 7

CONSUMPTION OF IRON ORE AND AGGLOMERATES AT U.S. IRON AND STEEL PLANTS, BY TYPE OF PRODUCT

(Thousand metric tons)

Type of product	1988	1989	1990	1991	1992
Blast furnaces:					
Direct-shipping ore	5,155	3,211	2,479	1,918	2,035
Pellets	61,025	61,659	60,512	r52,534	60,138
Sinter[1]	15,497	13,664	12,226	r10,561	11,438
Total[2]	81,676	78,533	75,217	r65,013	73,611
Steelmaking furnaces:					
Direct-shipping ore	194	142	53	33	20
Pellets	88	76	50	40	61
Sinter[1]	—	—	13	5	10
Total[2]	282	219	115	78	91
Grand total[2]	81,958	78,752	75,333	r65,091	73,702

rRevised.

[1]Includes briquettes, nodules, and other.

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

Source: American Iron and Steel Institute.

TABLE 8

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]	Miscella-neous[2]	Subtotal integrated iron and steel plants[3 4]	Direct-reduced iron for steelmaking[5]	Nonsteel end uses[6]	Total
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	r57,380	53	6,212	16	r63,661	584	691	r64,936
1992	62,382	54	6,108	10	68,554	389	976	69,919

rRevised. NA Not available.

[1]Excludes dust, mill scale, and other revert iron-bearing materials.

[2]Sold to nonreporting companies or used for purposes not listed.

[3]Data from American Iron Ore Association.

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

[5]U.S. Bureau of Mines estimates based on production reports compiled by Midrex Corp.

[6]Includes 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 9
GREAT LAKES FREIGHT RATES FOR IRON ORE, 1990-92

Origin	Destination	Dollars per long ton[1]	
		Class X	Other
Head of the Lakes	Lower lake ports	6.00	6.50
Marquette	do.	—	5.40
Escanaba	Lake Erie ports	4.50	4.88
Do.	Lower Lake Michigan ports	3.60	3.90

[1]Excludes winter surcharges for shipments after Dec. 15 and before Apr. 15.

Sources: Cleveland-Cliffs Inc., Interlake Steamship Co., and Skillings' Mining Review.

TABLE 10
UNITED STATES AND CANADIAN IRON ORE SHIPMENTS ON THE GREAT LAKES

(Thousand metric tons)

Loading district	1988	1989	1990	1991	1992
Lake Superior	46,098	45,296	46,661	44,734	45,897
Lake Michigan	6,660	5,742	4,987	5,218	6,133
Eastern Canada	9,209	9,480	10,836	8,375	8,853
Total[1,2]	61,966	60,518	62,484	r58,326	60,883
U.S. flag fleet shipments[3]	55,028	51,799	54,055	49,794	51,359
Percent carried by U.S. fleet	89	86	87	85	84

rRevised.
[1]Includes transshipments.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes mill scale, scarfer ore, and slag, in addition to iron ore.

Source: Lake Carriers' Association, 1992 Annual Report.

TABLE 11
U.S. EXPORTS OF IRON ORE AND AGGLOMERATES, BY COUNTRY OF DESTINATION

(Thousand metric tons and thousand dollars)

	1988		1989		1990		1991		1992	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Canada	5,277	193,249	5,359	192,334	3,193	123,601	4,032	154,934	5,044	185,972
India	(1)	25	1	59	1	57	(1)	12	(1)	12
Mexico	1	62	(1)	15	1	103	2	75	(1)	46
Netherlands	(1)	3	—	—	(1)	6	—	—	—	—
Venezuela	4	348	(1)	44	—	—	—	15	2	46
Other	3	109	4	345	4	308	12	1,205	11	785
Total[2]	5,285	193,796	5,365	192,796	3,199	124,076	4,045	156,242	5,055	186,864

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 12
U.S. EXPORTS OF IRON ORE AND AGGLOMERATES, BY TYPE OF PRODUCT

Type of product	1990			1991			1992		
	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	11	333	31.45	13	733	55.07	15	488	31.60
Coarse ores	6	213	36.53	(2)	6	32.26	3	98	29.87
Fine ores	10	346	35.25	10	771	78.65	7	203	27.30
Pellets	3,018	116,845	38.71	4,017	154,361	38.43	4,653	170,193	36.58
Briquetes	—	—	—	1	44	68.43	1	64	64.43
Other agglomerates	136	5,498	40.38	4	283	73.43	375	15,768	42.05
Roasted pyrites	19	840	45.12	(2)	45	99.96	1	50	94.48
Total[3]	3,199	124,076	38.78	4,045	156,242	38.62	5,055	186,864	36.97

[1]Unit values shown are calculated from unrounded data.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13
U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1988		1989		1990		1991		1992	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Australia	1,076	16,780	394	5,211	14	584	—	—	163	3,453
Brazil	4,935	78,092	5,169	90,885	4,276	90,443	2,481	55,188	2,442	52,962
Canada	9,157	285,961	8,538	292,866	9,344	339,622	7,299	266,496	6,834	242,877
Chile	139	2,772	61	1,200	138	2,905	103	2,154	107	2,158
India	126	2,820	59	1,037	—	—	(1)	2	—	—
Liberia	128	1,460	200	2,950	—	—	—	—	—	—
Mauritania	522	7,864	594	10,130	666	14,142	459	10,057	280	6,200
Norway	—	—	40	693	—	—	—	—	—	—
Peru	181	2,939	186	4,280	59	1,623	157	3,980	70	1,883
Philippines[2]	239	5,432	66	1,622	—	—	—	—	—	—
Spain	—	—	—	—	1	61	1	38	—	—
Sweden	88	4,678	57	1,000	54	2,273	51	2,300	64	2,807
Venezuela	3,568	75,443	4,232	110,367	3,503	107,848	2,763	94,476	2,540	83,287
Other	[3]24	[3]301	(1)	21	[4](1)	[4]24	22	2,086	4	164
Total[5]	20,183	484,54	19,596	522,262	18,054	559,525	13,335	[r]436,777	12,504	395,791

[r]Revised.
[1]Less than 1/2 unit.
[2]Sinter made from raw materials supplied by Australia, Brazil, and other countries.
[3]Excludes 28,923 metric tons of crude iron sulfate crystals valued at $318,651, originally reported as iron ore from the Federal Republic of Germany.
[4]Excludes 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.
[5]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 14
U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY TYPE OF PRODUCT

Type of product	1990			1991			1992		
	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	294	7,733	26.27	398	8,765	22.00	374	7,511	20.09
Coarse ores	545	14,445	26.15	63	1,749	27.54	(2)	6	54.36
Fine ores	7,338	181,696	24.76	3,549	87,481	24.75	3,244	73,653	22.70
Pellets	9,875	355,470	36.00	9,317	338,493	36.33	8,880	314,372	35.40
Briquetes	2	165	92.41	(2)	31	86.01	—	—	—
Other agglomerates	(2)	14	730.58	2	54	27.49	2	76	39.27
Roasted pyrites	(2)	2	343.60	5	205	44.79	4	173	47.62
Total	18,054	559,525	30.99	r13,335	r436,777	32.75	12,504	395,791	31.65

rRevised.
[1]Unit values shown are calculated from unrounded data.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 15
U.S. IMPORTS OF IRON ORE AND AGGLOMERATES IN 1992, BY COUNTRY AND TYPE OF PRODUCT

(Thousand metric tons)

Country of origin	Concentrates	Coarse ores	Fine ores	Pellets	Other agglomerates	Roasted pyrites	Total[1]
Australia	—	—	163	—	—	—	163
Brazil	31	—	2,290	121	—	—	2,442
Canada	268	(2)	—	6,566	—	—	6,834
Chile	75	—	33	—	—	—	107
Mauritania	—	—	280	—	—	—	280
Peru	—	—	—	69	2	(2)	70
Sweden	—	—	51	13	—	—	64
Venezuela	—	—	427	2,113	—	—	2,540
Other	—	—	—	—	(2)	4	4
Total[1]	374	(2)	3,244	8,880	2	4	12,504

[1]Data may not add to totals shown because of independent rounding.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 16
AVERAGE UNIT VALUE FOR SELECTED IMPORTS OF IRON ORE AND AGGLOMERATES IN 1992

Type of product	Country of origin	Average unit value[1] (dollars per metric ton gross weight)
Coarse ores	Venezuela	—
Fine ores	Brazil	21.23
Do.	Canada	—
Do.	Mauritania	22.15
Do.	Venezuela	29.40
Pellets	Brazil	29.79
Do.	Canada	36.19
Do.	Peru	26.16
Do.	Venezuela	33.47

[1]Weighted averages of individual Customs values.

Source: Bureau of the Census.

TABLE 17

U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY CUSTOMS DISTRICT

(Thousand metric tons and thousand dollars)

Customs district	1988		1989		1990		1991		1992	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Baltimore	7,759	183,932	6,062	158,193	3,559	99,849	3,027	89,515	3,100	93,350
Charleston	439	10,088	524	14,858	563	16,629	638	22,293	445	14,895
Chicago	1,837	28,820	2,795	52,162	1,654	32,561	1,124	24,708	1,240	26,624
Cleveland	1,401	41,315	1,557	48,401	1,931	66,811	1,641	56,805	809	28,085
Detroit	520	19,607	528	24,773	978	42,185	344	13,679	409	15,044
Houston-Galveston	62	1,115	28	519	(1)	18	21	556	31	737
Mobile	1,595	40,708	2,284	68,830	3,480	121,704	2,571	97,363	2,537	91,562
New Orleans	1,496	22,673	1,845	30,830	1,910	37,308	1,113	26,138	1,221	27,916
Philadelphia	5,031	135,335	3,968	123,112	3,967	141,970	2,826	104,883	2,709	97,477
Other	43	951	4	584	12	488	30	836	(1)	102
Total[2]	20,183	484,543	19,596	522,262	18,054	559,525	r13,335	r436,777	12,504	395,791

rRevised.

[1]Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 18

U.S. IMPORTS OF PELLETS, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1990		1991		1992	
	Quantity	Value	Quantity	Value	Quantity	Value
Brazil	509	14,948	170	5,092	121	3,593
Canada	7,588	279,961	6,905	256,292	6,566	237,602
Germany	—	—	71	3,033	—	—
Peru	59	1,621	155	3,894	69	1,798
Sweden	—	—	—	—	13	655
U.S.S.R.[1]	—	—	19	1,940	—	—
Venezuela	1,719	58,940	1,997	68,243	2,113	70,723
Total[2]	9,875	355,470	9,317	338,493	8,880	314,372

[1]Dissolved in Dec. 1991.

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

Source: Bureau of the Census.

TABLE 19

IRON ORE, IRON ORE CONCENTRATES, AND IRON ORE AGGLOMERATES: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	Gross weight[3]					Metal content[4]				
	1988	1989	1990	1991	1992e	1988	1989	1990	1991	1992e
Albania[5]	1,067	1,179	930	r e750	200	e470	e520	e410	r e330	88
Algeria	3,118	2,748	r2,941	r2,344	2,300	1,559	1,374	1,470	r e1,170	1,150
Argentina	1,037	1,017	992	e980	1,000	550	r539	r526	e520	530
Australia[6]	e99,450	r108,680	r113,530	r121,820	117,170	r62,654	r68,468	r71,524	r76,747	73,800
Austria	r2,311	2,410	r2,301	r2,130	71,650	727	r761	r653	r481	370
Azerbaijan[8]	—	—	—	—	(9)	—	—	—	—	(9)
Bolivia	34	14	125	102	70	21	9	79	r72	50
Bosnia and Herzegovina[10]	—	—	—	—	500	—	—	—	—	200
Brazil	146,008	157,900	r152,300	r151,500	146,000	97,139	105,100	r101,272	r100,748	99,600
Bulgaria	1,826	1,613	1,079	e1,000	1,000	528	482	321	300	300
Canada[11]	39,934	39,445	35,670	r36,383	34,136	24,268	23,971	22,472	r22,921	21,506
Chile	7,710	8,761	8,248	8,414	8,500	5,089	5,478	5,035	5,136	5,200
China[6]	r154,380	r162,160	r169,360	r175,300	194,000	r50,310	r51,560	r50,490	r52,820	67,900
Colombia	609	573	628	r685	690	e280	e260	e283	e295	300
Czechoslovakia	1,773	1,780	1,831	r1,738	1,700	e440	e470	e480	r e450	450
Egypt	r2,000	2,562	2,405	r2,144	2,100	e1,000	e1,500	e1,500	r e1,300	1,260
Finland[12]	556	—	—	—	—	360	—	—	—	—
France	9,872	9,319	8,729	7,472	5,700	3,119	2,945	2,793	2,316	1,700
Germany: Western states	70	102	r84	r120	100	10	14	12	17	14
Greece[5]	1,573	2,013	r2,113	r2,024	1,500	640	820	r861	r815	610
India	49,961	r53,418	54,579	57,638	54,000	31,226	r33,440	r34,200	r35,600	33,800
Indonesia	203	143	145	r173	250	118	83	84	r100	145
Iran[13]	2,005	2,296	3,240	4,890	5,000	1,100	e1,300	e1,800	e2,700	3,000
Japan	97	41	34	31	735	61	25	21	19	722
Kazakhstan[8]	—	—	—	—	20,000	—	—	—	—	11,000
Korea, North[e]	9,000	9,500	9,500	10,000	10,500	4,200	4,400	4,400	4,700	4,900
Korea, Republic of	390	334	298	r222	250	218	187	180	r134	150
Liberia	12,767	11,700	4,050	1,100	71,742	7,910	7,087	e2,490	710	1,000
Macedonia[10]	—	—	—	—	150	—	—	—	—	24
Malaysia	132	193	344	r376	7320	81	118	210	229	7195
Mauritania	r10,004	r12,110	r11,590	r10,246	10,300	r e6,500	r e7,150	r e6,800	r e6,500	6,500
Mexico[14]	8,431	8,141	8,073	r7,539	7,380	5,564	5,373	5,328	r4,976	4,800
Morocco	114	176	148	r99	98	70	107	90	r60	60
New Zealand[15]	2,351	2,367	2,296	r2,265	2,300	e1,300	e1,300	e1,300	r e1,300	1,300
Nigeria	304	e300	374	398	400	e150	e150	e180	e200	200
Norway	2,644	2,358	2,081	2,209	72,152	r1,718	r1,532	r1,352	r1,435	1,403
Peru	4,171	r4,507	r3,307	r3,593	2,500	2,839	2,923	2,147	r2,161	1,500
Poland	6	7	2	r(9)	—	e2	e2	e1	r e(9)	—
Portugal[16]	33	13	12	r11	10	8	6	4	4	4
Romania[8]	2,482	2,482	2,002	e1,800	1,000	e260	e260	e250	e220	130
Russia	—	—	—	—	82,500	—	—	—	—	45,000
South Africa, Republic of[17]	25,248	29,958	30,291	r28,958	728,226	16,461	19,461	19,689	r18,819	18,350
Spain[18]	4,212	4,566	3,030	r3,920	2,750	1,925	2,120	1,394	r1,840	1,290
Sweden	20,440	21,763	19,877	r19,328	719,280	r13,392	14,124	12,901	r12,599	12,600
Thailand	99	177	129	240	250	55	98	71	132	135

See footnotes at end of table.

TABLE 19—Continued

IRON ORE, IRON ORE CONCENTRATES, AND IRON ORE AGGLOMERATES: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	Gross weight[3]					Metal content[4]				
	1988	1989	1990	1991	1992e	1988	1989	1990	1991	1992e
Tunisia	325	280	291	295	290	r e172	r e148	r e154	r e156	154
Turkey	5,481	4,518	5,050	5,400	5,300	2,983	r2,453	r e2,740	r e3,000	r e3,000
Ukraine[8]	—	—	—	—	75,700	—	—	—	—	40,000
U.S.S.R.[19]	249,754	241,348	236,000	r199,000	—	138,217	134,789	e132,000	e110,000	—
United Kingdom	224	34	55	r59	25	49	8	12	r13	5
United States[18]	57,515	59,032	56,408	56,596	755,593	36,468	37,413	35,695	35,333	735,251
Venezuela	18,932	18,390	20,365	21,222	22,000	12,340	12,016	12,655	13,187	14,400
Yugoslavia[20]	5,545	5,080	4,132	e2,574	—	1,844	1,305	e1,578	e900	—
Zambia	(9)	(9)	1	r(9)	1	(9)	(9)	(9)	(9)	(9)
Zimbabwe	r1,020	1,143	r1,259	1,136	1,136	e630	e690	e730	r e660	660
Total	r967,218	r998,651	r982,229	r956,224	929,754	r537,025	r554,339	r540,637	r524,125	516,006

eEstimated. rRevised.

[1]Table includes data available through July 20, 1993.

[2]In addition to the countries listed, Cuba and Vietnam may also produce iron ore, but definitive information on output levels, if any, is not available.

[3]Insofar 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.

[4]Data 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 and North Korea.

[5]Nickeliferous iron ore.

[6]Data on gross weight presented for this country are taken from the Trust Fund Project on Iron Ore Information, United Nations Conference on Trade and Development (UNCTAD) publication.

[7]Reported figure.

[8]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[9]Less than 1/2 unit.

[10]Formerly part of Yugoslavia; data were not reported separately until 1992.

[11]Series represent gross weight and metal content of usable iron ore (including byproduct ore) actually produced, natural weight.

[12]Includes magnetite concentrate, pelletized iron oxide (from roasted pyrite), and roasted pyrite (purple ore).

[13]Data are for year beginning Mar. 21 of that stated.

[14]Gross weight calculated from reported iron content based on grade of 66% Fe.

[15]Concentrates from titaniferous magnetite beach sands.

[16]Includes manganiferous iron ore.

[17]Includes magnetite ore as follows, in thousand metric tons: 1988—5,492; 1989—6,594; 1990—5,613; 1991—5,658; and 1992—4,647.

[18]Includes byproduct ore.

[19]Dissolved Dec. 1991.

[20]Dissolved Apr. 1992.

TABLE 20

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 1989	Fiscal year 1990	Fiscal year 1991	Fiscal year 1992
Australia:					
Hamersley Iron Pty. Ltd. and Mount Newman Mining Co. Pty. Ltd.	Lump ore	33.76	39.15	41.48	38.84
Do.	Fines	26.76	31.03	33.49	31.85
Robe River Iron Associates	do.	23.18	26.88	29.01	27.37
Savage River Mines Ltd	Pellets	42.77	46.63	47.13	43.81
Brazil:					
Cia. Nipo-Brasileira de Pelotizacao (Nibrasco)	do.	45.20	49.28	49.81	46.30
Cia. Vale do Rio Doce (Carajas)	Fines	23.99	27.82	30.03	29.06
Do.	Lump ore	30.99	35.94	38.08	33.13
Cia. Vale do Rio Doce (Itabira)	do.	25.60	29.69	31.46	29.46
Mineraes Brasileiras Reunidas S.A.	do.	25.05	29.05	30.78	28.82
Do.	Fines	24.46	28.36	30.61	29.11
Samarco Mineracao S.A.	Pellet feed	19.73	22.88	24.70	23.99
Canada: Iron Ore Co. of Canada (Carol Lake)	Concentrates	22.88	26.53	28.63	27.70
Chile:					
Minera del Pacifico S.A. (El Algarrobo)	Pellets	40.73	44.40	45.79	43.15
Minera del Pacifico S.A. (El Romeral)	Fines	18.58	21.55	23.26	22.12
India:					
Minerals and Metals Trading Corp. (Bailadila)	Lump ore	32.55	37.74	39.99	37.54
Do.	Fines	25.71	29.81	32.17	30.59
Peru: Empresa Minera del Hierro del Peru S.A.	Pellets	32.97	35.94	36.32	(1)
South Africa, Republic of:					
South African Iron and Steel Industrial Corp. Ltd	Lump ore	[2]26.05	30.21	32.01	[2]30.27
Do.	Fines	[2]20.37	23.62	25.49	[2]24.24

[1]No quotation published.
[2]Price per dry metric ton unit.

Sources: The TEX Report (Tokyo) and Iron Ore Manual, 1992-93.

TABLE 21

IRON ORE: WORLD PELLETIZING CAPACITY, BY CONTINENT AND COUNTRY, IN 1992

	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	20	30	69	102.49
South America:				
Argentina	1	1	4	1.00
Brazil	3	8	8	25.00
Chile	1	1	1	4.20
Peru	1	2	2	3.20
Venezuela	1	1	2	6.60
Total	7	13	17	40.00
Europe:				
Belgium[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[5]	3	3	4	10.80
Turkey	1	1	1	1.30
U.S.S.R.[6]	7	13	NA	80.00
Yugoslavia[7]	1	1	1	.60
Total	17	24	NA	100.75
Africa:				
Liberia[8]	1	1	1	3.00
Morocco[9]	1	1	1	.85
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	4.50
India[10]	1	1	1	3.00
Iran	1	1	1	2.50
Japan[3]	1	2	2	4.40
Total	8	9	NA	18.40

See footnotes at end of table.

TABLE 21—Continued

IRON ORE: WORLD PELLETIZING CAPACITY, BY CONTINENT AND COUNTRY, IN 1992

	Number			Rated capacity (million metric tons, gross weight)
	Sites	Plants[1]	Units	
Oceania: Australia[11]	2	2	6	4.00
World total	58	82	NA	271.54

NA Not available.

[1]Staged 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.

[2]The 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 1.3-Mmt/yr Republic plant, which has been on care and maintenance since 1981.

[3]Pellets produced from imported direct-shipping ores and/or concentrates.

[4]The 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.

[5]In 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.

[6]Based on incomplete information.

[7]The Skopje plant operated by Rudnici i Zelezara was recently idled.

[8]Excludes 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.

[9]The Nador plant operated by Societe d'Exploitation des Mines du Rif (SEFERIF) has been idle for several years.

[10]There 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.

[11]There 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

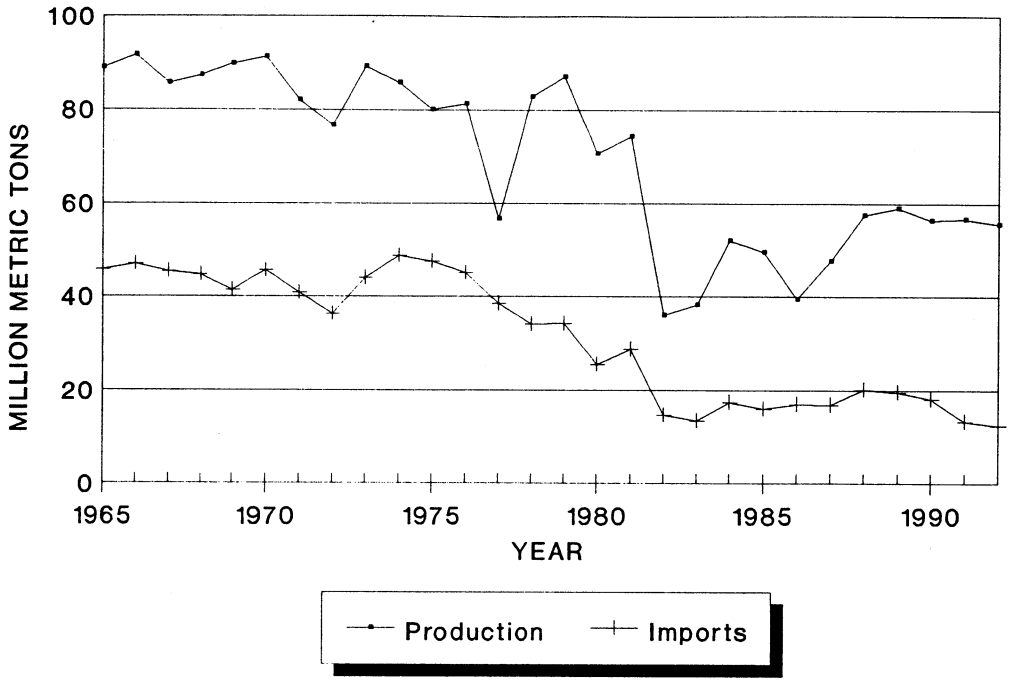


FIGURE 2

CONSUMPTION OF IRON ORE IN U.S. SINTERING PLANTS

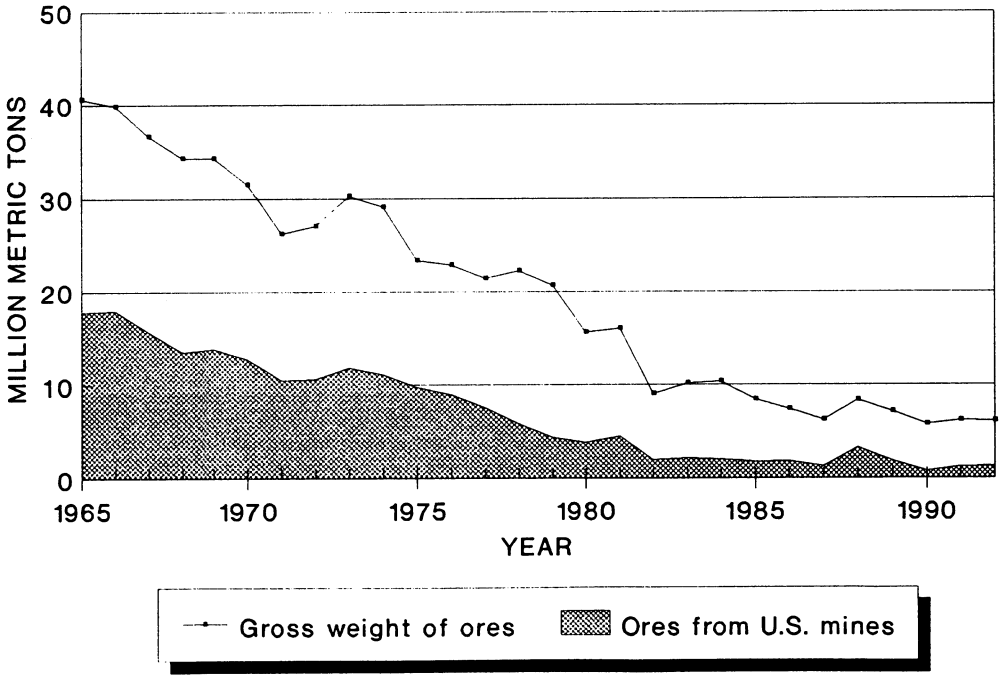


FIGURE 3

WORLD DIRECT-REDUCED IRON PRODUCTION

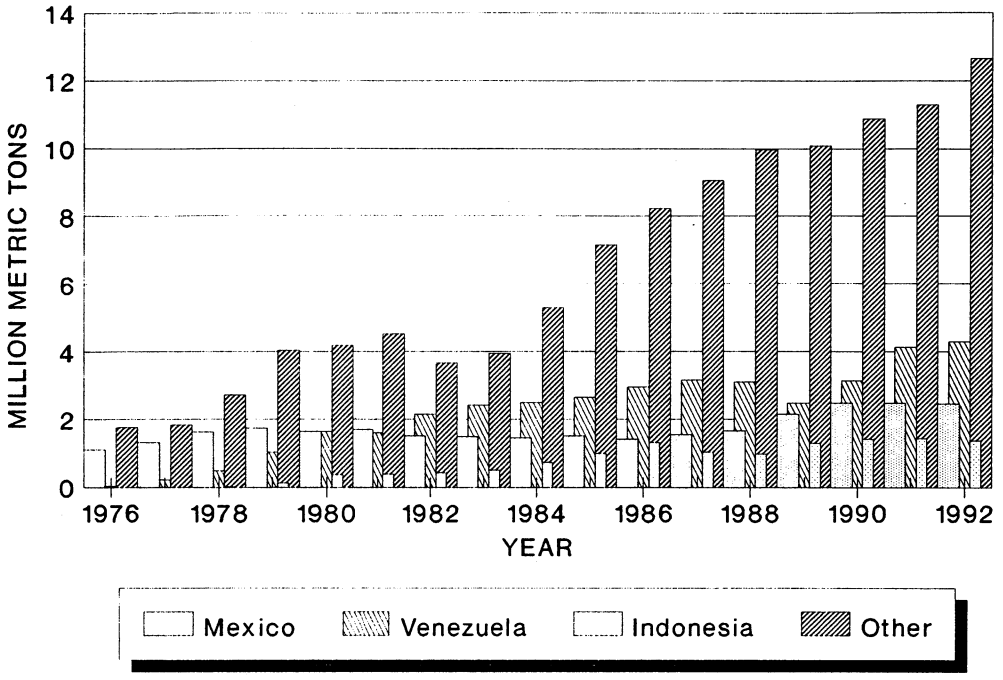
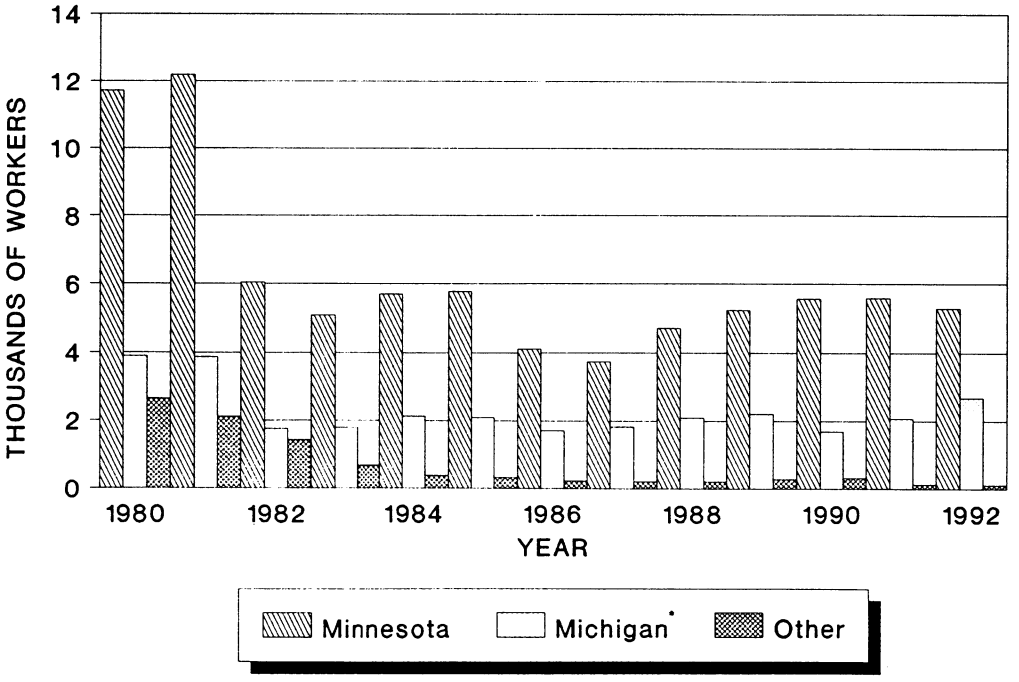


FIGURE 4

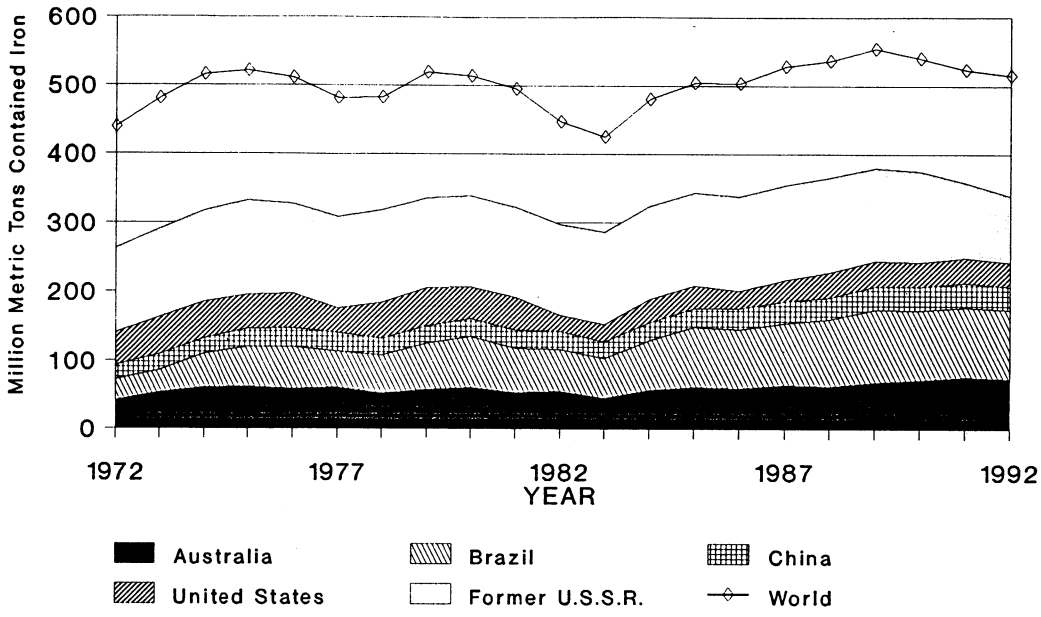
EMPLOYMENT AT IRON MINES AND BENEFICIATING PLANTS



* 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 AND STEEL

By Gerald W. Houck

Mr. Houck, a physical scientist with 36 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 Corporation. Ferroalloys survey data were prepared by Jo-Ann Sterling, statistical assistant, and David Kulha, management analyst.

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.

Data tables on ferroalloys production and consumption are contained in this chapter. The reader is referred to the Annual Reports dealing with specific elements, especially those for chromium, manganese, and silicon, for analysis and detail with respect to the ferroalloys industry.

Consistent with international usage, the U.S. Bureau of Mines is reporting all data on iron and steel in metric units, unless otherwise noted.

This was another poor year for the U.S. steel industry, despite strong increases in both production and shipments of steel. Production of raw steel in the United States increased 5.7%, to 84.3 million metric tons, from 79.7 million tons produced in 1991. Net shipments of steel mill products by U.S. companies increased about 4%, to 74.6 million tons, from 71.5 million tons in 1991.

Imports of steel mill products increased about 8%, to 15.5 million tons, from 14.3 million tons in 1991. Imports captured 18.0% of the apparent consumption of steel mill products, up from 17.8% in 1991. Imports of fabricated steel products, such as fasteners, wire, and fabricated structural steel, totaled 1.8 million tons, representing another 2% of the U.S. steel market.

Exports of steel mill products declined to 3.9 million tons, from 5.8 million tons in 1991. This decline ended a 5-year period of increasing exports and marked a return to about the same level of exports that was recorded in 1989 and 1990.

Prices of steel mill products declined once more in 1992. The Bureau of Labor Statistics' Producer Price Index for steel mill products declined 2.8%, to 106.4 (1982 base = 100.0).

Despite the improvement in volume, lower prices prevented the U.S. steel industry from achieving profitable operations. The American Iron and Steel Institute (AISI), reporting on the aggregated financial results of companies that produced about 66% of the Nation's raw steel in 1992, announced that losses in 1992 were $3,838 million on steel sales of $26,838 million. These companies have reported cumulative losses of $15,348 million over the 11-year period of 1982-92.

World production of raw steel in 1992 was 721.3 million tons, down 2% from that of 1991. Production in Eastern Europe and the former U.S.S.R. fell dramatically—more than 15% in 1992, adding to an 18% decline in 1991. Production in Japan was down more than 10%, and production in Western Europe declined about 4%. In China and in the other developing nations of Asia, Africa, and the Middle East, however, growth continued at a vigorous pace; production in China increased 13%.

DOMESTIC DATA COVERAGE

Data regarding U.S. production of iron and steel, and shipments of steel mill products are those reported by the AISI. 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 that contains carbon, manganese, and often other alloying elements. Steel containing only carbon and manganese is called "carbon steel"; steel containing metallic elements such as chromium, molybdenum, or nickel is termed "alloy steel"; 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 meet the customer's requirements.

"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 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 (DRI).

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 21% of U.S. production in 1992 was cast in ingot form and subsequently rolled into semifinished form. The integrated steel industry in the United States in 1992 consisted of 16 companies operating ironmaking and steelmaking facilities at 23 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 tin-plated. 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 thin-slab (50-mm), continuous casting machines, closely coupled to a hot-strip mill, producing commercial quality hot bands. 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, although 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 about 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

Trade Agreements.—From October 1, 1984, until March 31, 1992, the import of steel products into the United States was limited by a program of "Voluntary Restraint Agreements (VRA's)," which were negotiated following an investigation conducted by the U.S. International Trade Commission (ITC) 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 initially 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 2½ years, to terminate March 31, 1992. Negotiations resulted in new agreements with the European Community and the 16 other countries.

Anticipating the expiration of the VRA's, the United States, along with more than 30 other countries, has negotiated in an effort to reach a "Multilateral Steel Agreement." The principal U.S. objectives for a multilateral agreement include prohibitions against most subsidies, the elimination of tariff and nontariff barriers to trade, and the establishment of an effective mechanism to resolve disputes. Agreement on the Multilateral Steel Agreement was not reached before the expiration of the VRA's on March 31, 1992.

Following the expiration of the VRA's, some U.S. steel companies filed new countervailing duty and antidumping suits, claiming injury to the domestic steel industry as a result of government-subsidized or unfairly traded steel imported into the United States from numerous countries, including those that have been the source of most of the imported steel in the U.S. market. The most important of these suits were filed on June 30, 1992, dealing with hot-rolled, cold-rolled, and galvanized carbon steel sheets and hot-rolled carbon steel plates. Claims of subsidization were made against imported steel from 13 countries, and claims of unfair trade were made against 20 countries. The countries against whom the charges were filed had imported more than 5.8 million tons of the covered products during 1991. The products involved are the most important products of the integrated steel companies and represent more than one-half of all steel products shipped in this country.

To dispose of unfair trade cases such as these, the U.S. Department of Commerce (DOC) is responsible for determining whether there was subsidization or unfair trade, and if so, the value of it in relation to the value of the products imported. This determination establishes the percentage amount of a countervailing duty or antidumping duty that may be assessed. The ITC is responsible for determining whether the subsidization or unfair trade resulted in injury to the U.S. industry.

In this case, the DOC made preliminary determinations that there was indeed illegal subsidization and unfair trade, and the ITC determined preliminarily that there was injury to the U.S. industry in most of the cases. As a result, effective December 7, 1992, in the subsidy cases, and effective February 6, 1993, in the antidumping cases, importers of the covered products were required to make cash deposits or to post bond equal to the amount of the estimated dumping margins. Recovery of the deposit or bond is subject to final calculation of the duties and to a final determination of injury by the ITC. The duties are determined and applied on a company-specific basis and differ widely. For example, the duties for hot-rolled plate range from 1.47% to 109.22%. Final determination of injury was expected from the ITC on July 27, 1993.

In addition to cases involving the major flat-rolled steel products, several other cases were processed during the year. Imports of steel rails from Japan, Luxembourg, and the United Kingdom were determined not to have been a cause of injury to the U.S. steel industry. Imports of special quality steel bars from Brazil also were determined not to have been a cause of injury. Imports from Brazil, France, Germany, and the United Kingdom of bars containing bismuth or lead to improve machinability were determined to have been a cause of injury, and duties were imposed on these particular steel products. Imports of standard and structural steel pipes and tubes from Brazil, the Republic of Korea, Mexico, Taiwan, and Venezuela also were determined to be a cause of injury, and dumping duties were assessed.

Research Programs.—The U.S. Department of Energy continued its research and development efforts under the Steel and Aluminum Energy Conservation and Technology Competitiveness Act of 1988, commonly known as the Metals Initiative. Work continued on five projects in steel processing carried over from prior years, and a sixth

project was selected for inclusion in the program. A requirement of the program is that industry sponsors provide cost-sharing contributions equal to a minimum of 30% of the total cost of any project.

The most notable of the steel projects was the Direct Steel Making Project, managed and jointly sponsored by the AISI. The objective of the project was to develop an energy efficient, economically competitive direct steelmaking process. The advantages of such a process would be: (1) more effective use of domestic raw materials; (2) continuous, rather than batch operations; (3) elimination of coke and the environmental impacts related to coke; (4) ease of startup and shutdown; and (5) facilitation of incremental capacity increases and adaptation to market conditions by modular design.

The process being investigated was an in-bath smelting process, coupled to continuous refining. Coal is injected into a molten bath of partially reduced iron ore, and the key to the success of the process is the efficient use of the energy of the gases generated. The carbon in the coal is a reductant for the iron ore and a source of thermal energy. Carbon monoxide is released, which must be partially combusted within the vessel to provide heat for the process. The partially combusted smelter off-gas also must serve as the fuel and the reductant for a prereduction furnace to produce hot wustite pellets from hematite. Based on successes achieved with the process, AISI has decided that the best approach to advance the program is to install and operate a modified smelter to demonstrate sustained, continuous pilot-scale ironmaking during 1993. Success with this phase of the project was expected to lead to demonstration of the direct ironmaking process at a steel plant.

The AISI direct ironmaking process had many features in common with other programs under investigation in other countries. See discussion under Technology in this report.

Four other projects that were studied within the Metals Initiative included (1) Development of an ultrahigh carbon steel and a steel processing sequence to produce superplastic steel on a production scale, managed by Lawrence Livermore National Laboratory, with cost-sharing by Caterpillar, Inc. and North Star Steel Co.; (2) Electrochemical Dezincing of Steel Scrap, by Argonne National Laboratory, with cost-sharing by Metal Recovery Industries (U.S.), Inc. (a pilot plant was under construction to demonstrate a two-step process to electrolytically dissolve zinc from the surface of steel scrap and recover the zinc for purification and sale); (3) Direct Strip Casting, under investigation by Armco Inc. with additional sponsorship by Westinghouse Electric Corp. and North American Refractories; and (4) Rapid Analysis of Molten Metal Using Laser Produced Plasma, at Lehigh University, with sponsorship by the AISI, the Electric Power Research Institute, and an industrial consortium of nine companies. The objective of this program was to develop a probe that can be immersed in molten steel to produce an elemental analysis in less than 1 minute. Current practice requires removal of a molten sample, which must be frozen and analyzed in a laboratory, a sequence that requires a minimum of 4 to 8 minutes.

During 1992, approval was given to begin negotiation on a sixth steel project within the Metals Initiative. This was to be a multiyear project to improve quality, lower production cost, and conserve energy by focusing on the development of real-time measurement and control of product properties, reduction of waste material, and elimination of off-line testing. This program was to be managed by AISI and will include six individual projects involving different sensors and control systems needed for steel processing.

A second Department of Energy program, the Clean Coal Technology Program, provided funding to demonstrate new technologies for the environmentally sound and efficient use of coal. At the Bethlehem Steel Corp. plant at Burns Harbor Indiana, support was given for the installation of a system to inject pulverized coal into existing ironmaking blast furnaces and to demonstrate sustained operation with a variety of coal particle sizes and coal types and to assess the interactive nature of these parameters. DOE is providing about $31 million, 22% of the project cost.

The U.S. Bureau of Mines demonstrated the feasibility of recovering a high-quality graphite product from kish, a waste product of iron blast furnaces that is currently disposed of in landfills. The process is being demonstrated on a pilot scale at a site in Indiana, in cooperation with members of the steel and graphite user industry. The amount of flake graphite that could be recovered from kish was estimated to be more than adequate for supplying all the flake graphite needs of the United States. There are currently no domestic resources for flake graphite, which is used in refractories and crucibles for steelmaking, in lubricants, and in electric motor brushes and batteries.

Production

Production of raw steel in the United States increased 5.7% to 84.3 million tons, from 79.7 million tons produced in 1991. Raw steel production capability was estimated by AISI as 102.6 million tons, down from 106.7 million tons in 1991. Production in 1992 represented 82.2% of estimated capability, compared with 74.7% in 1991.

Net shipments of steel mill products by U.S. companies increased about 4% to 74.6 million tons, from 71.5 million tons in 1991.

Electric arc furnace steelmaking was utilized for 32.0 million tons, 38.0% of total steelmaking in 1992. This is only slightly less than the record percentage for electric arc steelmaking of 38.4% set in 1991.

Basic oxygen steelmaking was utilized for 52.3 million tons, 61.6% of raw steel production, compared with 47.8 million tons and 60.0% of production in 1991.

For the first time since the open-hearth process was invented in the 19th century, there was no production of open-hearth steel reported in the United States for 1992. In 1991, open-hearth production was 1.3 million tons and 1.6% of production.

The trend toward the use of continuous casting continued. Continuous casting production was 66.9 million tons, 79.3% of production, compared with 60.5 million tons, 75.8% in 1991.

Nucor Corp., operator of the first minimill to produce flat-rolled steel at its plant in Crawfordsville, IN, started up a similar minimill, at Hickman, AR. Each of the two Nucor flat-roll minimills has a capacity of about 1 million tons, and Nucor has announced its intention to expand each of the plants to about 2 million tons. Nucor's eventual goal is to have four plants with a total capacity of 8 million tons.

Florida Steel Corp., one of the largest of the U.S. minimill companies with five steelmaking plants in Florida and Tennessee, was purchased by Kyoei Steel, a Japanese minimill. Florida steel will operate as a wholly owned subsidiary of the Japanese firm, which also owns minority interests in two other U.S. minimill steelmaking companies.

Two significant mergers took place in the U.S. specialty steel industry. In the first merger, Armco Inc. acquired Cyclops Industries, Inc. Both were major producers of stainless flat-rolled steel and long products, with a total of five locations producing stainless steel. Armco announced that it would consolidate production of steel for its long products operations in the Bridgeville, PA, plant, formerly part of Cyclops. Steelmaking at Armco's Baltimore, MD, Specialty Steel Div. was discontinued.

The second important merger was the purchase by Lukens Inc., a Pennsylvania steel producer, of Washington Steel Co., Washington, PA, producer of stainless flat-rolled steel. Lukens had a strong position as a processor of stainless steel into plate products for other steelmakers, but itself had not been a melter of stainless steel.

Bethlehem Steel Corp. closed its Bar, Rod and Wire Div., including its steelmaking plant in Johnstown, PA.

Sharon Steel Corp., a small integrated company with blast furnaces and a steelmaking plant located in Farrell, PA, shut down in November 1992. Sharon had been attempting to develop a plan to emerge from bankruptcy proceedings.

Consumption and Uses

Shipments of steel mill products by U.S. companies were up 4.3%, to 74.6 million tons, but export shipments were down 41% from their record-setting level. Shipments to domestic customers were up more than 7%. Automotive shipments were up 11%, appliances were up 8%, and shipments to service centers and distributors were up 10%. Construction products were up about 7%.

Shipments of steel for containers, packaging, and shipping materials declined 7% in addition to a 5% decline in 1991.

Shipments for oil and gas drilling, mining, quarrying, and lumbering were about the same as the 1991 level, as were shipments for industrial and agricultural machinery, equipment, and tools.

Markets and Prices

Prices for steel mill products continued under severe pressure during the entire year. The Bureau of Labor Statistics' Producer Price Index for steel mill products was down by 2.8% at 106.4 (1982 base=100). Numerous efforts by steel companies to increase their prices were reported, but vigorous competition prevented prices from being increased.

Foreign Trade

Exports of steel mill products declined to 3.9 million tons, from 5.8 million tons in 1991. Canada was again the nation receiving the largest amount of U.S. exported steel, 1.3 million tons, with Mexico again in second place, also receiving 1.3 million tons. Declines in exports to Japan, the Republic of Korea, and Taiwan accounted for most of the year-to-year decrease in exports from those in 1991.

Imports of steel mill products increased about 8% from those of 1991. The European Community, Canada, and Japan were major sources for steel mill product imports. Increased imports from Canada accounted for almost all of the year-to-year increase. Brazil and the Republic of Korea also were 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.

World Review

World production of pig iron and DRI in 1992 totaled 518.6 million tons, down 1% from that of 1991. Production dropped about 9% in Japan and almost 4% in the European Community. The collapse of economies in Eastern Europe and the former U.S.S.R. resulted in a 12% drop in that region. Steel production in these countries was down 32% compared with that of 1988.

Production in China increased about 9% to an estimated 73 million tons. With the breakup of the former U.S.S.R. into independent republics, China now rivals Japan for status as the top pig iron-producing nation in the world. India and the Republic of Korea are other major iron-producing nations that achieved continued growth in 1992.

Direct-Reduced Iron.—Although pig iron production dropped, world production of DRI increased to almost 21 million tons in 1992, with an 8% increase in the latest year and 52% 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.

World capacity for DRI production was estimated to be 30 million tons, with an additional 8 million tons under construction. In India, one large gas-based direct reduction plant and several small coal-based plants were started up, bringing India's capacity for DRI to 2.2 million tons. An additional 2.7 million tons of capacity is under construction, with completion planned from 1993 through 1995.

Iran's program to develop DRI facilities was interrupted by its war with Iraq. With that conflict over,

construction of these facilities was resumed in 1989. About 1.3 million tons of capacity was started up in 1992; an additional 3.0 million tons was scheduled for 1993-94, which would bring Iran's total capacity for DRI to 5.8 million tons.

A gas-based direct reduction plant with a capacity of 0.65 million tons was started up in Saudi Arabia, and gas-based plants were under construction in Malaysia (1.2 million tons scheduled for 1993) and Indonesia (1.35 million tons scheduled for 1993).

Steel.—World production of steel was 721.3 million tons, down 2% from that of 1991. With the world economy in a recession, production in Japan was down more than 10% and in the European Community down 4%. The former U.S.S.R., which had been the leading steelmaking nation of the world, was dissolved into 14 independent republics. The combined production in the republics was down 12% from that of the former U.S.S.R. in 1991. Two of the republics, Russia and Ukraine, were fourth and fifth, respectively, among the steelmaking nations in 1992. Japan replaced the former U.S.S.R. in first place, followed by the United States and China.

Production of steel continued to increase in China, the Republic of Korea, India, and the Middle East.

OUTLOOK

The outlook for 1993 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, the Republic of Korea, the Far East, and the Middle East. The major economies of the European Community are suffering through a recession, and European steel production will decline again. In Japan, production will recover from the depressed levels of 1992.

For the long term, little growth of steel consumption is expected in the United States or countries with highly developed economies. Steel consumption tends to expand much more slowly than overall economic growth and to contract when economic growth is weak. The outlook for the U.S. steel industry is more uncertain. Imports have tended to capture an increasing share of the U.S. market, except when restrained by such devices as the VRA's. Even though U.S. companies have made great progress in modernizing their mills, adopting efficient technology, and reducing their costs, they have been unable to achieve profitability due to persistently low prices caused by intense competition by the foreign and domestic producers.

An important part of the competition to the integrated U.S. steel industry is that posed by minimills producing flat-rolled steel. As described above, one steel company, Nucor Corp., has demonstrated that flat-rolled steel can be produced in a minimill at lower cost than that attainable by the integrated process. Buoyed by the success of its first plant, in Crawfordsville, IN, Nucor started up a second flat-roll minimill, in Hickman, AR, in 1992. Based on further success with the new processes, Nucor has announced its intention to double the capacity of the two plants, to a total of 4 million tons, and to build 2 more plants, either alone or in joint venture with others, increasing its capacity to 8 million tons. Other companies, noting Nucor's success and optimism about the possibilities of minimill production of flat-rolled steel, have announced similar intentions.

Some observers of the industry predict that as much as 20 million tons of capacity will be built by about the year 2000. With little or no growth in the market, any new capacity will have to displace either imports or integrated production from the U.S. market.

The supply of raw material for increased minimill production may become a problem in the United States. Although the United States traditionally has an excess supply of scrap and is a net exporter of about 9 million tons per year, the supply of low residual scrap necessary to produce flat-rolled steel and some other products may not be adequate. As noted in the section on DRI, imports of DRI are increasing. In early 1993, Nucor announced that it will construct a plant in Trinidad to produce iron carbide, a form of DRI, for use in its U.S. plants. The plant will have a capacity of about 300,000 tons per year. Other minimill operators and iron ore producers are reported to be considering direct reduction plants to provide the necessary supply of low residual raw materials for the growing flat-roll minimill sector of the industry.

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TABLE 1
SALIENT IRON AND STEEL STATISTICS

(Thousand metric tons)

	1988	1989	1990	1991	1992
United States:					
Pig iron:					
Production[1]	50,571	50,687	49,668	4,123	47,377
Exports	65	11	14	15	33
Imports for consumption	635	443	347	434	497
Direct-reduced iron:					
Production	290	r290	390	410	390
Exports	17	23	63	22	34
Imports for consumption	176	226	385	423	607
Raw steel production:[2]					
Carbon steel	78,764	78,227	78,553	70,651	74,805
Stainless steel	1,995	1,747	1,848	1,704	1,808
All other alloy steel	9,890	8,878	9,325	7,384	7,709
Total[3]	90,650	88,852	89,726	79,738	84,322
Steel mill products:					
Net shipments	76,058	76,294	77,093	71,528	74,607
Exports[4]	1,877	4,153	3,904	5,757	3,890
Imports[4]	18,952	15,713	15,575	r14,375	15,490
Producer price index for steel mill products[5] (1982=100.0)	110.7	114.5	112.1	109.5	106.4
World production:[6]					
Pig iron	r538,978	r545,987	r531,828	r506,166	e497,620
Direct-reduced iron	r14,417	r16,555	r18,205	r19,413	e20,946
Raw steel	r780,318	r786,712	r771,169	r736,007	e721,315

eEstimated. rRevised.
[1]American Iron and Steel Institute (AISI).
[2]Raw steel is defined by AISI as steel in the first solid state after melting, suitable for rolling.
[3]Data may not add to totals shown because of independent rounding.
[4]Source: Bureau of the Census.
[5]Source: Bureau of Labor Statistics.
[6]Sources: U.S. Bureau of Mines and International Iron and Steel Institute.

TABLE 2
MATERIALS CONSUMED IN BLAST FURNACES AND PIG IRON PRODUCED

(Thousand metric tons)

Material	1988	1989	1990	1991	1992
Iron oxides:[1]					
Ores	5,155	3,211	2,479	1,918	2,035
Pellets	61,025	61,659	60,512	51,290	60,138
Sinter[2]	15,497	13,664	12,226	10,299	11,438
Total[3]	81,676	78,533	75,217	63,507	73,611
Scrap[4]	2,732	3,006	2,527	r1,939	2,354
Coke[1]	r26,700	26,467	24,946	22,496	22,664
Pig iron produced	50,571	50,687	49,668	44,123	47,377

rRevised.
[1]American Iron and Steel Institute.
[2]Includes sintered ore and pellet fines, dust, mill scale, and other revert iron-bearing materials; also some nodules.
[3]Data may not add to totals shown because of independent rounding.
[4]Mainly briquetted turnings and borings, shredded scrap, etc.; scrap produced at blast furnaces and remelted not included.

TABLE 3

DISTRIBUTION OF SHIPMENTS OF STEEL MILL PRODUCTS, BY PERCENT

	1988	1989	1990	1991	1992
Net shipments thousand metric tons	r76,058	76,294	77,093	71,528	74,607
Shipments by steel type:					
Carbon steel	92.7	93.3	92.7	93.2	93.2
Alloy steel	5.3	4.9	5.5	5.0	5.0
Stainless steel	2.0	1.7	1.8	1.8	1.8
Steel mill products:					
Ingots, blooms, billets, and slabs	2.30	2.48	2.33	3.23	3.00
Wire rods	4.83	4.94	5.09	5.54	5.49
Structural shapes-heavy	5.80	5.93	6.67	6.65	6.18
Steel piling	.42	.44	.50	.55	.55
Plates—cut lengths	6.02	6.05	6.04	5.42	5.30
Plates—in coils	2.72	2.73	3.31	3.38	3.33
Rails—standard	.55	.54	.48	.48	.53
Rails—other	.04	.01	.01	.02	.01
Railroad accessories	.14	.11	.12	.11	.15
Bars—hot-rolled	7.71	7.49	7.83	6.89	7.06
Bars—light-shaped	1.64	1.57	1.44	1.47	1.36
Bars—reinforcing	6.07	5.96	6.24	6.16	5.81
Bars—cold-finished	1.79	1.75	1.75	1.70	1.77
Tool steel	.08	r.08	.07	.06	.08
Pipe and tubing—standard pipe	1.48	r1.40	1.39	1.23	1.29
Pipe and tubing—oil country goods	1.35	r1.08	1.43	1.37	1.19
Pipe and tubing—line pipe	.96	r1.04	1.32	1.82	1.35
Pipe and tubing—mechanical tubing	1.07	.96	1.02	.94	.96
Pipe and tubing—pressure tubing	.07	.06	.06	.06	.06
Pipe and tubing—stainless	.07	.06	.05	.04	.04
Pipe and tubing—structural	.21	.14	.16	.19	.17
Pipe for piling	.09	.04	.04	.03	.04
Wire	1.28	1.19	1.08	1.10	1.09
Tin mill products—blackplate	.34	.37	.32	.32	.28
Tin mill products—tinplate	3.35	3.32	3.26	3.49	3.30
Tin mill products—tin-free steel	1.07	1.11	1.07	1.22	1.10
Tin mill products—tin coated sheets	.10	.10	.09	.09	.09
Sheets—hot-rolled	15.02	15.34	15.75	16.69	16.25
Sheets—cold-rolled	16.54	16.47	15.53	14.63	15.43
Sheets and strip—hot-dip galvanized	9.68	10.16	9.27	8.76	9.97
Sheets and strip—electrogalvanized	2.55	2.56	2.43	2.66	2.91
Sheets, and strip—other metallic coated	1.51	1.64	1.48	1.45	1.64
Sheets and strip—electrical	.62	.58	.57	.58	.53
Strip—hot-rolled	1.43	1.29	.81	.68	.67
Strip—cold-rolled	1.12	1.03	.96	.96	1.01
Total steel mill products	100.00	100.00	100.00	100.00	100.00
Shipments by markets:					
Service centers and distributors	25.1	24.7	24.8	24.7	25.9
Construction	14.4	13.7	14.3	14.5	14.9
Automotive	15.0	14.0	13.1	12.7	13.5
Machinery	9.6	r9.2	r8.8	8.0	7.8

See footnotes at end of table.

TABLE 3—Continued

DISTRIBUTION OF SHIPMENTS OF STEEL MILL PRODUCTS, BY PERCENT

	1988	1989	1990	1991	1992
Shipments by markets—Continued:					
Containers	5.3	5.3	5.3	5.4	4.8
All others	30.6	r33.1	r33.7	34.7	33.1

rRevised.

Source: American Iron and Steel Institute.

TABLE 4

U.S. IMPORTS AND EXPORTS OF STEEL MILL PRODUCTS, BY COUNTRY

(Thousand metric tons)

Country	1988		1989		1990		1991		1992	
	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports
Argentina	484	43	191	40	171	19	177	21	78	16
Australia	256	7	246	47	278	—	334	49	343	8
Austria	124	—	74	—	129	—	141	—	17	—
Brazil	1,242	6	1,252	26	1,335	14	r1,375	14	1,449	22
Canada	2,878	448	2,699	579	2,606	1,580	2,657	1,520	3,840	1,280
China	29	100	16	373	13	7	12	91	11	88
European Community	5,648	230	5,061	331	4,949	269	4,240	226	4,127	171
Finland	193	—	194	—	199	—	179	1	173	—
Japan	3,892	192	3,314	524	2,826	411	2,558	604	2,414	120
Korea, Republic of	1,186	41	901	658	1,205	279	1,286	790	1,453	116
Mexico	427	312	399	429	585	591	454	1,159	385	1,276
South Africa, Republic of	—	—	—	—	—	—	—	11	227	40
Sweden	518	4	228	3	265	—	273	2	311	1
Taiwan	213	61	128	127	174	17	117	396	56	46
Turkey	258	—	182	—	119	—	88	29	108	6
Venezuela	152	9	142	16	184	28	84	102	86	44
All others	r1,452	r424	r686	r1,000	r537	688	r401	r741	411	655
Total[1]	18,952	1,877	15,713	4,153	15,575	3,904	r14,375	5,757	15,490	3,890

rRevised.

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

Source: American Iron and Steel Institute.

TABLE 5

U.S. EXPORTS OF IRON AND STEEL PRODUCTS

(Thousand metric tons)

	1990	1991	1992
Steel mill products:			
Ingots, blooms, billets, and slabs	474	634	384
Wire rods	97	151	64
Structural shapes-heavy	279	368	268
Steel piling	6	9	9
Plates—cut lengths	152	251	176
Plates—in coils	264	412	196
Rails—standard	53	20	7
Rails—other	5	9	5
Railroad accessories	4	8	12
Bars—hot-rolled	195	209	197
Bars—light-shaped	48	45	42
Bars—concrete reinforcing	108	213	167
Bars—cold-finished	49	51	65
Tool steel	4	9	5
Pipe and tubing—standard pipe	29	34	39
Pipe and tubing—oil country goods	177	329	206
Pipe and tubing—line pipe	67	147	170
Pipe and tubing—mechanical tubing	6	9	13
Pipe and tubing—stainless	12	14	13
Pipe and tubing—nonclassified	108	126	144
Pipe and tubing—structural	22	19	23
Pipe for piling	5	6	7
Wire	64	81	82
Tin mill products—blackplate	2	4	4
Tin mill products—tinplate	134	137	253
Tin mill products—tin-free steel	23	34	54
Sheets—hot-rolled	622	1,450	359
Sheets—cold-rolled	325	367	324
Sheets and strip—hot-dip galvanized	181	163	146
Sheets and strip—electrogalvanized	79	112	124
Sheets and strip—other metallic coated	94	91	112
Sheets and strip—electrical	43	76	43
Strip—hot-rolled	65	66	75
Strip—cold-rolled	107	103	100
Total steel mill products[1]	3,904	5,757	3,890
Fabricated steel products:			
Structural shapes—fabricated	194	248	194
Rails—used	42	41	19
Railroad products	11	20	23
Wire rope	4	4	4
Wire—stranded products	13	17	16
Wire—other products	9	14	15
Springs	27	26	31
Nails and staples	11	13	16
Fasteners	164	153	178
Chains and parts	21	21	22

See footnotes at end of table.

TABLE 5—Continued

U.S. EXPORTS OF IRON AND STEEL PRODUCTS

(Thousand metric tons)

	1990	1991	1992
Fabricated steel products—Continued:			
Grinding balls	41	45	40
Pipe and tube fittings	16	16	19
Other	25	27	32
Total fabricated steel products	578	645	609
Total all steel products[1]	4,481	6,402	4,499
Cast iron and steel products:[2]			
Cast steel pipe fittings	80	72	104
Cast iron pipe and fittings	11	13	16
Cast steel rolls	11	11	10
Cast grinding balls	17	14	16
Granules—shot and grit	26	26	27
Other castings	27	29	29
Total cast iron and steel products[1]	172	165	201

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

Source: American Iron and Steel Institue.

TABLE 6

U.S. IMPORTS OF PIG IRON, BY COUNTRY

(Metric tons)

Country	1988	1989	1990	1991	1992
Brazil	450,795	310,196	219,041	327,603	308,610
Canada	131,874	120,597	124,938	84,254	85,013
Russia[1]	—	—	—	—	19,029
South Africa, Republic of	—	—	—	21,243	77,607
U.S.S.R.[2]	—	—	—	770	—
Other	52,416	12,072	3,233	r449	6,288
Total[1]	635,085	442,865	347,212	[3]434,318	496,547

rRevised.

[1]Formerly part of the U.S.S.R.

[2]The U.S.S.R. dissolved in Dec. 1991.

[3]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 7

U.S. IMPORTS OF MAJOR IRON AND STEEL PRODUCTS

(Thousand metric tons)

	1990	1991	1992
Steel mill products:			
Ingots, blooms, billets and slabs	2,144	r2,048	2,172
Wire rods	871	750	1,014
Structural shapes-heavy	750	417	407
Steel piling	81	57	53
Plates—cut lengths	870	727	819
Plates—in coils	557	444	640
Rails and railroad accessories	120	141	147
Bars—hot-rolled	614	603	682
Bars—light-shaped	84	65	83
Bars—reinforcing	134	97	108
Bars—cold-finished	147	138	138
Tool steel	53	60	61
Pipe and tubing—standard pipe	863	759	529
Pipe and tubing—oil country goods	352	374	91
Pipe and tubing—line pipe	631	910	367
Pipe and tubing—mechanical tubing	169	154	134
Pipe and tubing—pressure tubing	35	33	25
Pipe and tubing—stainless	43	44	39
Pipe and tubing—nonclassified	9	6	4
Pipe and tubing—structural	250	190	206
Pipe for piling	4	11	5
Wire	392	355	391
Tin mill products—blackplate	133	117	138
Tin mill products—tinplate	284	282	292
Tin mill products—tin-free steel	103	104	120
Sheets—hot rolled	2,070	1,924	2,427
Sheets—cold rolled	1,859	1,712	1,931
Sheets and strip—hot-dip galvanized	1,146	1,154	1,567
Sheets and strip—electrogalvanized	350	224	290
Sheets and strip—other metallic coated	175	172	257
Sheets and strip—electrical	69	74	74
Strip—hot-rolled	88	96	125
Strip—cold-rolled	126	128	154
Total steel mill products[1]	15,575	r14,375	15,490
Fabricated steel products:			
Structural shapes-fabricated	87	69	67
Rails—used	154	93	78
Railroad products	40	38	44
Wire rope	85	79	78
Wire—stranded products	152	99	112
Wire—other products	77	60	64
Springs	213	190	209
Nails and staples	341	263	311

See footnotes at end of table.

TABLE 7—Continued

U.S. IMPORTS OF MAJOR IRON AND STEEL PRODUCTS

(Thousand metric tons)

	1990	1991	1992
Fabricated steel products—Continued:			
Fasteners	655	619	639
Chains and parts	67	60	60
Pipe and tube fittings	126	118	78
Other	20	22	20
Total fabricated steel products[1]	2,016	1,709	1,762
Total all steel products	17,591	16,084	17,252
Cast iron and steel products:[2]			
Cast steel pipe fittings	20	16	18
Cast iron pipe and fittings	27	23	23
Other products	168	148	149
Total cast products[1]	215	187	191

[r]Revised.

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

Source: American Iron and Steel Institute.

TABLE 8
U.S. IMPORTS OF STAINLESS STEEL

(Metric tons)

Product	1988	1989	1990	1991	1992
Semifinished	56,615	56,355	55,177	44,418	33,727
Plate	14,376	16,069	18,734	19,503	31,577
Sheet and strip	107,578	127,477	140,017	145,766	187,434
Bars and shapes	36,944	39,387	40,393	47,621	55,424
Wire and wire rods	36,163	39,024	37,608	38,965	53,256
Pipe and tube	33,341	33,800	42,837	43,743	38,657
Total[1]	285,017	312,112	334,766	340,015	400,077

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

Sources: International Trade Commission and American Iron and Steel Institute.

TABLE 9
U.S. SHIPMENTS OF IRON AND STEEL CASTINGS

(Thousand metric tons)

	1988	1989	1990	1991	1992
Ductile iron castings	2,912	3,013	2,890	2,530	2,777
Gray iron castings	5,390	5,115	4,602	r4,181	4,328
Malleable iron castings	293	271	263	r238	234
Steel castings	1,077	1,074	1,028	r868	898
Steel investment castings	43	43	36	r33	32
Total	[1]9,714	9,516	8,819	r7,850	8,269

rRevised.
[1]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10
COAL AND COKE AT COKE PLANTS[1]

(Thousand metric tons)

	1988	1989	1990	1991	1992
Coal: Consumption	38,000	36,748	35,269	30,712	29,362
Coke:[2]					
Production	26,258	25,442	25,054	21,814	21,237
Exports	992	984	519	671	582
Imports	2,439	2,097	694	997	1,578
Consumption, apparent	27,234	26,248	25,230	21,968	22,398

[1]Includes furnace and merchant coke plants.
[2]Coke production and consumption do not include breeze.

Source: Energy Information Administration, Quarterly Coal Report (DOE/EIA-0121).

TABLE 11

PIG IRON[1] AND DIRECT-REDUCED IRON:[2] WORLD PRODUCTION, BY COUNTRY[3]

(Thousand metric tons)

Country[4]	1988	1989	1990	1991	1992[e]
Albania	172	179	96	e50	10
Algeria	1,500	1,301	1,037	r877	850
Argentina:					
Pig iron	1,596	2,062	r1,883	1,366	900
Direct-reduced iron	1,067	1,166	r1,034	954	1,000
Australia	5,730	6,094	6,125	5,647	6,000
Austria	3,665	3,823	3,452	3,439	5,3,067
Belgium	9,147	r9,437	9,416	r9,354	5,8,533
Bosnia and Herzegovina[6]	—	—	—	—	60
Brazil:					
Pig iron	r23,454	24,363	r21,141	22,695	5,23,152
Direct-reduced iron	195	258	260	r226	230
Bulgaria	1,437	1,484	1,143	r1,100	5,1,050
Burma:[e]					
Pig iron	1	r3	(7)	3	1
Direct-reduced iron	20	20	20	20	20
Canada:					
Pig iron	9,498	10,139	7,346	8,268	5,8,621
Direct-reduced iron	747	710	730	r553	5,639
Chile	776	679	675	703	750
China	57,040	58,200	62,380	67,000	73,000
Colombia	309	297	323	r305	300
Croatia[6]	—	—	—	—	150
Czechoslovakia	9,706	9,911	9,667	8,479	5,8,039
Egypt:					
Pig iron	1,112	1,105	1,100	e1,250	1,200
Direct-reduced iron	699	817	710	e620	850
Finland	2,174	2,284	2,283	2,331	5,2,452
France	14,786	15,071	14,415	13,645	5,13,051
Georgia[8]	—	—	—	—	500
Germany:					
Pig iron:					
Eastern states[9]	2,786	2,732	r2,163	—	—
Western states	r31,890	r32,112	r29,585	—	—
Total	r34,676	r34,844	r31,748	r30,608	5,28,538
Direct-reduced iron: Western states[e]	5,270	353	310	260	250
Greece	r—	r—	r—	r—	—
Hungary	2,093	1,954	1,697	1,311	5,1,176
India:					
Pig iron	11,735	12,080	12,645	e14,176	15,100
Direct-reduced iron	190	340	e750	e1,180	1,440
Indonesia: Direct-reduced iron	980	1,262	e1,300	e1,350	1,400
Iran:					
Pig iron[e]	e250	e250	1,267	1,952	5,2,053
Direct-reduced iron	—	r40	r264	r470	5,709
Iraq: Direct-reduced iron[e]	20	200	170	r—	—
Italy	11,349	11,795	11,803	10,862	5,10,461

See footnotes at end of table.

TABLE 11—Continued

PIG IRON[1] AND DIRECT-REDUCED IRON:[2] WORLD PRODUCTION, BY COUNTRY[3]

(Thousand metric tons)

Country[4]	1988	1989	1990	1991	1992e
Japan	79,295	80,197	80,229	79,985	5 73,144
Kazakhstan[8]	—	—	—	—	4,000
Korea, North e	6,500	6,500	6,500	6,500	6,600
Korea, Republic of	12,578	14,846	15,339	18,510	5 19,323
Libya: Direct-reduced iron e	—	e 90	e 500	r 780	850
Luxembourg[9]	2,521	2,685	2,616	r 2,463	5 2,256
Macedonia[6]	—	—	—	—	100
Malaysia: Direct-reduced iron	454	570	e 600	e 600	600
Mexico:					
Pig iron	3,678	3,230	3,665	r 2,962	5 3,404
Direct-reduced iron	1,686	r 2,164	2,525	r 2,462	5 2,394
Morocco e	15	15	15	15	15
Netherlands[9]	4,994	5,163	4,960	r 4,696	5 4,852
New Zealand: Direct-reduced iron[8]	418	493	549	594	5 384
Nigeria: Direct-reduced iron e	5 145	143	140	140	140
Norway	367	r 240	54	61	5 80
Pakistan e	5 933	1,000	1,000	1,100	1,100
Paraguay	63	63	61	60	60
Peru:					
Pig iron	202	r 199	r 93	r 207	150
Direct-reduced iron	r 51	r 46	r 29	r 24	20
Poland	10,264	9,488	8,658	6,355	5 6,348
Portugal	545	377	339	251	5 402
Qatar: Direct-reduced iron	443	531	e 530	e 530	530
Romania	8,941	9,052	6,355	r 4,525	5 3,125
Russia:[8]					
Pig iron	—	—	—	—	44,000
Direct-reduced iron[10]	—	—	—	—	1,580
Saudi Arabia: Direct-reduced iron	r 1,080	1,205	r 1,085	r 1,117	1,610
Serbia and Montenegro[6]	—	—	—	—	600
South Africa, Republic of:					
Pig iron	6,171	6,543	6,257	6,968	5 6,498
Direct-reduced iron	r 759	r 772	r 882	r 863	5 910
Spain	4,639	5,722	5,542	r 5,404	5 5,076
Sweden	r 2,527	r 2,638	2,736	2,812	5 2,735
Switzerland e	70	70	70	70	70
Taiwan	5,675	5,780	5,474	5,561	5,500
Trinidad and Tobago: Direct-reduced iron	593	612	697	r 710	700
Tunisia e	r 5 128	r 140	r 140	r 140	140
Turkey	4,462	3,523	4,827	4,594	4,500
Ukraine[8]	—	—	—	—	5 35,300
U.S.S.R.:[11]					
Pig iron	114,558	113,928	110,163	r 89,400	—
Direct-reduced iron e [10]	5 1,600	1,700	1,600	1,500	—
United Kingdom	13,056	12,638	12,277	r 11,883	5 11,351

See footnotes at end of table.

TABLE 11—Continued

PIG IRON[1] AND DIRECT-REDUCED IRON:[2] WORLD PRODUCTION, BY COUNTRY[3]

(Thousand metric tons)

Country[4]	1988	1989	1990	1991	1992e
United States:					
Pig iron	50,571	50,687	49,668	44,123	[5]47,377
Direct-reduced iron	290	290	r390	410	[5]390
Venezuela:					
Pig iron	503	489	314	—	—
Direct-reduced iron	2,710	2,773	e3,130	e4,050	4,300
Yugoslavia[12]	2,916	2,899	2,313	e1,600	—
Zimbabwe[e]	600	520	[5]521	r500	500
Grand total	r553,395	r562,542	r550,033	r525,579	518,566
Of which:					
Pig iron	r538,978	r545,987	r531,828	r506,166	497,620
Direct reduced iron	r14,417	r16,555	r18,205	r19,413	20,946

[e]Estimated. [r]Revised.

[1]Production is pig iron unless otherwise specified.

[2]Direct-reduced iron is obtained from ore by reduction of oxides to metal without melting.

[3]Table excludes ferroalloy production except where otherwise noted. Table includes data available through July 6, 1993.

[4]In addition to the countries listed, Vietnam has facilities to produce pig iron and may have produced limited quantities during 1988-92, but output is not reported and available information is inadequate to make reliable estimates of output levels.

[5]Reported figure.

[6]Formerly part of Yugoslavia; data were not reported separately until 1992.

[7]Less than 500 tons.

[8]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[9]Includes blast furnace ferroalloys.

[10]All production in the U.S.S.R. from 1988-91 came from Russia.

[11]Dissolved in Dec. 1991.

[12]Dissolved in Apr. 1992.

TABLE 12

RAW STEEL:[1] WORLD PRODUCTION, BY COUNTRY[2]

(Thousand metric tons)

Country[3]	1988	1989	1990	1991	1992[e]
Albania[e]	110	112	65	35	5
Algeria	r1,300	943	r836	r1,393	1,400
Angola[e]	10	10	10	10	10
Argentina	3,652	3,909	3,634	2,966	2,600
Australia	6,399	6,735	6,666	6,018	4,6,322
Austria	4,560	4,718	4,292	4,186	4,3,946
Azerbaijan[5]	—	—	—	—	300
Bangladesh[6]	r70	86	r75	r58	44
Belarus[5]	—	—	—	—	700
Belgium	11,222	r10,952	r11,419	r11,334	4,10,276
Benine	—	2	8	8	8
Bosnia and Herzegovina[7]	—	—	—	—	250
Brazil	r24,657	r25,055	r20,567	22,617	24,000
Bulgaria	2,875	2,899	2,185	r1,615	1,500
Canada	14,866	15,458	12,281	12,987	4,13,924
Chile	909	800	772	805	850
China	59,430	61,200	66,100	70,570	80,000
Colombia	754	706	r701	r664	670
Croatia[7]	—	—	—	—	100
Cuba	314	336	e270	r180	4,162
Czechoslovakia	15,319	15,465	14,877	12,133	11,140
Denmark	650	625	610	633	4,591
Dominican Republic	75	55	36	39	35
Ecuador	24	23	20	r21	19
Egypt	2,025	2,114	2,235	2,541	2,500
El Salvador	11	12	r e12	r e11	11
Finland	2,798	2,921	2,861	r2,890	4,3,077
France	19,122	19,335	19,032	18,437	4,17,961
Georgia[5]	—	—	—	—	700
Germany:					
Eastern states	8,131	7,829	r5,546	—	—
Western states	41,023	41,073	38,435	—	—
Total	49,154	48,902	r43,981	42,169	4,39,768
Greece	959	958	1,050	980	4,923
Guatemala	23	23	r e22	e20	18
Honduras[e]	7	8	8	8	7
Hong Kong[e]	300	320	350	350	350
Hungary	3,583	3,356	2,963	r1,931	4,1,559
India[6]	14,309	14,608	14,963	r17,100	18,000
Indonesia	2,050	r2,383	r2,892	e3,250	3,100
Iran	978	1,081	1,425	2,203	4,2,937
Iraq[e]	50	300	150	20	100
Ireland	271	324	326	293	4,257
Israel[e]	120	118	144	r160	160
Italy	23,760	25,213	25,439	r25,046	4,24,904
Jamaica	r25	r34	r22	r36	37
Japan	105,681	107,908	110,339	109,649	4,98,131
Jordan	r e200	r177	r179	r200	200

See footnotes at end of table.

TABLE 12—Continued

RAW STEEL:[1] WORLD PRODUCTION, BY COUNTRY[2]

(Thousand metric tons)

Country[3]	1988	1989	1990	1991	1992[e]
Kazakhstan[5]	—	—	—	—	5,000
Korea, North[e]	8,000	8,000	8,000	8,000	8,100
Korea, Republic of	19,117	21,873	23,125	26,001	[4]28,054
Latvia[5]	—	—	—	—	246
Libya	[r]10	[r]10	500	500	822
Luxembourg	[r]3,661	3,721	[r]3,560	3,379	[4]3,068
Macedonia[7]	—	—	—	—	150
Malaysia	[r]925	1,125	1,200	1,200	1,250
Mexico	7,779	7,851	8,726	7,883	[4]8,435
Moldova[5]	—	—	—	—	619
Morocco[e]	7	7	7	7	7
Netherlands	5,518	5,681	5,412	[r]5,171	[4]5,438
New Zealand	460	608	765	[e]700	600
Nigeria	192	213	[r]133	[r]137	140
Norway	[r]869	[r]678	[r]376	438	[4]446
Pakistan[e]	1,000	1,000	1,000	1,000	1,000
Paraguay	62	63	63	60	60
Peru	481	401	284	418	400
Philippines[e]	[4]331	300	300	250	250
Poland	16,873	15,094	13,625	10,439	9,800
Portugal	811	762	746	[r]541	[4]749
Qatar	527	[r]550	[r]580	[r]580	580
Romania	14,496	14,415	9,787	[r]7,116	[4]5,372
Russia[5]	—	—	—	—	67,000
Saudi Arabia	1,614	1,810	1,833	[e]1,850	1,900
Serbia and Montenegro	—	—	—	—	700
Singapore	413	495	489	[e]490	500
Slovenia[7]	—	—	—	—	400
South Africa, Republic of	8,837	9,337	[r]8,619	9,358	[4]9,061
Spain	11,685	12,684	12,705	[r]12,933	[4]12,295
Sweden	4,779	[r]4,692	4,454	4,248	[4]4,356
Switzerland	825	916	970	955	[4]1,050
Syria[e]	70	70	70	70	70
Taiwan	8,313	9,047	9,747	10,957	11,000
Thailand	552	689	685	711	750
Trinidad and Tobago	361	294	372	[r]444	440
Tunisia	150	194	[r]184	[e]200	200
Turkey	7,982	7,934	9,462	9,336	10,343
Ukraine[5]	—	—	—	—	42,000
U.S.S.R.[8]	163,037	160,096	154,414	132,666	—
United Kingdom	19,013	18,813	17,908	16,511	16,050
United States	90,650	88,852	89,726	79,738	84,322
Uruguay	29	47	40	[e]40	40
Uzbekistan[5]	—	—	—	—	800
Venezuela[9]	3,165	2,941	[r]3,176	[r]3,119	3,200
Vietnam[e]	115	115	120	120	120

See footnotes at end of table.

TABLE 12—Continued

RAW STEEL:[1] WORLD PRODUCTION, BY COUNTRY[2]

(Thousand metric tons)

Country[3]	1988	1989	1990	1991	1992[e]
Yugoslavia[10]	4,487	4,500	3,609	[r]2,295	—
Zimbabwe	[r]500	[r]650	580	[r e]580	580
Total	[r]780,318	[r]786,712	[r]771,169	[r]736,007	721,315

[e]Estimated. [r]Revised.

[1]Steel 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.

[2]Table includes data available through July 6, 1993.

[3]In addition to the countries listed, Burma, Ghana, and Mozambique are known to have steelmaking plants, but available information is inadequate to make reliable estimates of output levels.

[4]Reported figure.

[5]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[6]Data are for year ending June 30 of that stated.

[7]Formerly part of Yugoslavia; data were not reported separately until 1992.

[8]Dissolved in Dec. 1991.

[9]Includes steel castings.

[10]Dissolved in Apr. 1992.

TABLE 13

GOVERNMENT INVENTORY OF FERROALLOYS, DECEMBER 31, 1992

(Metric tons of alloy, unless otherwise stated)

Alloy	Stock-pile grade	Non-stock-pile grade	Total
Ferrochromium:			
High-carbon	747,965	629	748,594
Low-carbon	273,944	13,784	287,728
Ferrochromium-silicon	51,699	1,242	52,941
Ferrocolumbium (kilograms contained columbium)	271,434	150,820	422,254
Ferromanganese:			
High-carbon	983,636	—	983,636
Medium-carbon	25,448	—	25,448
Ferrotungsten (kilograms contained tungsten)	385,404	532,732	918,136
Silicomanganese	12,149	—	12,149

TABLE 14

PRODUCERS OF FERROALLOYS IN THE UNITED STATES IN 1992

Producer	Plant location	Products[1]	Type of furnace
	FERROALLOYS (except ferrophosphorus)		
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	FeSi	Do.
Bear Metallurgical Inc.	Butler, PA	FeV	Metallothermic.
Cabot Corp.	Revere, PA	FeCb, Nicb	Do.
Cyprus Minerals Co.	Greenvalley, 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	FeB, FeCr, FeMn, FeSi, Mn, Si, SiMn, other[2]	Electric and electrolytic.
Galt Alloys Inc.	Canton, OH	FeTi, FeAl	Electric
Glenbrook Nickel Co.	Riddle, OR	FeNi	Do.
Globe Metallurgical Inc.	Beverly, OH, Selma, AL	FeSi, Si	Do.
HTP Co.	Sharon, PA	FeTi	Metallothermic.
Keokuk Ferro-Sil Inc.	Keokuk, IA	FeSi, silvery pig iron	Electric.
Kerr-McGee Chemical Corp.	Hamilton (Aberdeen), 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	Metallothermic.
Satra Concentrates Inc.	Steubenville, OH	FeCr, FeCrSi	Slag conversion.
Silicon Metaltech Inc.	Wenatchee, WA	Si	Electric.
Simetco	Montgomery, AL	do.	Do.
SKW Alloys Inc.	Calvert City, KY, Niagara Falls, NY	FeCr, FeCrSi, FeSi, Si	Do.
Strategic Minerals Corp. (STRATCOR), U.S. Vanadium Corp.	Niagara Falls, NY	FeV	Do.
Teledyne Inc., Teledyne Wah Chang, Albany Div.	Albany, OR	FeCb	Metallothermic.
Union Oil Co. of California, Molycorp Inc.	Washington, PA	FeMo	Electric and metallothermic.
	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.

[1]Cr, chromium metal; FeAl, ferroaluminum; FeB, ferroboron; 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; NiCb, nickelcolumbium; Si, silicon metal; SiMn, silicomanganese.

[2]Includes specialty silicon alloys, zirconium alloys, and miscellaneous ferroalloys.

TABLE 15

U.S. FERROALLOY PRODUCTION[1] AND SHIPMENTS[2]

(Metric tons, gross weight, unless otherwise specified)

	1992			
	Net production	Net shipments		Stocks, December 31
		Quantity	Value (thousands)	
Ferrosilicon[3]	346,290	341,737	$136,831	84,712
Silicon metal	158,550	167,310	188,806	10,391
Other[4]	243,515	259,574	312,535	27,560
Ferrophosphorus	25,098	26,198	3,168	14,072
Total[5]	773,453	794,818	641,341	136,736

[1]Does not include alloys produced for consumption in the making of other ferroalloys.
[2]Gross sales (including exports) minus purchases.
[3]Includes all regular and specialty grades of ferrosilicon, excluding silvery pig iron.
[4]Includes 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.
[5]Data may not add to totals shown because of independent rounding.

TABLE 16

REPORTED U.S. CONSUMPTION OF FERROALLOYS AS ADDITIVES IN 1992, BY END USE[1]

(Metric tons of alloys unless otherwise specified)

End use	FeMn	SiMn	FeSi	FeTi	FeP	FeB
Steel:						
Carbon	265,947	76,589	[2]51,347	1,579	6,063	537
Stainless and heat-resisting	[2]15,447	5,169	[2]104,883	1,756	(3)	23
Other alloy	[2]48,063	20,643	[2]33,531	270	1,040	214
Tool	(3)	(3)	[2]2,384	W	—	—
Unspecified	1,339	546	10,252	—	—	—
Total steel[4]	330,796	102,947	202,397	3,606	7,102	774
Cast irons	11,401	11,355	197,603	W	1,084	(5)
Superalloys	[6]103	—	[7]89	523	—	(5)
Alloys (excluding alloy steels and superalloys)	21,036	(8)	[7]3,498	738	215	141
Miscellaneous and unspecified	(5)	(8)	190,172	77	15	5
Total[4]	363,336	114,303	593,760	4,943	8,416	919
Total 1991[r]	357,653	102,033	567,260	4,979	8,440	875
Percent of 1991	102	112	105	99	100	105
Consumer stocks, December 31	[9] [10]28,429	7,106	15,472	582	1,167	132

[r]Revised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1]FeMn, ferromanganese, including spiegeleisen and manganese metal; SiMn, silicomanganese; FeSi, ferrosilicon, including silicon metal, silvery pig iron, and inoculant alloys; FeTi, ferrotitanium, including other titanium material; FeP, ferrophosphorus, including other phosphorus materials; FeB, ferroboron including other boron materials.
[2]Part included with "Steel: Unspecified."
[3]Included with "Steel: Unspecified."
[4]Data may not add to totals shown because of independent rounding.
[5]Included with "Alloys (excluding alloy steels and superalloys)."
[6]Part included with "Alloys (excluding alloy steels and superalloys)."
[7]Part included with "Miscellaneous and unspecified."
[8]Included with "Cast irons."
[9]Includes some producer stocks.
[10]Part withheld to avoid disclosing company proprietary data.

TABLE 17

REPORTED U.S. CONSUMPTION OF FERROALLOYS AS ALLOYING ELEMENTS IN 1992, BY END USE[1]

(Metric tons of contained elements unless otherwise specified)

End use	FeCr	FeMo	FeW	FeV	FeCb	FeNi
Steel:						
Carbon	[2]7,477	120	—	1,262	838	—
Stainless and heat-resisting	[2]165,403	209	52	28	347	14,583
Other alloy	[2]27,079	1,331	66	1,817	931	470
Tool	[2]1,907	280	407	453	[3]	—
Unspecified	[3]	—	[4]	21	8	—
Total steel[5]	201,866	1,940	525	3,581	2,124	15,053
Cast irons	3,863	635	—	17	—	W
Superalloys	[2]4,861	52	W	13	412	W
Alloys (excluding alloy steels and superalloys)	[2]249	[2]84	—	[2]444	W	W
Miscellaneous and unspecified	6,601	87	46	19	20	257
Total[5]	217,440	2,797	572	4,073	2,555	15,310
Total 1991	r208,164	[2]2,495	445	r3,293	r2,412	r14,319
Percent of 1991	104	112	129	124	106	107
Consumer stocks, December 31	11,706	195	18	392	NA	2,411

rRevised. NA Not available. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

[1]FeCr, ferrochromium, including other chromium ferroalloys and chromium metal; FeMo, ferromolybdenum, including calcium molybdate; FeW, ferrotungsten, including scheelite; FeV, ferrovanadium, including other vanadium-carbon-iron ferroalloys; FeCb, ferrocolumbium, including nickel columbium; FeNi, ferronickel.

[2]Part included with "Miscellaneous and unspecified."

[3]Included with "Steel: Unspecified."

[4]Included with "Miscellaneous and unspecified."

[5]Data may not add to totals shown because of independent rounding.

TABLE 18

FERROALLOY PRICES IN 1992

	High	Low	Average[1]
Standard-grade ferromanganese[2]	560.00	470.00	509.27
Medium-carbon ferromanganese[3]	54.00	49.50	51.67
Silicomanganese[4]	24.75	22.80	23.83
Charge-grade ferrochromium[3]	49.00	36.00	46.16
High-carbon ferrochromium[3]	47.85	33.50	44.33
Low-carbon ferrochromium[3]	90.50	71.50	80.71
50%-grade ferrosilicon[3]	39.25	34.25	36.95
75%-grade ferrosilicon[3]	38.25	31.25	35.41
Silicon metal[4]	66.75	54.75	59.98
Ferromolybdenum[5]	3.35	2.85	3.15
Molybdenum oxide[5]	2.44	1.82	2.21
Ferrovanadium[6]	12.25	10.25	11.39

[1]Annual weighted average.

[2]Dollars per long ton.

[3]Cents per pound of contained element.

[4]Cents per pound.

[5]Dollars per pound of contained element.

[6]Dollars per kilogram of contained element.

TABLE 19

U.S. EXPORTS OF FERROALLOYS AND FERROALLOY METALS IN 1992

Alloy	Quantity (metric tons)	Content (metric tons)	Value (thousands)
Ferroalloys:			
Ferrochromium with greater than 4% carbon	8,292	4,907	$7,188
Ferrochromium with less than 4% carbon	1,860	1,085	2,808
Ferrochromium-silicon	671	235	737
Ferrocolumbium	902	(1)	8,254
Ferromanganese with greater than 2% carbon	4,637	(1)	2,991
Ferromanganese, other	8,766	(1)	10,005
Silicomanganese	9,171	(1)	6,500
Ferromolybdenum	536	319	4,403
Ferronickel	4,055	2,374	9,752
Ferrophosphorus	2,142	(1)	1,470
Ferrosilicon (greater than 55% silicon)	15,380	9,614	14,364
Ferrosilicon, other	40,616	20,203	31,461
Ferrovanadium	326	(1)	3,727
Ferrozirconium	88	(1)	130
Ferrotungsten and ferrosilicon-tungsten	106	53	132
Ferroalloys, n.e.c.	2,217	(1)	3,497
Total ferroalloys	99,765	XX	107,419
Metals:			
Chromium	299	(1)	4,176
Manganese	5,005	(1)	11,946
Silicon:			
Less than 99% silicon	5,779	5,540	8,123
99% to 99.99% silicon	1,238	1,226	1,727
Greater than 99.99% silicon	1,514	1,514	83,963
Total ferroalloy metals	13,835	XX	109,935
Grand total	113,600	XX	217,354

XX Not applicable.
[1]Not recorded.

Source: Bureau of the Census.

TABLE 20

U.S. IMPORTS FOR CONSUMPTION OF FERROALLOYS AND FERROALLOY METALS IN 1992

Alloy	Gross weight (metric tons)	Content (metric tons)	Value (thousands)
Chromium alloys:			
Ferrochromium containing 4% or more carbon	376,926	221,052	$193,456
Ferrochromium containing less than 3% carbon	33,871	22,281	41,684
Ferrochromium-silicon	9,379	3,643	7,666
Total chromium alloys	420,176	246,976	242,806
Manganese alloys:			
Ferromanganese containing more than 4% carbon	226,841	175,056	97,399
Ferromanganese containing more than 1% to 2% carbon	66,126	53,513	53,977
Ferromanganese containing 1% or less carbon	11,190	9,901	15,440
Silicomanganese	257,177	169,047	118,464
Total manganese alloys[1]	561,335	407,517	285,279
Silicon alloys:			
Less than 55% silicon containing more than 2% magnesium	3,265	1,466	3,796
Less than 55% silicon, n.e.c.	78,990	36,266	22,452
55% to 80% silicon, containing more than 3% calcium	2,486	1,565	2,415
55% to 80% silicon, n.e.c.	162,133	121,338	84,754
80% to 90% silicon	726	632	493
Total silicon alloys[1]	247,601	161,267	113,911
Other ferroalloys:			
Ferrocerium and other cerium alloys	164	(2)	1,844
Ferromolybdenum	1,722	1,096	7,209
Ferronickel	35,122	13,015	88,035
Ferroniobium (columbium)	3,767	(2)	31,075
Ferrophosphorus	7,492	(2)	1,920
Ferrotitanium and ferrosilicon titanium	1,357	(2)	3,202
Ferrotungsten and ferrosilicon tungsten	575	414	2,194
Ferrovanadium	767	592	7,038
Ferrozirconium	1	(2)	2
Ferroalloys, n.e.c.	16,518	(2)	23,830
Total other ferroalloys	67,485	XX	166,349
Total ferroalloys	1,296,597	XX	808,345
Metals:			
Chromium	5,451	(2)	36,361
Manganese, unwrought	8,372	(2)	12,593
Manganese, other	5,507	(2)	9,353
Silicon, less than 99% silicon	13,804	13,446	13,233
Silicon 99 to 99.99% silicon	17,993	17,640	22,920
Silicon, greater than 99.99% silicon	919	919	56,581
Total ferroalloy metals	52,046	XX	151,041
Grand total	1,348,643	XX	959,386

XX Not applicable.

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

[2]Not recorded.

Source: Bureau of the Census.

TABLE 21

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1988	1989	1990	1991	1992[e]
Albania: Electric furnace, ferrochromium	33,700	38,800	24,000	[e]35,000	15,000
Argentina: Electric furnace:					
Ferromanganese	19,737	[r]24,441	[r]24,344	[e]23,800	24,300
Silicomanganese	11,610	[r]21,160	[r]21,805	[e]21,500	21,500
Ferrosilicon	30,539	[r]35,667	[r]23,641	[e]17,500	25,000
Silicon metal[e]	10,000	10,000	10,000	10,000	10,000
Other	[r]5,952	[r]5,805	[r]6,310	[e]7,200	6,500
Total[e]	[r]77,838	[r]97,073	[r]86,100	[e]80,000	87,300
Australia: Electric furnace:[e]					
Ferromanganese	[4]58,000	[4]67,000	70,000	55,000	55,000
Silicomanganese	44,000	55,000	65,000	[r]65,000	65,000
Ferrosilicon	18,000	20,000	20,000	20,000	20,000
Silicon metal	8,000	9,000	33,000	30,000	30,000
Total	128,000	151,000	188,000	[r]170,000	170,000
Austria: Electric furnace:					
Ferronickel	5,000	7,000	8,100	8,600	6,100
Other	[r]15,000	[r]8,000	[r]3,900	[r]3,400	5,900
Total	20,000	15,000	12,000	12,000	12,000
Belgium: Electric furnace, ferromanganese[e]	95,000	95,000	90,000	90,000	90,000
Bosnia and Herzegovina:[5] Electric furnace:					
Ferrosilicon	—	—	—	—	10,000
Silicon metal	—	—	—	—	5,000
Other	—	—	—	—	500
Total	—	—	—	—	15,500
Brazil: Electric furnace:					
Ferromanganese	180,588	180,668	170,504	169,103	179,500
Silicomanganese	193,490	208,262	216,779	272,046	260,500
Ferrosilicon	267,538	286,994	229,408	190,864	230,000
Silicon metal	79,287	116,779	131,614	106,002	87,000
Ferrochromium	130,024	113,267	83,753	82,225	82,000
Ferrochromium-silicon	9,177	8,938	4,973	4,524	4,500
Ferronickel	33,930	34,997	34,257	33,281	34,000
Other	79,090	81,901	68,026	77,235	77,000
Total	973,124	1,031,806	939,314	935,280	954,500
Bulgaria: Electric furnace:[e]					
Ferromanganese[6]	31,000	30,000	—	—	—
Ferrosilicon	15,000	14,000	14,000	14,000	10,000
Other	1,000	1,000	1,000	1,000	1,000
Total	47,000	45,000	15,000	15,000	11,000
Canada: Electric furnace:[e]					
Ferromanganese[6]	161,000	185,000	185,000	45,000	—
Ferrosilicon	90,266	88,370	90,000	106,850	21,613
Other	66,300	106,000	100,000	95,000	8,817
Total	317,566	379,370	375,000	246,850	30,430
Chile: Electric furnace:					
Ferromanganese	6,935	7,492	[r]3,587	[r]6,277	6,500
Silicomanganese	683	180	[r]985	[e]700	400

See footnotes at end of table.

TABLE 21—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1988	1989	1990	1991	1992[e]
Chile—Continued:					
Ferrosilicon	5,686	6,370	r4,662	e5,600	5,600
Ferrochromium	2,212	2,840	r1,868	e2,000	2,000
Ferromolybdenum	1,191	2,990	r2,283	e3,100	2,100
Total	16,707	19,872	r13,385	r e17,677	16,600
China:[e]					
Blast furnace:					
Ferromanganese	220,000	240,000	240,000	250,000	250,000
Other	186,000	160,000	170,000	170,000	180,000
Electric Furnace:					
Ferromanganese	89,000	120,000	130,000	140,000	150,000
Silicomanganese	220,000	240,000	240,000	250,000	270,000
Ferrosilicon	787,600	900,000	900,000	950,000	1,000,000
Ferrochromium	(7)	r(7)	(7)	(7)	(7)
Other	581,400	r722,000	720,000	790,000	850,000
Total	2,084,000	2,382,000	2,400,000	2,550,000	2,700,000
Colombia: Electric furnace, ferronickel	41,672	41,454	43,847	r49,824	49,828
Croatia:[5] Electric furnace:					
Ferromanganese	—	—	—	—	35,000
Silicomanganese	—	—	—	—	30,000
Ferrochromium	—	—	—	—	56,456
Total	—	—	—	—	121,456
Czechoslovakia: Electric furnace:					
Ferromanganese[e 6]	95,087	100,159	101,660	90,000	90,000
Ferrosilicon	22,730	20,997	20,474	e15,000	15,000
Silicon metal[e]	5,000	5,000	5,000	5,000	5,000
Ferrochromium	29,183	29,844	31,866	r33,708	37,756
Other[e 8]	10,000	10,000	10,000	10,000	10,000
Total	162,000	166,000	169,000	r153,708	157,756
Dominican Republic: Electric furnace, ferronickel	73,363	r78,170	71,753	r72,655	68,500
Egypt: Electric furnace, ferrosilicon	7,806	e7,800	7,922	e7,900	7,900
Finland: Electric furnace, ferrochromium	156,000	169,000	r157,000	r190,000	187,000
France:					
Blast furnace:					
Ferromanganese	323,945	346,295	319,930	e320,000	300,000
Electric furnace:					
Ferromanganese	22,000	27,000	36,640	e30,000	60,000
Silicomanganese[9]	59,000	e59,000	61,900	e30,000	30,000
Ferrosilicon	e196,000	r125,390	117,490	r105,800	100,000
Silicon metal[e]	70,000	72,000	64,000	r64,000	60,000
Ferrochromium[e]	r13,200	r18,100	25,000	r23,100	6,694
Other[e 10]	60,000	60,000	70,000	50,000	60,000
Total[e]	r744,145	r707,785	694,960	r622,900	616,694
Georgia:[11] Electric furnace:					
Ferromanganese	—	—	—	—	100,000
Silicomanganese	—	—	—	—	100,000

See footnotes at end of table.

TABLE 21—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1988	1989	1990	1991	1992[e]
Georgia:[11] Electric furnace—Continued:					
Other	—	—	—	—	10,000
Total	—	—	—	—	210,000
Germany:[e]					
Blast furnace, Western states:					
Ferromanganese	r274,000	r305,000	r250,000	r220,000	190,000
Electric furnace:					
Ferromanganese[6]					
Eastern states	67,000	67,000	65,000	—	—
Western states	35,000	45,000	38,000	—	—
Total	102,000	112,000	103,000	40,000	30,000
Ferrosilicon:					
Eastern states	25,000	25,000	24,000	—	—
Western states	50,000	55,000	46,000	—	—
Total	75,000	80,000	70,000	50,000	20,000
Silicon metal, Eastern states	3,400	3,000	3,000	2,600	500
Ferrochromium:					
Eastern states	22,000	22,000	21,000	—	—
Western states	r34,900	r33,346	r37,466	—	—
Total	r56,900	r55,346	r58,466	r33,654	26,500
Other[8]:					
Eastern states	13,600	13,000	12,000	—	—
Western states	62,000	66,000	54,000	—	—
Total	75,600	79,000	66,000	r40,000	30,000
Grand total	586,900	634,346	550,466	r386,254	297,000
Greece: Electric furnace:					
Ferrochromium	r44,147	r43,579	30,300	r e10,500	—
Ferronickel	50,500	r41,200	r60,500	r64,020	65,000
Total	r94,647	r84,779	r90,800	r e74,520	65,000
Hungary: Electric furnace:[e]					
Ferrosilicon	10,100	10,200	9,000	9,000	7,000
Silicon metal	2,000	2,000	2,000	2,000	2,000
Other	1,000	1,000	1,000	1,000	1,000
Total	13,100	13,200	12,000	12,000	10,000
Iceland: Electric furnace, ferrosilicon	70,051	r72,007	62,791	50,299	50,000
India: Electric furnace:					
Ferromanganese	138,331	157,766	160,000	r148,000	145,000
Silicomanganese	52,895	72,229	75,000	r46,172	45,000
Ferrosilicon	46,721	r62,056	r71,753	r67,917	70,000
Silicon metal	686	—	—	—	—
Ferrochromium	140,261	135,165	r122,000	r96,007	100,000
Ferrochromium-silicon	2,769	11,384	7,000	r8,800	9,000
Other	445	442	400	r6,767	6,500
Total	382,108	r439,042	r436,153	r373,663	375,500
Indonesia: Electric furnace, ferronickel	26,852	26,058	25,025	e25,000	26,000
Italy:					
Blast furnace ferroalloys: Spiegeleisen	251	—	—	—	—

See footnotes at end of table.

TABLE 21—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1988	1989	1990	1991	1992[e]
Italy—Continued:					
Electric furnace:					
Ferromanganese	r12,280	r14,220	r10,995	r14,145	14,000
Silicomanganese[e]	69,000	47,000	56,000	55,000	50,000
Ferrosilicon	51,131	65,171	r34,761	r12,648	12,000
Silicon metal[e]	18,000	19,000	13,000	16,200	10,100
Ferrochromium	r87,100	r75,567	r53,000	r47,082	62,000
Other[e 12]	14,500	15,000	14,500	14,500	14,000
Total[e]	r252,262	r235,958	r182,256	r159,575	162,100
Japan: Electric furnace:					
Ferromanganese	378,351	394,055	452,434	463,722	4361,941
Silicomanganese	106,970	122,192	77,465	87,229	496,360
Ferrosilicon	73,767	74,936	62,599	62,362	437,656
Ferrochromium[13]	295,406	324,371	293,345	270,786	4267,857
Ferronickel	242,276	275,341	234,311	295,422	4237,350
Other[14]	10,293	11,111	12,078	r12,317	412,179
Total	1,107,063	1,202,006	1,132,232	1,191,838	41,013,343
Kazakhstan:[11] Electric furnace:					
Ferrosilicon	—	—	—	—	700,000
Ferrochromium	—	—	—	—	400,000
Ferrochromium-silicon	—	—	—	—	40,000
Other	—	—	—	—	20,000
Total	—	—	—	—	1,160,000
Korea, North: Electric furnace:					
Ferromanganese[6]	70,000	70,000	70,000	e70,000	70,000
Ferrosilicon	30,000	30,000	30,000	e30,000	30,000
Other[8]	20,000	20,000	20,000	e20,000	20,000
Total	120,000	120,000	120,000	e120,000	120,000
Korea, Republic of: Electric furnace:					
Ferromanganese	75,924	85,329	84,000	r94,893	95,000
Ferrosilicon	8,909	4,582	2,000	r—	55
Other	89,966	101,818	99,000	r74,173	74,000
Total	174,799	191,729	185,000	r169,066	169,055
Macedonia:[5] Electric furnace:					
Ferrochromium	—	—	—	—	6,000
Ferrochromium-silicon	—	—	—	—	2,000
Ferrosilicon	—	—	—	—	50,000
Silicon metal	—	—	—	—	3,000
Total	—	—	—	—	61,000
Mexico: Electric furnace:					
Ferromanganese	165,487	168,042	186,328	r147,000	150,000
Silicomanganese	80,223	98,852	r71,000	r67,000	70,000
Ferrosilicon	16,553	9,474	r7,000	r6,000	5,000
Ferrochromium	9,295	2,569	275	r72	70
Other	727	92	250	r105	300
Total	272,285	279,029	264,853	r220,177	225,370
New Caledonia: Electric furnace, ferronickel	146,300	142,500	126,500	r137,600	4127,600

See footnotes at end of table.

TABLE 21—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1988	1989	1990	1991	1992[e]
Norway: Electric furnace:					
Ferromanganese	361,345	220,591	213,266	173,212	[4]202,680
Silicomanganese	232,501	[r]270,305	[r]223,310	226,737	[4]213,106
Ferrosilicon	380,976	[r]398,744	397,520	377,455	[4]367,034
Silicon metal	88,854	100,194	76,601	[e]65,000	60,000
Ferrochromium[e]	—	—	[r]60,000	[r]83,000	[4]102,000
Other[9]	[e]14,000	[e]14,000	[e]14,000	[e]14,000	14,000
Total	[e]1,077,676	[e]1,003,834	[r e]984,697	[r e]939,404	958,820
Peru: Electric furnace:					
Ferromanganese	996	1,145	[e]900	[e]1,000	1,000
Ferrosilicon	625	281	[e]500	[e]600	600
Total	1,621	1,426	[e]1,400	[e]1,600	1,600
Philippines: Electric furnace:[e]					
Ferromanganese	—	—	—	[e]5,000	5,000
Ferrosilicon	—	9,000	10,000	[e]10,000	10,000
Ferrochromium	[r]73,000	[r]82,000	[r]56,000	[r 4]23,730	27,400
Total	[r]73,000	[r]91,000	[r]66,000	[r]38,730	42,400
Poland:					
Blast furnace:					
Spiegeleisen	1,078	906	140	[e]140	140
Ferromanganese	91,117	90,267	71,000	[r]57,400	50,000
Electric furnace:					
Ferromanganese[6]	3,400	1,427	5,400	[e]5,000	5,000
Ferrosilicon	58,700	83,210	88,600	[e]80,000	75,000
Silicon metal[e]	10,000	10,000	10,000	[4]9,000	9,000
Ferrochromium	36,316	24,300	13,700	[e]12,000	10,000
Other[e 8]	66,000	[4]60,718	[4]33,100	[4]30,000	25,000
Total[e]	266,611	270,828	221,940	[r]193,540	174,140
Portugal: Electric furnace:[e]					
Ferromanganese[15]	10,000	[4]13,170	[4]12,480	[4]12,000	10,000
Silicomanganese[15]	5,000	—	—	—	—
Ferrosilicon	—	—	—	—	—
Silicon metal	2,500	—	—	—	—
Total	17,500	[4]13,170	[e]12,480	12,000	10,000
Romania: Electric furnace:[e]					
Ferromanganese	80,000	80,000	80,000	70,000	50,000
Silicomanganese	40,000	40,000	40,000	20,000	15,000
Ferrosilicon	50,000	50,000	50,000	30,000	25,000
Silicon metal	4,500	4,500	4,500	3,000	2,000
Ferrochromium	[r]23,430	[r]26,849	[r]20,633	[r]20,380	[4]6,977
Total	[r]197,930	[r]201,349	[r]195,133	[r]143,380	98,977
Russia:[11]					
Blast furnace:					
Spiegeleisen	—	—	—	—	10,000
Ferromanganese	—	—	—	—	200,000
Ferrophosphorus	—	—	—	—	30,000
Ferrosilicon	—	—	—	—	500,000

See footnotes at end of table.

TABLE 21—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1988	1989	1990	1991	1992[e]
Russia—Continued:					
Electric furnace:					
Silicon metal	—	—	—	—	60,000
Ferrochromium	—	—	—	—	500,000
Ferrochromium-silicon	—	—	—	—	60,000
Ferronickel	—	—	—	—	35,000
Other	—	—	—	—	60,000
Total	—	—	—	—	1,455,000
Serbia and Montenegro:[5] Electric furnace:					
Ferronickel	—	—	—	—	12,000
Slovenia:[5] Electric furnace:					
Ferrochromium	—	—	—	—	[4]17,100
Ferrochromium-silicon	—	—	—	—	1,000
Ferrosilicon	—	—	—	—	15,000
Calcium-silicon	—	—	—	—	500
Other	—	—	—	—	5,000
Total	—	—	—	—	38,600
South Africa: Electric furnace:					
Ferromanganese	447,000	r394,000	404,000	r260,000	270,000
Silicomanganese	248,000	258,000	234,000	r235,000	242,000
Ferrosilicon	87,000	93,000	r78,000	r68,000	64,000
Silicon metal	39,000	36,000	r36,000	40,000	35,000
Ferrochromium[16]	993,685	r1,049,900	1,022,000	r1,126,700	[4]665,000
Other[e]	1,000	2,000	e1,000	1,000	1,000
Total[e]	r1,815,685	r1,832,900	r1,775,000	r1,730,700	1,277,000
Spain: Electric furnace:[e]					
Ferromanganese	48,000	50,000	52,220	50,000	50,000
Silicomanganese	38,000	40,000	38,440	40,000	40,000
Ferrosilicon	36,000	38,000	37,500	40,000	40,000
Silicon metal	10,700	11,500	9,000	9,000	10,000
Ferrochromium	r25,400	r29,000	r15,000	r6,000	—
Other	5,000	5,000	5,000	5,000	5,000
Total	r163,100	r173,500	r157,160	r150,000	145,000
Sweden: Electric furnace:					
Ferrosilicon	20,622	r20,996	r18,736	r21,145	22,000
Silicon metal[e]	r17,059	r13,421	r10,000	—	—
Ferrochromium	143,055	r153,800	r117,680	r120,884	130,000
Total	r180,736	r188,217	r146,416	r142,029	152,000
Switzerland: Electric furnace:[e]					
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
Taiwan: Electric furnace:					
Ferromanganese	25,822	30,623	43,631	40,110	41,000
Silicomanganese	30,745	26,510	20,587	12,801	4,800
Ferrosilicon	19,601	19,277	15,501	6,252	2,700
Total	76,168	76,410	79,719	59,163	48,500

See footnotes at end of table.

TABLE 21—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1988	1989	1990	1991	1992[e]
Turkey: Electric furnace:					
Ferrosilicon	5,200	4,970	5,225	r7,000	7,000
Ferrochromium	54,030	59,715	62,040	r84,651	4,5 85,755
Total	59,230	64,685	67,265	r91,651	92,755
Ukraine:[11]					
Blast furnace:					
Electric furnace:					
Spiegeleisen	—	—	—	—	5,000
Ferromanganese	—	—	—	—	250,000
Silicomanganese	—	—	—	—	1,000,000
Ferrosilicon	—	—	—	—	500,000
Ferronickel	—	—	—	—	10,000
Other	—	—	—	—	40,000
Total	—	—	—	—	1,805,000
U.S.S.R.:[17]					
Blast furnace:					
Spiegeleisen	18,000	18,000	17,000	e15,000	—
Ferromanganese	604,000	609,000	r281,000	r235,000	—
Ferrophosphorus	25,000	29,000	r30,000	r31,000	
Electric furnace:[e 18]					
Ferromanganese	4,5 453,500	4,5 414,100	410,000	370,000	—
Silicomanganese	1,300,000	1,300,000	1,300,000	1,100,000	—
Ferrosilicon	1,911,800	1,872,600	1,860,000	r1,600,000	—
Silicon metal	65,000	65,000	65,000	60,000	—
Ferrochromium	r1,050,000	r975,000	r975,000	r925,000	—
Ferrochromium-silicon	r100,000	r100,000	r100,000	r100,000	—
Ferronickel	90,000	90,000	90,000	85,000	—
Other	160,000	160,000	160,000	140,000	—
Total[e]	r5,777,300	r5,632,700	r5,288,000	r4,661,000	—
United Kingdom:					
Blast furnace, ferromanganese	107,300	140,400	143,400	r178,400	130,000
Electric furnace, other[e]	10,000	10,000	10,000	10,000	10,000
Total[e]	117,300	150,400	153,400	188,400	140,000
United States: Electric furnace:					
Ferromanganese[19]	W	W	W	W	W
Ferrosilicon	449,328	475,256	433,726	338,154	4,5 346,290
Silicon metal	149,094	136,531	140,792	145,275	4,5 158,550
Ferrochromium[20]	119,645	146,844	108,932	68,327	4,5 60,945
Ferronickel	—	682	7,333	14,251	4,5 18,167
Other	228,023	171,137	183,910	211,266	4,5 189,501
Total	946,090	930,450	874,693	777,273	4,5 773,453
Uruguay: Electric furnace, ferrosilicon[e]	250	250	250	250	250
Venezuela: Electric furnace:					
Silicomanganese	33,760	32,387	e30,000	e30,000	31,000
Ferrosilicon	51,363	54,873	e55,000	e55,000	56,000
Total	85,123	87,260	e85,000	e85,000	87,000

See footnotes at end of table.

TABLE 21—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1988	1989	1990	1991	1992[e]
Yugoslavia:[21] Electric furnace—Continued:					
Ferromanganese	45,078	33,868	31,822	e20,000	—
Silicomanganese	46,804	52,588	60,601	e50,000	—
Ferrosilicon	120,522	122,179	103,188	r e80,000	—
Silicon metal	25,830	15,897	12,661	e10,000	—
Ferrochromium	93,349	90,428	82,687	e60,000	—
Ferrochromium-silicon	3,688	3,815	4,199	e3,000	—
Ferronickel	15,047	17,102	11,850	e7,000	—
Calcium-silicon	772	144	835	e1,000	—
Other	10,678	11,199	10,462	e9,000	—
Total	361,768	347,220	318,305	e240,000	—
Zimbabwe: Electric furnace:					
Ferromanganese	e2,000	—	—	—	—
Ferrochromium	r190,200	r209,807	r211,850	r178,901	e186,255
Ferrochromium-silicon	29,000	25,000	16,612	r27,755	28,000
Total	r e221,200	r234,807	r228,462	r206,656	214,255
Grand total	r19,667,576	r20,171,190	r19,135,677	r17,834,562	16,915,182
Of which:					
Blast furnace:					
Spiegeleisen[22]	19,329	18,906	17,140	15,140	15,140
Ferromanganese[22 23]	r1,620,362	r1,730,962	r1,305,330	r1,260,800	1,120,000
Other	211,000	r189,000	200,000	201,000	210,000
Total blast furnace	r1,850,691	r1,938,868	r1,522,470	r1,476,940	1,345,140
Electric furnace:					
Ferromanganese[23 24]	r3,177,861	r3,077,096	r3,132,211	r2,633,262	2,540,921
Silicomanganese[23 25]	2,812,681	r2,943,665	r2,832,872	r2,609,185	2,584,666
Ferrosilicon	5,018,384	r5,159,650	r4,934,247	r4,438,596	4,460,698
Silicon metal	610,910	631,822	628,168	r579,077	549,150
Ferrochromium[26]	r3,799,538	r3,856,091	r3,626,395	r3,533,707	3,040,765
Ferrochromium-silicon	r144,634	r149,137	r132,784	r144,079	144,500
Ferronickel	r724,940	r754,504	r713,476	r792,653	689,545
Other	r1,527,937	r1,660,357	r1,613,054	r1,627,063	1,559,797
Total electric furnace	r17,816,885	r18,232,322	r17,613,207	r16,357,622	15,570,042

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

[1]Table includes data available through July 6, 1993.

[2]To 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.

[3]To 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, ferrochromium, ferrochromium-silicon, and ferronickel. Ferroalloys other than those listed that have been identified specifically in sources, as well as those ferroalloys not identified specifically but which definitely exclude those listed previously in this footnote have been reported as "Other." 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.

[4]Reported figure.

[5]Formerly part of Yugoslavia; data were not reported separately until 1992. Imports of ferronickel originating in Macedonia were reported in 1992, but information on the output of the Kavadarci operation was not available.

[6]Includes silicomanganese.

[7]Included with other.

[8]Includes ferrochromium-silicon and ferronickel, if any was produced.

[9]Includes silicospiegeleisen.

[10]Includes ferronickel if any was produced.

[11]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[12]Series excludes calcium silicide.

[13]Includes ferrochromium-silicon.

[14]Includes calcium-silicon, ferrotungsten, ferromolybdenum, ferrovanadium, ferrocolumbium, and other ferroalloys.

[15]Estimated figures based on reported exports and an allowance for domestic use.

[16]Includes production from Bophuthatswana. Includes net production of ferrochromium-silicon, if there was any.

[17]Dissolved in Dec. 1991.

[18]Soviet production of electric furnace ferralloys 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.

[19]U.S. output of ferromanganese includes silicomanganese and manganese metal.

[20]U.S. output of ferrochromium includes high- and low-carbon ferrochromium, ferochromium-silicon, chromium metal, and other chromium materials.

[21]Dissolved in Apr. 1992.

[22]Spiegeleisen for the Western states of Germany is included with blast furnace ferromanganese.

[23]Ferromanganese includes silicomanganese (if any was produced) for countries carrying footnote 6 on "Ferromanganese" data line.

[24]U.S. production under "Other" for 1988-92.

[25]Includes silicospiegeleisen for France.

[26]Ferrochromium includes ferrochromium-silicon (if any was produced) for Japan, Republic of South Africa, and United States.

IRON AND STEEL SCRAP

By Raymond E. Brown

Mr. Brown, a physical scientist with 37 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 Henry F. Sattlethight and Cindy S. Liu, Section of Metals Data.

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. Recycling of ferrous scrap also reduced the burden on limited landfill capacity. Direct-reduced iron (DRI), 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.

Brokers, dealers, and other outside sources supplied domestic consumers in 1992 with 41.8 million metric tons[1] of all types of ferrous scrap at a delivered value of approximately $3.90 billion, while exporting 9.26 million tons (excluding used rails for rerolling and other uses and ships, boats, and other vessels for scrapping) valued at $1.10 billion. In 1991, domestic consumers received 41.4 million tons (revised) at a delivered value of approximately $4.21 billion (revised); exports totaled 9.35 million tons valued at $1.23 billion. This represented a tonnage increase of about 1% for received quantities and a tonnage decrease of about 1% for exported quantities. The total value of these received and exported scrap grades decreased by 8% and 11%, respectively.

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 81% of the total consumption shown in table 2 for the three types of scrap consumers indicated. Consumption for 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 1% for manufacturers of pig iron and raw steel and castings, 1% for manufacturers of steel castings, 6% for iron foundries and miscellaneous users, and 2% average for all types of manufacturers combined. *(See table 1.)*

ANNUAL REVIEW

Legislation and Government Programs

According to the U.S. Nuclear Regulatory Commission, radioactivity in scrap metal will be a problem for the foreseeable future. There have been at least 11 reported smeltings of discrete radioactive sources in the United States since 1983. Cleanups have cost, on the average, more than $1 million for each event. Accidental smeltings of radioactive scrap was an international problem as well as a domestic one.[2]

Recycling old landfills, an unusual approach taken by the Lancaster County Solid Waste Management Authority in Lancaster County, PA, had paid significant dividends. Excavating the landfill and sending it to Lancaster County's waste-to-energy facility enabled the county to extract four elements of value from the waste stream. These included landfill space, energy, ferrous metals, and soil.[3]

On September 1, Westchester County officials in Westchester County, NY, made recycling mandatory for residents and businesses in this suburban area.[4]

The Environmental Protection Agency (EPA) published its proposed rule for coke oven emissions in December. The proposed national emission standards for hazardous air pollutants would amend section 112 of the Clean Air Act Amendments of 1990. The proposed rule, which was based on a series of negotiations among government, industry, and environmental groups, provided two methods of compliance for coke producers and steel companies with coke ovens.[5]

The Steel Manufacturers Association (SMA) urged Congress to consider a long-term solution to the national budget deficit by adopting a value added tax, rather than an energy tax, as a major alternative to personal and corporate income taxes. The American Iron and Steel Institute (AISI) stated that a Btu energy tax would hit energy intensive industries hardest and undermine the international competitiveness of the

United States.

On November 10, the U.S. Bureau of Mines and the American Metal Market (AMM) cosponsored a conference, "Challenges Facing Materials Recycling," in Washington, DC. The conference provided an opportunity to exchange information, to generate ideas on reducing waste as a means of conserving natural resources, and to explore new avenues by which the Bureau could contribute in this effort. Dr. Herschel Cutler, Executive Director of the Institute of Scrap Recycling Industries, Inc. (ISRI), presented the keynote address. Dr. Cutler provided an overview of the challenges facing materials recycling and methods that could be implemented for increased materials recycling. Dr. Cutler stated that environmental laws like the Resource Conservation and Recovery Act (RCRA) were equating recyclable materials with garbage and were doing little to stimulate markets for these materials.

The luncheon speaker at the U.S. Bureau of Mines-AMM conference, a congressional representative from Indiana, said that the metals industries could see a "greener" RCRA reauthorization bill in the upcoming session of Congress.[6] A special report, "Iron and Steel Scrap Prices in the United States Through 1991," was prepared for and distributed to attendees at the November 10 forum by the Bureau's iron and steel scrap specialist. The U.S. Bureau of Mines scrap prices study revealed that, based on constant 1987 dollar terms, the selling price of No. 1 heavy melting steel scrap in 1991 was about one-half of that in 1909. A summary of this report also had been published by AMM on October 29, 1992.[7]

In December, a representative of the Association of Home Appliance Manufactures (AHAM) stated that AHAM supported the EPA's proposed regulations governing service and disposal of equipment using chlorofluorocarbons (CFC's) and hydrofluorocarbons. However, an official of ISRI opposed the proposed rule on refrigerant recycling. According to ISRI, the EPA-proposed rule improperly placed the ultimate responsibility for CFC removal on the recycler.

ISRI complained of "unnecessary and burdensome regulations" that, in its opinion, could be cut or curtailed. First on the ISRI list was the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA or Superfund), which, according to ISRI, made no distinction between materials headed for recycling and those headed for disposal. ISRI also asked the EPA to make a distinction within the current RCRA law between items considered waste and those considered secondary materials.[8]

Available Supply, Consumption, and Stocks

Overall domestic demand for ferrous scrap in 1992 by the iron and steel and the ferrous castings industries, the major consumers of this raw material, increased about 4% compared with that of 1991. Because of continued weak demand worldwide for ferrous scrap in 1992, average annual prices for most scrap grades declined.

According to the Steel Can Recyling Institute (SCRI), Pittsburgh, PA, the recycling rate for steel cans jumped from 34% in 1991 to nearly 41% in 1992. More than 1 million tons of steel cans (about 14 billion containers) was recycled in 1992. SCRI had set a recycling goal for steel cans of 66% by 1995. When SCRI was established in late 1988, only 15% of the steel cans produced was being recycled. The Can Manufacturers Institute (CMI), Washington, DC, reported that about 35.1 billion steel cans were shipped in the United States in 1992, down slightly from 35.3 billion in 1991.

Three of the Keep America Beautiful, Inc. (KAB) affiliates that had worked to educate citizens about recycling as well as increase the volume of metals and materials recovered were honored with the 1992 Steel Recycling Award at KAB's annual meeting in Washington, DC. The winners were Keep San Antonio, TX, Beautiful; Indianapolis, IN, Clean City Committee; and Pitt County, NC, Clean Sweep. The award was jointly sponsored by KAB, Stamford, CT; the SCRI, Pittsburgh, PA; and the AISI, Washington, DC.

In September, German automaker BMW AG was awarded "Best Recycling Innovation In 1992" at the National Recycling Coalitions (NRC) annual conference in Boston, MA. One reason for the company being chosen as the winner was because of its two-step approach to recycling.

Proler International Corp. sold its Houston, TX, ferrous and nonferrous scrapyard to the U.S. subsidiary of Compagnie Francaise des Ferrailles (CFF), a large French scrap processor. Proler International had been experiencing financial problems for about 2 years since the shutdown of its Houston detinning plant and writeoff of the operation. The sale to CFF included only the 18-hectare (44-acre) Wallisville Road facility and not the other two wholly owned shredder processing facilities in El Paso, TX, and Kansas City, KS, that Proler had been trying to sell. The sale of the Houston operation indicated that Proler would be moving its corporate headquarters to another location.[9]

Nucor Corp., headquarted in Charlotte, NC, commissioned in August a second minimill equipped with a thin-slab caster and hot-strip mill for the production of steel sheets. The new $300 million steel mill complex, in Hickman, AR, had a production capability of about 1 million tons per year. The capacity of the new steel mill in Hickman, AR, combined with that of the Crawfordsville, IN, plant provided Nucor with an overall capacity of approximately 2 million tons per year of hot-rolled steel sheets at yearend 1992. Also, Nucor and Oregon Steel Mills, Inc., planned to build a 1-million-ton-per-year thin-slab sheet minimill in the Western United States. Both companies signed a letter of intent at yearend for the construction and operation of the $350 million joint-venture plant, which would be 60% owned by Nucor. The new mill could start producing by late 1995. The partners were also assessing the addition

of virgin ironmaking facilities to feed the new minimill, including DRI and iron carbide. By the end of the 1990's, Nucor envisioned operating four flat-rolled minimill steel plants with a combined annual capacity of about 8 million tons. Each plant would have an annual capacity of about 2 million tons.

USX Corp., headquartered in Pittsburgh, PA, ceased producing structural and piling products when its Southworks in Chicago, IL, was closed in April 1992. The permanent closure brought an end to the plant's 112 years of steelmaking operations. The three electric furnaces at Southworks had been major consumers of ferrous scrap.

Co-Steel Inc., Toronto, Ontario, Canada, was also considering building a 0.8- to 1-million-ton-per-year thin-slab, flat-rolled minimill in the United States. Construction of the proposed U.S.-based facility could start in 1993. Thin-slab technology also was being assessed by some integrated steel producers.

Stafford Railsteel Corp., Charlotte, NC, a newly formed company, would construct a 450,000-ton-per-year greenfield plant to produce rails. A startup date of mid-1994 for the $105 million investment was targeted.[10]

There was no raw steel produced in U.S. open-hearth furnaces in 1992. The last open-hearth shop, owned by Geneva Steel Co., Provo, UT, switched from open-hearth to basic oxygen steelmaking in 1991.

Japanese minimill steel producer Kyoei Steel Ltd., Osaka, planned to acquire Florida Steel Corp.'s parent company, FLS Holdings, Inc., in a stock purchase deal valued at $53.5 million. Completion of the transaction was conditional, which included the purchase by Kyoei of 90% of Florida Steel's debentures.[11]

By the end of fiscal year 1993, Birmingham Steel Corp., headquartered in Birmingham, AL, planned to complete a $79 million program to modernize and upgrade four minimill steel plants in Birmingham, AL, Jackson, MS, Kankakee, IL, and Seattle, WA (Salmon Bay). Birmingham continued to evaluate new minimill technologies such as thin-slab and strip casting.

As part of a $42 million upgrade, New Jersey Steel Corp., Sayreville, NJ, decided to retrofit its existing electric arc furnace (EAF) with a Consteel continuous feeding and preheating system. The Consteel system used furnace offgas to preheat the scrap, which should save an estimated $10 per ton on steel production. Startup was scheduled for February 1994. Other modernizations planned for the Sayreville plant included buying a new caster, melt shop, and pollution control system and renovating the melt shop's infrastructure.

North Star Steel Co., headquartered in Minneapolis, MN, was considering building a 300,000- to 500,000-ton-per-year minimill in the Western United States for the production of rebar and wire rods. A decision to enter into a joint venture with Cleveland Cliffs Inc. was pending.

BMW of North America named three auto dismantlers that would participate in its pilot automobile recycling program in the United States. The recycling program was a cooperative effort between BMW and the Automotive Dismantlers and Recyclers Association (ADRA). Also, the Big Three domestic automakers combined their efforts and formed the Vehicle Recycling Partnership (VRP) to research and promote the recovery and reuse of materials from junked cars. Similar automotive recycling programs were active in Europe. Applications for stainless steel in North American-built cars and trucks were expected to increase again in the 1993 model year as a result of the automobile industry's strategy to improve the performance, durability, and fuel efficiency of its vehicles.

The Chicago Board of Trade (CBOT), Chicago, IL, still hoped to offer futures contracts for two grades of ferrous scrap and was reexamining the financial and bonding requirements that were said to pose the biggest hurdles to the trading scheme. The futures contracts for shredded scrap and No. 1 dealer bundles were to be a part of CBOT's Project A, an electronic trading system that began operating in October 1992. The CBOT board might offer a revised version of the scrap futures trading scheme by late February 1993.

Imports of metallurgical-grade coke increased 58% in 1992 to 1,578,000 tons compared with those of 1991. Metallurgical coke imports represented 7% of domestic apparent consumption in 1992 compared with 5% in 1991. The United States continued as a net importer of metallurgical coke. Domestic coal consumption in coke plants decreased 4% in 1992 to 29.4 million tons. Domestic metallurgical coal exports decreased 8% in 1992 to 53.9 million tons compared with those of 1991.

Raw steel production was 84.3 million tons in 1992 compared with 79.7 million tons in 1991. The shares of raw steel produced by electric, basic oxygen, and open-hearth furnaces were, respectively, 38%, 62%, and 0% in 1992 and 38%, 60%, and 2% in 1991. Continuous cast steel production represented 79% of total raw steel production in 1992 compared with 76% in 1991. Raw steel capacity utilization was 82% in 1992 and 75% in 1991. Raw steel production capability was 102.6 million tons in 1992 compared with 106.7 million tons in 1991.

Net shipments of all grades of steel mill products were 74.6 million tons in 1992 and 71.5 million tons in 1991. Imports of steel mill products increased from 14.4 million tons in 1991 to 15.5 million tons in 1992. Exports of steel mill products decreased from 5.76 million tons in 1991 to 3.89 million tons in 1992. The U.S. apparent supply of steel mill products increased from 80.1 million tons in 1991 to 86.2 million tons in 1992. Imports of steel mill products, as a share of the U.S. market, were 18% in both 1991 and 1992. Estimated steel mill processing yields [(total net shipments of steel mill products/total raw steel production) (100)] decreased from 90% in 1991 to 88% in 1992. Pig iron production increased from 44.1 million tons in 1991 to 47.4 million tons in 1992.

Iron castings shipments totaled 7.34 million tons in 1992 compared with 6.95 million tons (revised) in 1991. Steel castings shipments (including investment castings) totaled 0.93 million tons in 1992 compared with 0.90 million tons (revised)

in 1991.

In 1992, 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 1992, in million tons, was composed of 41.6 net receipts (total receipts minus shipments), 22.0 home scrap, and 0.4 withdrawals from stocks. The 1992 total was 64.0 million tons; the apparent total domestic consumption was 62.4 million tons (revised) in 1991. The total market for U.S. scrap (net receipts plus exports minus imports) was 49.6 million tons in 1992 compared with 48.7 million tons (revised) in 1991. Stocks of ferrous scrap at yearend 1992 held by both steel mills and iron foundries decreased while those held by steel foundries increased. *(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 $84.67 in 1992, ranging from a low of $82.67 in November to a high of $87.24 in April. Based on Iron Age data, also converted to metric tons, No. 1 heavy melting steel scrap cost $83.88 in 1992, ranging from $82.21 in November to $86.65 in December. The average composite price for No. 1 heavy melting steel scrap in 1992 was lower compared with that of 1991, by 8% based on AMM data and by 9% based on 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 14%, from $861.28 per ton in 1991 to $742.56 per ton in 1992.

In 1992, 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 10% to $118.74 per ton compared with that of 1991, while that of total imports decreased 16% to $112.20 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 1992 for all classes of ferrous scrap (including used rails for rerolling and other uses and ships, boats, and other vessels for scrapping) was $950 million in value and 8.0 million tons in quantity. This represented a decrease of 13% in value and 4% in quantity compared with the 1991 surplus of $1.09 billion in value and 8.3 million tons in quantity. The balance of trade for all U.S. merchandise [exports (f.a.s.) less imports (customs value)] showed a deficit of $84.3 billion in 1992, up from a deficit of $65.4 billion in 1991.

The quantity and value of total exports in 1992 declined by 1% and 11%, respectively, compared with those of 1991. In contrast, the quantity and value of total imports in 1992 increased by 19% and 3%, respectively, compared with those of 1991.

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 1992 went to 52 countries and totaled 8,709,768 tons valued at $881,952,004 for an average of $101.26 per ton. Six countries received 83% of the total quantity. The largest tonnages went to Turkey, 2,018,666 tons; the Republic of Korea, 2,000,927 tons; India, 1,235,968 tons; Canada, 1,012,893 tons; Mexico, 533,015 tons; and Taiwan, 456,600 tons. The value of scrap exports to these six countries was $711,099,299, 81% of the total value.

Total U.S. exports of stainless steel scrap in 1992 went to 34 countries and consisted of 223,200 tons valued at $153,701,762 averaging $688.63 per ton. Six countries received 90% of the total quantity. The largest tonnages went to the Republic of Korea, 64,588 tons; Japan, 56,787 tons; Spain, 41,406 tons; Canada, 22,420 tons; Italy, 7,913 tons; and Taiwan, 7,449 tons. The value of stainless steel scrap exports to these six countries was $137,695,695, 90% of the total value.

U.S. exports of alloy steel scrap (excluding stainless steel) in 1992 were shipped to 40 countries. The total comprised 328,984 tons valued at $64,148,317, for an average of $194.99 per ton. Six countries received 86% of the total quantity. The largest tonnages went to Canada, 127,370 tons; Hong Kong, 71,007 tons; Mexico, 32,031 tons; China, 30,778 tons; Republic of South Africa, 11,683 tons; and Japan, 10,750 tons. The value of alloy steel scrap to these six countries was $49,149,355, which was 77% of the total value.

In 1992, based on tonnage of iron and steel scrap by customs district, Los Angeles, CA, was the leading customs district for exports, accounting for 16% of the total exports. New York, NY, followed with 15%, and San Francisco, CA, with 11%. Laredo, TX, was the leading customs district for reexports, accounting for 68% of the total reexports. New York, NY, followed with 10%, and Los Angeles, CA, with 10%. Detroit, MI, was the leading customs district for imports, accounting for 29% of the total imports. Seattle, WA, followed with 25%, and Buffalo, NY, with 9%. For more details on customs districts, including tonnages and values, refer to published data in U.S. Bureau of Mines Mineral Industry Surveys on iron and steel scrap.[12]

Total U.S. imports for consumption of iron and steel scrap, which were supplied by 37 countries in 1992, contained 28,494 tons of tinplate waste or scrap valued at $7,062,603.

World Review

World demand for iron and steel scrap in 1992 was estimated to have decreased by 2% compared with that of 1991. However, demand for ferrous scrap in 1992 increased in certain major steel-

producing countries. These included industrialized countries such as Australia, Canada, Finland, the Netherlands, Sweden, Turkey, and the United States; Asian countries, such as China, India, Indonesia, and the Republic of Korea; Latin American countries, such as Brazil, Mexico, and Venezuela; and Middle Eastern countries, such as Iran and Saudi Arabia.

The United States continued to be the leading exporting country of iron and steel scrap. France, Germany, the Netherlands, Russia, and the United Kingdom were also major exporters of ferrous scrap.

European Community (EC) member states would be given 10 years to raise the EC packaging recovery rate from about 18% to 90% under a plan proposed by the EC. Details of the proposal, which must win approval by the EC's Council of Ministers, showed individual EC countries would have wide latitude in determining how the goal would be met on a national level. The aim was to cut a large share of the 50 million tons of packaging waste generated annually in the EC that was burned or sent untreated to landfills.[13]

The Bureau International de la Recuperation (BIR), Brussels, Belgium, supported various events such as roundtable discussions of policies governing the recycling of cars, packaging, and agricultural products in Europe. The BIR had encouraged more emphasis on the recycling of industrial waste and less on municipal waste.

The BIR and Greenpeace International, Washington, DC, continued not to agree on an accord on what constitutes hazardous waste. In a letter made available to the press, the BIR reiterated the scrap industry's support for the so-called red-yellow-green system that was devised by the Organization for Economic Cooperation and Development (OECD), Paris, France. The OECD defined scrap and waste products and outlined plans for monitoring or controlling cross-border shipments of the most hazardous of these materials. The system was devised as a means of complying with the Basel Convention, an international treaty designed to limit the shipments of hazardous wastes from the industrial countries to the world's less-developed nations. Greenpeace had opposed the OECD plan and instead had demanded that the definitions specified in the Basel Convention be applied by those who monitor trade in scrap and waste materials.

Officials of the International Iron and Steel Institute (IISI), Brussels, Belgium, invited executives of some of the largest electric furnace steel producers (minimills) to join IISI's trade organization. IISI's Secretary General disclosed during a report to delegates at the start of IISI's 26th annual meeting in Tokyo, Japan, that officials of the Institute had attempted to bring into the organization companies such as North Star Steel Co. and Birmingham Steel Corp., two of North America's biggest minimills. IISI projected that world steel usage would increase by about 32 million tons to 686 million tons by the year 2000.

According to the supplies director of the Gerdau minimill steel works group, Brazil's high port costs would have to be reduced before imported steel scrap could become a viable proposition for Brazilian electric steelmakers. Delegates at a seminar on scrap in Sao Paulo in October noted that the Government's port reform bill, which would deregulate the ports and clear the way for more competitive practices, was working its way through Congress and was expected to become law.[14]

Because of the success of a pilot project in three Ontario, Canada, communities, Ontario Hydro would expand its refrigerator recycling program provincewide at a cost of $27 million. Ontario Hydro was targeting secondary, operating refrigerators. Some second refrigerators had been sitting in basements, taking up space, and wasting electricity. Under the program, the electric utility would remove unwanted refrigerators and pay the owners $50, regardless of the refrigerator's condition.

China's economy, one of the fastest growing in the world, expanded at a rate of about 13% in 1992, far exceeding Government targets designed to keep down inflation. Raw steel production in China was 80.0 million tons in 1992 compared with 71.0 million tons in 1991.

In December, France's environmental minister planned to call for new regulations that would require all major consumer appliances sold throughout the EC to be completely recyclable within 10 years. The French Environmental Minister had announced plans earlier in the year to establish a system to process packaging waste similar to the programs Germany had pursed for the past 2 years. France's two major automakers, PSA Peugeot Citroen SA and state-owned Renault SA, had decided to work together to develop a system that would recycle up to 200 junked cars per day.

A joint venture between German steel and scrap group Klockner Kunstoff-und Automobilrecycling GmbH (KKA) and Kriesow, Germany's largest auto dismantler, to disassemble 25,000 cars annually was expected to begin in 1993. The joint venture was the first of KKA's overall plan for as many as 20 facilities around Germany in partnership with local dismantlers to process about one-half million autos per year. The first plant would be built in Hamburg, Germany, at a cost of about $9.4 million, shared equally between KKA and Kriesow.[15] Germany's Environmental Minister proposed a regulation that would require automakers to take back old cars that were no longer roadworthy. Metallgesellschaft AG, a German metals conglomerate, had formed a new unit for recycling in Australia and Southeast Asia. A German scrap recycler, a German aerospace company, and consortium of Russian defense companies had entered into a cooperative agreement to dismantle and recycle 1.6 million tons of Russian munitions.

The Indian steel ministry had taken a determined stand against the demands of DRI producers to increase the import duty on ferrous scrap. The duty on ferrous scrap imports had been cut from 35% to 10% about 1 year ago.[16] However, tariffs on Indian imports of ships for breaking were 15% in 1992, 5% higher than those for ferrous scrap imports.

Because increased volumes of ferrous scrap had been generated at home, Japan became a net exporter of ferrous scrap for the first time in 1992. Shipments of ferrous scrap to Japan had fallen off sharply during the second half of 1991 and throughout much of 1992. About 50% in volume of all steel cans produced in Japan had been recycled in 1991, up from about 45% in 1990.

An 800,000-ton-per-year direct-current (DC) EAF thin-slab casting flat product mill complex was to be installed in Monterrey, Mexico, by Hojalata Lamina SA de CV (Hylsa). Startup of the $400 million facility was scheduled for early 1995. The 150-ton DC furnace would be charged with DRI made from Hylsa's proprietary HYL technology.[17] The privatization program, under which the Mexican Government had been selling some of its industrial interests, was completed for the Mexican steel industry in 1991.

Much of what the Soviet Army left behind in eastern European cities and towns where its troops once were garrisoned may end up in local scrap yards. According to a report from the Polish press agency, residents who lived near an abandoned base in western Poland sifted through what remained at the site and sold it. The cache included 40 tons of artillery shells, missiles, and bombs.[18]

Pohang Iron and Steel Co. Ltd. (POSCO), headquartered in Pohang, the Republic of Korea, ordered a 600,000- to 700,000-ton-per-year Corex unit for its Pohang steelworks. The Corex hot-metal facility at Pohang would have doubled the capacity of the plant in operation at Iscor Ltd.'s works in the Republic of South Africa.

Russia was granted most-favored-nation status for trade relations with the United States on June 17, 1992.[19] The Russian metallurgical industry was characterized by a low share of advanced steelmaking methods. Of the total raw steel produced in Russia, basic oxygen furnaces and electric furnaces accounted for less than 50% and continuous casting amounted to only 18%.

Independent steel producers in Spain asked the state-owned Ensidesa-AHV group to close down its long products operations as part of a restructing plan that was being discussed. The minimill federation Siderinsa had called for negotiations to eliminate the overlap in wire rod and heavy sections between Ensidesa and the private-sector producers.

A 77-ton shipload of scrap metals contaminated with radioactive material returned to Russia. Swedish customs officials had discovered the hot metal aboard a ship that had carried scrap exported from Estonia. The contaminated metals had originated within Russia.[20]

Contaminated ferrous scrap imported into Taiwan in the early 1980's reportedly was the source of radiation found in three buildings in Taipei. Taiwan's Atomic Energy Council found contaminated steel reinforcing bars in the structure of an office building and two apartment buildings in the capital city.[21]

The United States continued to be Turkey's major supplier of ferrous scrap. However, the U.S. competitive position had eroded from providing Turkey with 70% of all iron and steel scrap imports in 1989 to just 45% in 1992. The United States was still the largest supplier of ferrous scrap to Turkey in 1992 but the Netherlands had rapidly become a serious competitor.

The United Kingdom's first dedicated car dismantling and recycling plant was opened by German automaker BMW AG and Bolney Motors, a British salvage company. The joint venture was the first of 15 similar partnerships that BMW hoped to make with British salvagers over the next 3 years, each capable of processing 2,500 vehicles. The BMW-Bolney plant would follow a reverse auto assembly line approach to dismantle vehicles, with as many components as possible resold through Bolney's established used-parts business. British steel mills consumed less scrap but more iron ore and pig iron in 1991 than in the past. The level of circulating scrap generated by the British steel industry had been declining since 1981 as a result of continuous casters taking a larger share of steel production capacity.

Current Research

Since 1985, EAF's had produced 36% to 38% of the nearly 80 to 90 million tons of raw steel produced annually in the United States. A review of EAF technologies, equipment, charge materials, and operating practices with respect to optimizing energy use was published by the Center for Materials Production (CMP), Pittsburgh, PA. The report was designed to provide operators and utility personnel with an understanding of the factors that impacted the use of electrical energy. Such an understanding would be supportive of the continued upward trend of EAF steel production as a percentage of the domestic total.[22] CMP also had sponsored a major symposium on EAF dust treatment technologies in Pittsburgh, PA, on January 28.

Cyprus Northshore Mining Co. planned to start building a 450,000-ton-per-year direct reduction iron plant at its Silver Bay, MN, taconite facility in 1993. Cyprus planned to use Midrex's Fastmet technology, which used coal as a reductant, for its initial $50 million plant that would begin production in late 1995. Three additional 450,000-ton-per-year iron furnaces also had been on the drawing board.[23]

Nucor would build the world's first commercial-scale iron carbide plant in Trinidad and Tobago and ship the iron units to the United States to feed its steel mills. The U.S. minimill steelmaker would spend $60 million to build a 300,000-ton-per-year single-module facility that could be significantly expanded in future years. Construction was expected to begin by the end of March 1993 with startup anticipated in late 1994. Nucor would use the iron units to supplant a portion, about 15%, of the low residual scrap consumed at its sheet mills in Crawfordsville, IN, and Hickman, AR. With combined annual steelmaking capacity at those two plants at about 2 million tons, iron carbide requirements would be about 300,000 tons per year.

A new system for recovering nonferrous metals from shredder fluff

began operation at The David J. Joseph Co.'s, Tampa, FL, processing yard. The nonferrous metal recovery system, which employed eddy current magnets, would remove virtually all of the nonferrous metals from the residue left by auto shredders, according to the manufacturer of the system.[24]

According to the Gas Research Institute, Chicago, IL, experiments conducted at Armco Steel Co., L.P.'s, Middletown, OH, Works No. 3 blast furnace showed natural gas could replace 25% or more of the coke burden and yield a net savings of about $5 per ton of hot metal. The experiments, which had been done over a 2-year period, showed that charging natural gas at a rate of 97 kilograms per metric ton of hot metal yielded a savings of 25% of the coke normally charged and increased productivity by 10%.

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.

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 increase from 49.6 million tons in 1992 to approximately 53 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 EAF's; 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.

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[1]All quantities are in metric tons unless otherwise specified.

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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)

	1988	1989	1990	1991	1992
Stocks, Dec. 31:					
Scrap at consumer plants	4,131	4,213	4,433	r4,106	3,726
Pig iron at consumer and supplier plants	188	276	169	r194	184
Total	4,319	4,489	4,602	r4,300	3,910
Consumption:					
Scrap[1]	69,692	65,507	70,451	r62,884	65,261
Pig iron[2]	53,567	52,968	51,100	r44,911	48,098
Exports:					
Scrap[3]	9,161	11,149	11,580	9,345	9,262
Value	$1,351,955	$1,748,643	$1,635,218	$1,232,845	$1,099,802
Imports for consumption:					
Scrap (includes tinplate and terneplate)[3]	942	1,016	1,309	1,073	1,316
Value	$133,577	$149,109	$171,510	$142,552	$147,616

rRevised.

[1]Internal evaluation indicates that scrap consumption by manufacturers of pig iron and raw steel and castings is understated by the following approximated quantities: 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; 2.8 million metric tons in electric furnaces in 1991; and 3.5 million metric tons in electric furnaces in 1992.

[2]Internal 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.

[3]Excludes 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 1992, 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	361	2	390	—	797	4	44
Cut structural and plate	1,961	87	523	60	2,598	83	155
No. 1 heavy melting steel	5,747	1,182	5,835	369	11,318	1,967	610
No. 2 heavy melting steel	3,678	111	645	9	4,564	10	333
No. 1 and electric-furnace bundles	4,444	427	850	2	5,406	470	327
No. 2 and all other bundles	1,192	17	83	—	1,335	(1)	75
Electric furnace, 1 foot and under (not bundles)	13	217	163	—	362	36	4
Railroad rails	339	20	18	—	379	(1)	27
Turnings and borings	1,241	3	89	—	1,325	13	71
Slag scrap (Fe content 70%)	1,059	201	2,090	1	2,818	560	114
Shredded or fragmentized	5,119	840	18	—	6,064	5	364
No. 1 busheling	2,018	125	100	(1)	2,180	66	154
All other carbon steel scrap	2,993	323	3,695	92	6,381	785	220
Stainless steel scrap	531	18	406	—	950	11	51
Alloy steel (except stainless)	115	104	505	—	691	27	85
Ingot mold and stool scrap	54	91	239	245	429	196	112
Machinery and cupola cast iron	41	(1)	5	—	43	3	3
Cast-iron borings	96	—	(1)	(1)	104	1	4
Motor blocks	—	—	—	—	—	—	—
Other iron scrap	306	31	521	3	651	237	84
Other mixed scrap	563	68	431	1	905	147	104
Total[2]	31,873	3,866	16,607	783	[3]49,300	4,622	2,941
MANUFACTURERS OF STEEL CASTINGS							
Carbon steel:							
Low-phosphorus plate and punchings	546	—	153	1	715	(1)	36
Cut structural and plate	223	12	38	(1)	268	—	33
No. 1 heavy melting steel	114	1	77	(1)	181	1	14
No. 2 heavy melting steel	147	1	3	—	157	(1)	10
No. 1 and electric furnace bundles	7	—	—	—	7	—	2
No. 2 and all other bundles	6	(1)	—	—	6	—	(1)
Electric furnace, 1 foot and under (not bundles)	57	9	—	—	65	—	4
Railroad rails	86	—	—	—	85	—	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 1992, 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	22	—	12	—	30	4	2
Slag scrap (Fe content 70%)	1	—	2	—	4	—	4
Shredded or fragmentized	81	7	(1)	—	86	—	2
No. 1 busheling	95	—	—	—	96	—	6
All other carbon steel scrap	312	2	291	(1)	577	(1)	40
Stainless steel scrap	27	(1)	18	—	54	(1)	8
Alloy steel (except stainless)	77	—	136	—	200	5	56
Ingot mold and stool scrap	—	—	—	(1)	(1)	(1)	(1)
Machinery and cupola cast iron	43	—	8	—	51	—	3
Cast-iron borings	66	1	13	—	55	—	4
Motor blocks	(1)	—	—	—	(1)	—	—
Other iron scrap	23	—	45	—	58	4	13
Other mixed scrap	1	—	11	—	11	—	(1)
Total[2]	1,933	32	806	2	2,707	13	238
IRON FOUNDRIES AND MISCELLANEOUS USERS							
Carbon steel:							
Low-phosphorus plate and punchings	1,058	32	126	(1)	1,226	1	44
Cut structural and plate	1,097	11	26	(1)	1,159	(1)	47
No. 1 heavy melting steel	158	22	89	—	202	69	29
No. 2 heavy melting steel	153	(1)	169	—	219	104	3
No. 1 and electric-furnace bundles	104	175	16	—	296	—	4
No. 2 and all other bundles	158	(1)	—	—	161	—	8
Electric furnace, 1 foot and under (not bundles)	52	4	1	—	57	—	1
Railroad rails	172	—	2	—	174	2	12
Turnings and borings	263	23	2	—	295	2	27
Slag scrap (Fe content 70%)	40	—	3	—	40	3	1
Shredded or fragmentized	969	69	—	—	1,680	(1)	36
No. 1 busheling	415	114	24	—	605	(1)	17
All other carbon steel scrap	403	(1)	15	—	425	—	29
Stainless steel scrap	10	—	8	—	17	—	5
Alloy steel (except stainless)	26	—	3	—	30	(1)	10
Ingot mold and steel scrap	136	10	85	2	256	(1)	7
Machinery and cupola cast iron	953	205	219	26	1,424	3	97
Cast-iron borings	471	110	65	—	647	3	38

See footnotes at end of table.

TABLE 2—Continued

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF IRON AND STEEL SCRAP IN 1992, 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 USERS—Continued							
Carbon steel—Continued:							
Motor blocks	393	40	518	—	958	11	29
Other iron scrap	489	31	2,021	28	2,568	12	55
Other mixed scrap	438	1	375	1	819	18	46
Total[2]	7,957	849	3,767	57	13,255	229	547
TOTAL—ALL TYPES OF MANUFACTURERS							
Carbon steel:							
Low-phosphorus plate and punchings	1,965	34	669	1	2,738	5	124
Cut structural and plate	3,281	110	587	60	4,025	83	235
No. 1 heavy melting steel	6,019	1,205	6,001	369	11,701	2,037	653
No. 2 heavy melting steel	3,978	112	817	9	4,940	114	346
No. 1 and electric-furnace bundles	4,555	602	866	2	5,709	470	333
No. 2 and all other bundles	1,356	17	83	—	1,502	(1)	83
Electric furnace, 1 foot and under (not bundles)	122	230	164	—	484	36	9
Railroad rails	597	20	20	—	638	2	41
Turnings and borings	1,526	26	103	—	1,650	19	100
Slag scrap (Fe content 70%)	1,100	201	2,095	1	2,862	563	119
Shredded or fragmentized	6,169	916	18	—	7,830	5	402
No. 1 busheling	2,528	239	124	(1)	2,881	66	178
All other carbon steel scrap	3,708	325	4,001	92	7,383	785	289
Stainless steel scrap	568	18	432	—	1,021	11	63
Alloy steel (except stainles2s)	218	104	644	—	921	32	151
Ingot mold and steel scrap	190	101	324	247	685	196	119
Machinery and cupola cast iron	1,037	205	232	26	1,518	6	103
Cast-iron borings	633	111	78	(1)	806	4	46
Motor blocks	393	40	518	—	958	11	29
Other iron scrap	818	62	2,587	31	3,277	253	151
Other mixed scrap	1,002	69	817	2	1,735	165	150
Total[2]	41,764	4,747	21,180	841	65,261	4,865	3,726

[1]Less than 1/2 unit.

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

[3]Internal evaluation reveals that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 3.5 million metric tons.

TABLE 3

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF IRON AND STEEL SCRAP IN 1991, BY GRADE[1]

(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	457	—	3	—	446	1	37
Cut structural and plate	1,918	106	339	13	2,358	54	144
No. 1 heavy melting steel	6,466	294	6,501	427	11,782	1,880	810
No. 2 heavy melting steel	3,577	129	611	2	4,493	6	306
No. 1 and electric-furnace bundles	4,767	222	701	2	5,085	589	507
No. 2 and all other bundles	1,091	23	71	—	1,179	(2)	57
Electric furnace, 1 foot and under (not bundles)	14	215	(2)	—	231	—	10
Railroad rails	280	17	23	2	334	2	27
Turnings and borings	1,080	4	118	—	1,201	8	67
Slag scrap (Fe content 70%)	1,076	220	2,154	1	2,935	494	135
Shredded or fragmentized	4,770	877	19	—	5,616	—	330
No. 1 busheling	1,837	125	97	(2)	1,978	35	154
All other carbon steel scrap	3,138	177	3,753	28	6,238	794	259
Stainless steel scrap	510	19	378	—	913	3	52
Alloy steel (except stainless)	124	92	502	—	672	8	92
Ingot mold and stool scrap	93	97	216	265	515	177	129
Machinery and cupola cast iron	36	(2)	4	—	37	2	5
Cast-iron borings	144	—	(2)	(2)	132	8	13
Motor blocks	—	—	—	—	—	—	—
Other iron scrap	189	37	448	1	439	262	70
Other mixed scrap	408	70	182	—	639	17	85
Total[3]	31,976	2,724	16,121	740	[4]47,224	4,342	3,289
MANUFACTURERS OF STEEL CASTINGS							
Carbon steel:							
Low-phosphorus plate and punchings	537	—	129	—	689	—	37
Cut structural and plate	254	12	37	—	301	4	35
No. 1 heavy melting steel	124	1	81	1	194	1	14
No. 2 heavy melting steel	147	1	3	—	157	—	10
No. 1 and electric-furnace bundles	10	—	—	—	9	—	2
No. 2 and all other bundles	6	—	—	—	6	—	—
Electric furnace, 1 foot and under (not bundles)	57	9	—	—	65	—	4
Railroad rails	66	—	1	—	66	—	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 1991, BY GRADE[1]

(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	16	—	17	—	29	4	2
Slag scrap (Fe content 70%)	1	—	2	—	3	—	—
Shredded or fragmentized	71	7	—	—	76	—	2
No. 1 busheling	67	—	—	—	68	—	6
All other carbon steel scrap	304	2	301	2	601	—	24
Stainless steel scrap	27	1	30	—	65	—	10
Alloy steel (except stainless)	73	—	147	—	206	4	56
Ingot mold and stool scrap	—	—	—	—	—	—	—
Machinery and cupola cast iron	41	—	8	—	49	—	3
Cast-iron borings	66	—	17	—	58	—	5
Motor blocks	—	—	—	—	—	—	—
Other iron scrap	24	2	51	—	70	6	11
Other mixed scrap	1	—	11	—	11	—	—
Total[3]	1,891	34	833	4	2,723	19	222
IRON FOUNDRIES AND MISCELLANEOUS USERS							
Carbon steel:							
Low-phosphorus plate and punchings	970	29	116	—	1,125	—	44
Cut structural and plate	1,073	15	23	—	1,139	—	52
No. 1 heavy melting steel	101	20	27	—	141	5	27
No. 2 heavy melting steel	138	—	245	—	208	182	4
No. 1 and electric-furnace bundles	98	177	13	—	287	—	5
No. 2 and all other bundles	106	—	1	—	110	—	9
Electric furnace, 1 foot and under (not bundles)	50	5	8	—	60	—	2
Railroad rails	198	—	2	—	196	2	12
Turnings and borings	349	38	4	—	384	2	41
Slag scrap (Fe content 70%)	42	—	4	—	42	4	2
Shredded or fragmentized	957	38	—	—	1,630	—	39
No. 1 busheling	414	94	15	—	573	—	15
All other carbon steel scrap	383	6	14	—	406	—	30
Stainless steel scrap	6	—	8	—	12	—	4
Alloy steel (except stainless)	22	—	2	—	24	—	10
Ingot mold and stool scrap	164	21	125	1	305	—	27
Machinery and cupola cast iron	908	204	246	26	1,390	3	106
Cast-iron borings	392	91	66	—	542	6	36
Motor blocks	349	45	509	—	904	11	35

See footnotes at end of table.

TABLE 3—Continued

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF IRON AND STEEL SCRAP IN 1991, BY GRADE[1]

(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 USERS—Continued							
Carbon steel—Continued:							
Other iron scrap	488	14	2,192	1	2,702	13	58
Other mixed scrap	325	10	395	1	756	14	40
Total[3]	7,534	809	4,014	29	12,937	243	596
TOTAL—ALL TYPES OF MANUFACTURERS							
Carbon steel:							
Low-phosphorus plate and punchings	1,964	29	248	—	2,259	1	117
Cut structural and plate	3,246	134	399	13	3,797	59	231
No. 1 heavy melting steel	6,691	315	6,609	427	12,117	1,886	852
No. 2 heavy melting steel	3,862	131	859	2	4,859	188	319
No. 1 and electric-furnace bundles	4,874	399	714	2	5,381	589	514
No. 2 and all other bundles	1,203	23	72	—	1,295	—	67
Electric furnace, 1 foot and under (not bundles)	121	229	9	—	356	—	16
Railroad rails	544	17	26	2	596	4	40
Turnings and borings	1,445	42	139	—	1,614	14	111
Slag scrap (Fe content 70%)	1,118	220	2,160	1	2,980	498	136
Shredded or fragmentized	5,798	922	19	—	7,322	—	371
No. 1 busheling	2,318	218	112	—	2,619	35	175
All other carbon steel scrap	3,825	184	4,068	30	7,244	794	314
Stainless steel scrap	543	19	416	—	990	3	66
Alloy steel (except stainless)	220	92	651	—	903	13	158
Ingot mold and stool scrap	257	118	341	266	821	177	157
Machinery and cupola cast iron	986	204	258	26	1,477	4	113
Cast-iron borings	602	91	83	—	732	15	53
Motor blocks	349	45	509	—	904	11	35
Other iron scrap	701	53	2,691	2	3,211	281	138
Other mixed scrap	734	80	587	1	1,405	31	124
Total[3]	41,401	3,567	20,969	774	62,884	4,603	4,106

[1]All data for 1991 have been revised.

[2]Less than 1/2 unit.

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

[4]Internal evaluation reveals that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 2.8 million metric tons.

TABLE 4

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF PIG IRON AND DIRECT-REDUCED IRON IN 1992

(Thousand metric tons)

	Receipts	Production	Consumption	Shipments	Stocks, Dec. 31
MANUFACTURERS OF PIG IRON AND RAW STEEL AND CASTINGS					
Pig iron	2,106	47,531	47,359	2,277	124
MANUFACTURERS OF STEEL CASTINGS					
Pig iron	22	—	22	1	5
IRON FOUNDRIES AND MISCELLANEOUS USERS					
Pig iron	748	—	717	28	56
TOTAL—ALL TYPES OF MANUFACTURERS					
Pig iron[1]	2,876	47,531	48,098	2,306	[1]184
Direct-reduced or prereduced iron	917	W	898	5	120

W Withheld to avoid disclosing company proprietary data; included in "Receipts."
[1]Data do not add to total shown because of independent rounding.

TABLE 5

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF PIG IRON AND DIRECT-REDUCED IRON IN 1991[1]

(Thousand metric tons)

	Receipts	Production	Consumption	Shipments	Stocks, Dec. 31
MANUFACTURERS OF PIG IRON AND RAW STEEL AND CASTINGS					
Pig iron	1,788	44,350	44,095	1,971	127
MANUFACTURERS OF STEEL CASTINGS					
Pig iron	23	—	21	1	5
IRON FOUNDRIES AND MISCELLANEOUS USERS					
Pig iron	834	—	795	37	62
TOTAL—ALL TYPES OF MANUFACTURERS					
Pig iron[2]	[2]2,646	44,350	44,911	2,009	194
Direct-reduced or prereduced iron	838	W	855	—	100

W Withheld to avoid disclosing company proprietary data; included in "Receipts."
[1]All data for 1991 have been revised.
[2]Data do not add to total shown because of independent rounding.

TABLE 6

CONSUMPTION OF IRON AND STEEL SCRAP AND PIG IRON IN THE UNITED STATES IN 1992, 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]	2,354	—	—	—	—	—	2,354	—
Basic oxygen process[3]	15,382	47,290	—	—	—	—	15,382	47,290
Electric furnace[4]	31,422	16	2,493	22	5,741	485	39,656	523
Cupola furnace	22	4	209	(5)	7,476	225	7,707	229
Other (including air furnace)[6]	119	—	5	—	38	8	162	8
Direct castings[7]	—	49	—	—	—	—	—	49
Total[1]	49,300	47,359	2,707	22	13,255	717	65,261	48,098

[1]Data may not add to totals shown because of independent rounding.
[2]Includes consumption in blast furnaces producing pig iron.
[3]Includes scrap and pig iron processed in metallurgical blast cupolas and used in oxygen converters.
[4]Internal evaluation indicates that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 3.5 million metric tons.
[5]Less than 1/2 unit.
[6]Includes vacuum melting furnaces and miscellaneous uses.
[7]Includes ingot molds and stools.

TABLE 7

CONSUMPTION OF IRON AND STEEL SCRAP AND PIG IRON IN THE UNITED STATES IN 1991, BY TYPE OF FURNACE OR OTHER USE[1]

(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]	1,939	—	—	—	—	—	1,939	—
Basic oxygen process[4]	13,943	42,955	—	—	—	—	13,943	42,955
Open-hearth furnace	548	997	—	—	—	—	548	997
Electric furnace[5]	30,375	5	2,528	20	5,957	549	38,860	574
Cupola furnace	51	22	162	(6)	6,932	242	7,146	265
Other (including air furnace)[7]	368	9	33	—	47	4	448	13
Direct castings[8]	—	106	—	—	—	—	—	106
Total[2]	47,224	44,095	2,723	21	12,937	795	62,884	44,911

[1]All data for 1991 have been revised.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes consumption in blast furnaces producing pig iron.
[4]Includes scrap and pig iron processed in metallurgical blast cupolas and used in oxygen converters.
[5]Internal evaluation indicates that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 2.8 million metric tons.
[6]Less than 1/2 unit.
[7]Includes vacuum melting furnaces and miscellaneous uses.
[8]Includes ingot molds and stools.

TABLE 8

PROPORTION OF IRON AND STEEL SCRAP AND PIG IRON USED IN FURNACES IN THE UNITED STATES IN 1992

(Percent)

Type of furnace	Scrap	Pig iron
Basic oxygen process	24.5	75.5
Electric furnace	98.7	1.3
Cupola furnace	97.1	2.9
Other (including air furnace)	95.6	4.4

TABLE 9

PROPORTION OF IRON AND STEEL SCRAP AND PIG IRON USED IN FURNACES[1] IN THE UNITED STATES IN 1991

(Percent)

Type of furnace	Scrap	Pig iron
Basic oxygen process	24.5	75.5
Open-hearth furnace	35.4	64.6
Electric furnace	98.5	1.5
Cupola furnace	96.4	3.6
Other (including air furnace)	97.1	2.9

[1]All data for 1991 have been revised.

TABLE 10

IRON AND STEEL SCRAP SUPPLY[1] AVAILABLE FOR CONSUMPTION IN 1992, 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[3]
	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	1,967	26	218	1	2,210	37	2,173
Pennsylvania	3,753	812	2,193	55	6,814	429	6,385
Total	5,720	838	2,411	56	9,024	466	8,558
North Central:							
Illinois	4,524	411	1,586	4	6,525	133	6,392
Indiana	4,050	458	6,879	90	11,476	2,889	8,588
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	3,228	193	1,309	5	4,734	10	4,723
Michigan	2,857	512	1,740	48	5,157	221	4,936
Ohio	5,184	952	2,539	562	9,239	868	8,371
Total	19,843	2,526	14,053	709	37,131	4,121	33,010
South Atlantic:							
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	3,927	678	1,614	7	6,226	159	6,068
South Central:							
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	9,280	695	2,116	22	12,113	100	12,013
Mountain and Pacific:							
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	2,994	10	984	47	4,036	18	4,018
Grand total[3]	41,764	4,747	21,180	841	68,531	4,865	63,666

[1]New 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.

[2]Obsolete scrap includes ingot molds, stools and scrap from old equipment, buildings, etc.

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

[4]Includes scrap shipped, transferred, or otherwise disposed of during the year.

TABLE 11

IRON AND STEEL SCRAP SUPPLY[1] AVAILABLE FOR CONSUMPTION IN 1991, BY REGION AND STATE[2]

(Thousand metric tons)

Region and State	Receipts of scrap		Production of home scrap		Total new supply[4]	Shipments of scrap[5]	New supply available for consumption[4]
	From brokers, dealers, and other outside sources	From other own 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	1,985	35	216	(6)	2,239	17	2,222
Pennsylvania	4,877	187	2,349	55	7,464	409	7,056
Total[4]	6,862	222	2,565	55	9,704	426	9,278
North Central:							
Illinois	4,597	418	1,558	10	6,584	66	6,518
Indiana	3,670	480	6,416	89	10,654	2,873	7,781
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	3,157	183	1,275	1	4,616	9	4,607
Michigan	2,885	437	1,724	8	5,054	174	4,880
Ohio	4,856	601	2,240	509	8,205	708	7,497
Total[4]	19,165	2,119	13,213	617	35,114	3,830	31,284
South Atlantic:							
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	3,550	404	1,597	16	5,566	192	5,374
South Central:							
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	8,755	775	2,532	44	12,105	145	11,960
Mountain and Pacific:							
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	3,069	47	1,062	43	4,222	10	4,212
Grand total[4]	41,401	3,567	20,969	774	66,711	4,603	62,107

[1]New 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.

[2]All data for 1991 have been revised.

[3]Obsolete scrap includes ingot molds, stools and scrap from old equipment, buildings, etc.

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

[5]Includes scrap shipped, transferred, or otherwise disposed of during the year.

[6]Less than 1/2 unit.

TABLE 12

U.S. CONSUMPTION OF IRON AND STEEL SCRAP AND PIG IRON[1] IN 1992, 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	1,625	2	44	(3)	564	22	2,233	24
Pennsylvania	5,539	3,086	202	8	863	247	6,604	3,340
Total[2]	7,164	3,088	247	8	1,427	268	8,838	3,364
North Central:								
Illinois	4,942	2,331	189	—	1,226	38	6,356	2,370
Indiana	7,355	16,866	314	4	1,014	95	8,682	16,965
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	1,897	(3)	422	3	2,433	130	4,753	133
Michigan	2,513	5,694	6	(3)	2,514	70	5,033	5,765
Ohio	6,997	10,733	386	5	1,111	35	8,494	10,774
Total[2]	23,703	35,625	1,317	12	8,298	369	33,318	36,007
South Atlantic:								
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	5,141	4,580	16	(3)	929	33	6,087	4,614
South Central:								
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	9,884	2,635	615	(3)	1,786	40	12,284	2,675
Mountain and Pacific:								
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	3,407	1,430	512	1	816	7	4,734	1,438
Grand total[2]	[4]49,300	47,359	2,707	22	13,255	717	65,261	48,098

[1]Includes molten pig iron used for ingot molds and direct castings.

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

[3]Less than 1/2 unit.

[4]Internal evaluation indicates that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 3.5 million metric tons.

TABLE 13

U.S. CONSUMPTION OF IRON AND STEEL SCRAP AND PIG IRON[1] IN 1991, BY REGION AND STATE[2]

(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	1,569	2	48	(4)	614	25	2,231	28
Pennsylvania	5,838	3,219	226	3	926	322	6,989	3,544
Total[3]	7,406	3,221	274	4	1,540	347	9,220	3,572
North Central:								
Illinois	5,212	2,338	189	—	1,154	40	6,556	2,378
Indiana	6,664	15,514	309	4	864	87	7,838	15,605
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	1,999	—	410	3	2,314	128	4,724	131
Michigan	2,423	4,868	6	(4)	2,543	73	4,973	4,942
Ohio	6,003	8,789	378	8	1,042	45	7,423	8,841
Total[3]	22,302	31,509	1,292	16	7,919	373	31,513	31,898
South Atlantic:								
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	4,494	4,336	15	(4)	927	27	5,436	4,363
South Central:								
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	9,584	3,708	609	(4)	1,723	41	11,916	3,750
Mountain and Pacific:								
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	3,438	1,321	534	1	827	7	4,799	1,329
Grand total[3]	[5]47,224	44,095	2,723	21	12,937	795	62,884	44,911

[1]Includes molten pig iron used for ingot molds and direct castings.
[2]All data for 1991 have been revised.
[3]Data may not add to totals shown because of independent rounding.
[4]Less than 1/2 unit.
[5]Internal evaluation indicates that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 2.8 million metric tons.

TABLE 14

U.S. CONSUMER STOCKS OF IRON AND STEEL SCRAP AND PIG IRON, DECEMBER 31, 1992, BY REGION AND STATE

(Thousand metric tons)

Region and State	Carbon steel[1]	Stainless steel	Alloy steel[2]	Cast iron[3]	Other grades of scrap	Total scrap stocks[4]	Pig iron stocks
New England and Middle Atlantic:							
Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island	97	4	50	20	1	172	4
Pennsylvania	240	44	36	41	2	363	9
Total	337	48	86	61	3	535	13
North Central:							
Illinois	330	—	6	30	10	377	12
Indiana	475	2	2	79	18	576	80
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	181	2	5	27	26	241	23
Michigan	116	1	1	39	31	186	9
Ohio	348	8	41	73	2	471	24
Total[4]	1,450	12	54	248	87	1,851	147
South Atlantic:							
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	257	3	1	82	3	345	11
South Central:							
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	709	(5)	4	41	10	764	9
Mountain and Pacific:							
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	160	1	6	17	47	231	4
Grand total[4]	2,913	63	151	448	150	3,726	184

[1]Excludes rerolling rails.
[2]Excludes stainless steel.
[3]Includes borings.
[4]Data may not add to totals shown because of independent rounding.
[5]Less than 1/2 unit.

TABLE 15

U.S. CONSUMER STOCKS OF IRON AND STEEL SCRAP AND PIG IRON, DECEMBER 31, 1991, BY REGION AND STATE[1]

(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	76	3	50	24	2	155	4
Pennsylvania	389	44	46	84	4	567	16
Total	465	47	96	108	6	722	20
North Central:							
Illinois	303	—	15	39	14	371	10
Indiana	506	2	3	85	16	611	83
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	206	3	3	26	17	256	25
Michigan	145	(6)	1	32	7	185	7
Ohio	462	11	29	72	1	576	18
Total[5]	1,622	16	52	254	55	1,999	144
South Atlantic:							
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	293	2	1	59	4	359	8
South Central:							
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	664	(6)	3	58	10	736	20
Mountain and Pacific:							
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	218	1	6	17	49	290	2
Grand total[5]	3,262	66	158	496	124	4,106	194

[1]All data for 1991 have been revised.
[2]Excludes rerolling rails.
[3]Excludes stainless steel.
[4]Includes borings.
[5]Data may not add to totals shown because of independent rounding.
[6]Less than 1/2 unit.

TABLE 16

U.S. AVERAGE MONTHLY PRICE AND COMPOSITE PRICE FOR NO. 1 HEAVY MELTING STEEL SCRAP IN 1992, WITH ANNUAL AVERAGES FOR 1991 AND 1992

(U.S. dollar per metric ton)

Month	Chicago	Philadelphia	Pittsburgh	Composite price
January	89.07	77.75	86.12	84.32
February	89.07	78.58	87.77	85.14
March	89.07	80.70	90.05	86.61
April	89.07	80.70	91.93	87.24
May	88.28	79.13	90.30	85.90
June	86.30	78.74	86.12	83.72
July	86.12	78.74	86.12	83.66
August	86.17	79.58	86.12	83.95
September	87.10	79.72	86.12	84.32
October	84.15	79.72	85.13	83.00
November	84.15	79.72	84.15	82.67
December	86.96	81.60	87.91	85.49
Annual average:				
1992	87.13	79.56	87.32	84.67
1991	93.69	88.00	93.68	91.79

Source: American Metal Market.

TABLE 17

U.S. EXPORTS OF IRON AND STEEL SCRAP,[1] BY COUNTRY[2]

(Thousand metric tons and thousand U.S. dollars)

Country	1988		1989		1990		1991		1992	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Canada	570	62,367	937	106,296	939	109,220	806	98,636	1,163	130,845
China	28	5,010	44	11,129	65	11,372	37	9,930	215	39,523
Italy	81	12,926	147	27,446	170	26,297	44	8,224	75	9,606
Japan	589	148,362	434	139,245	481	119,866	340	92,386	161	53,889
Korea, Republic of	2,139	271,155	2,710	404,815	2,931	409,677	2,784	381,691	2,067	240,077
Mexico	831	101,785	521	63,585	568	72,186	516	56,868	566	63,465
Spain	367	108,067	597	119,784	236	35,685	118	18,640	119	34,451
Taiwan	607	89,021	369	64,386	481	71,761	800	100,990	473	55,513
Turkey	1,801	230,853	2,926	393,503	2,748	335,781	1,776	196,626	2,019	192,034
Venezuela	234	26,109	74	8,166	45	5,243	6	1,108	75	8,366
Other	1,916	296,298	2,391	410,288	2,917	438,130	2,118	267,746	2,329	272,033
Total[3]	9,161	1,351,955	11,149	1,748,643	11,580	1,635,218	9,345	1,232,845	9,262	1,099,802

[1]Excludes used rails for rerolling and other uses and ships, boats, and other vessels for scrapping.
[2]U.S. exports were shipped to 59 countries in 1992 compared with 57 in 1991.
[3]Data 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	1988		1989		1990		1991		1992	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Export:										
No. 1 heavy melting scrap	2,177	255,370	2,530	308,485	2,479	297,504	2,263	243,849	2,118	205,378
No. 2 heavy melting scrap	627	68,102	953	109,101	804	91,587	766	79,869	742	67,853
No. 1 bundles	67	8,852	93	12,990	157	19,596	85	8,609	121	11,332
No. 2 bundles	337	31,567	419	41,505	340	32,489	401	34,717	186	13,780
Stainless steel scrap	220	239,807	265	320,683	233	212,368	232	196,380	223	153,702
Shredded steel scrap	2,640	343,188	3,496	486,999	3,674	482,465	2,161	247,519	2,853	290,736
Borings, shovelings and turnings	467	36,230	674	55,765	247	20,442	173	13,191	226	16,221
Other steel scrap[1]	1,852	277,281	1,609	276,420	2,428	322,550	1,670	224,031	1,708	230,949
Iron scrap	773	91,557	1,110	136,694	1,218	156,217	1,593	184,681	1,085	109,851
Total[2]	9,161	1,351,955	11,149	1,748,643	11,580	1,635,218	9,345	1,232,845	9,262	1,099,802
Ships, boats, and other vessels for scrapping	299	43,548	114	16,698	23	3,842	114	8,158	92	7,622
Used rails for rerolling and other uses[3]	38	7,330	55	20,062	48	14,385	48	12,422	22	5,998
Total exports[2]	9,498	1,402,833	11,319	1,785,403	11,651	1,653,445	9,507	1,253,425	9,376	1,113,422
Imports for consumption:										
Iron and steel scrap	942	133,577	1,016	149,109	1,309	171,510	1,073	142,552	1,316	147,616
Ships, boats and other vessels for breaking up (for scrapping)[4]	—	—	(5)	4	—	—	2	60	(5)	31
Used rails for rerolling and other uses[3]	—	—	89	14,844	154	25,148	93	16,173	78	15,583
Total imports[2]	942	133,577	1,105	r163,957	1,464	196,658	r1,169	r158,784	1,393	163,231

rRevised.

[1]Includes tinplate and terneplate.

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

[3]Totals for 1989 through 1992 contain mixed (used plus new) rails: exports contained 1,191 metric tons valued at $8,664,660 in 1989; 5,979 metric tons valued at $4,439,351 in 1990; 6,828 metric tons valued at $3,963,245 in 1991; and 2,376 metric tons valued at $1,783,731 in 1992. Imports contained 3,674 metric tons valued at $1,065,953 in 1989, and no mixed rails for all following years.

[4]Not included in previous Iron and Steel Scrap Annual Reports.

[5]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 19

U.S. EXPORTS OF USED RAILS[1] FOR REROLLING AND OTHER USES, BY COUNTRY[2]

(Thousand metric tons and thousand dollars)

Country	1988		1989		1990		1991		1992	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Canada	1	134	4	774	6	3,966	5	2,762	2	467
Korea, Republic of	—	—	—	—	(3)	49	—	—	—	—
Mexico	36	6,794	48	14,569	35	8,810	41	8,599	19	4,649
Turkey	—	—	—	—	(3)	6	—	—	—	—
Other	1	401	4	4,719	6	1,553	2	1,061	1	882
Total[4]	38	7,330	55	20,062	48	14,385	48	12,422	22	5,998

[1]Exports for 1989 through 1992 contain mixed (used plus new) rails: 1,191 metric tons valued at $8,664,660 in 1989; 5,979 metric tons valued at $4,439,351 in 1990; 6,828 metric tons valued at $3,963,245 in 1991; and 2,376 metric tons valued at $1,783,731 in 1992.
[2]U.S. exports of mixed rails were shipped to 20 countries in 1992.
[3]Less than 1/2 unit.
[4]Data 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		1992	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Austria	16	$26,919	—	—	—	—	—	—
Canada	862,790	121,453,758	1,083,779	$134,150,277	892,941	$104,016,351	912,742	$92,743,795
France	26,769	206,662	118	258,338	15	85,617	98	162,640
Germany	3,399	1,215,127	931	790,684	2,229	2,609,394	170	532,999
Japan	59,687	5,884,543	67,113	7,170,079	52,417	6,330,555	88,315	12,313,331
Mexico	51,585	13,216,965	63,605	18,731,528	64,476	18,552,101	66,847	18,309,030
Netherlands	3,241	1,512,094	812	96,614	—	—	351	281,947
Russia[2]	—	—	—	—	—	—	140	109,944
Sweden	82	210,689	8,828	42,536	—	—	—	—
U.S.S.R.[3]	—	—	262	2,740,648	295	412,301	—	—
United Kingdom	324	904,630	28,350	1,347,463	9,400	949,789	4,344	920,133
Other	7,718	4,477,282	55,669	6,181,966	51,593	9,595,615	242,642	22,242,394
Total	1,015,612	149,108,669	1,309,466	171,510,133	1,073,366	142,551,723	1,315,649	147,616,213

[1]Includes tinplate and terneplate, excludes used rails for rerolling and other uses, and ships, boats, and other vessels for scrapping.
[2]Formerly part of the U.S.S.R.
[3]Dissolved in Dec. 1991.

Source: Bureau of the Census.

TABLE 21

U.S. IMPORTS FOR CONSUMPTION OF IRON AND STEEL SCRAP,[1] BY CLASS

Class	1989		1990		1991		1992	
	Quantity (metric tons)	Value	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	43,029	$3,973,893
No. 2 heavy melting scrap	10,540	1,162,945	10,651	1,093,062	9,402	898,752	5,842	505,322
No. 1 bundles	64,567	8,130,056	140,584	16,207,757	94,238	10,463,921	79,518	8,481,802
No. 2 bundles	5,544	725,792	12,923	1,450,614	4,938	530,448	10,079	1,104,214
Stainless steel scrap	53,290	29,826,184	102,144	31,284,356	33,046	23,138,547	76,007	21,807,038
Shredded steel scrap	56,069	12,361,167	46,125	6,296,095	30,992	3,301,902	44,615	4,630,690
Borings, shovelings and turning	15,214	1,388,505	28,794	2,959,970	31,218	2,888,257	36,570	3,382,611
Other iron and steel scrap	677,398	77,711,456	762,191	87,700,496	718,617	83,580,530	953,774	95,430,922
Cast iron scrap	96,639	13,711,619	154,854	19,106,205	98,342	12,500,758	66,215	8,299,721
Total	1,015,612	149,108,669	r1,309,466	171,510,133	r1,073,366	142,551,723	1,315,649	147,616,213

rRevised.

[1]Excludes used rails for rerolling and other uses and ships, boats, and other vessels for scrapping.

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		1992	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Australia	—	—	6	$7,234	—	—	—	—
Canada	80,121	$13,521,929	151,879	23,421,711	93,011	$16,152,456	77,030	$15,215,964
Finland	—	—	—	—	—	—	10	13,247
France	(2)	1,599	—	—	(2)	2,460	(2)	1,416
Germany	5	4,881	2,439	1,641,592	—	—	5	10,194
Israel	—	—	—	—	2	5,650	—	—
Japan	25	15,202	158	77,265	—	—	(2)	1,632
Korea, Republic of	—	—	—	—	—	—	473	238,804
Luxembourg	—	—	—	—	—	—	9	5,250
Mexico	—	—	—	—	20	12,000	30	96,900
U.S.S.R.[3]	8,958	1,290,199	—	—	—	—	—	—
United Kingdom	5	10,674	—	—	—	—	—	—
Total[4]	89,115	14,844,484	154,483	25,147,802	93,033	16,172,566	77,558	15,583,407

[1]Imports contain 3,674 metric tons of mixed (used plus new) rails valued at $1,065,953 in 1989, and no mixed rails for all following years.

[2]Less than 1/2 unit.

[3]Dissolved in Dec. 1991.

[4]Data 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 COUNTRY[1]

Country	1990				1991				1992			
	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%		More than 80%		Minimum of 99.94%		More than 80%		Minimum of 99.94%	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Argentina	360	$264,877	40	$23,200	333	$239,803	214	$136,820	300	$212,233	179	$105,178
Brazil	1,191	796,936	—	—	660	459,347	62	38,475	1,682	359,847	7	5,000
Canada	747	510,523	21	13,883	394	273,549	25	10,550	579	220,638	25	19,530
Colombia	10	4,250	—	—	6	4,791	4	17,408	36	6,837	—	—
Germany	223	469,872	28	34,944	184	156,900	85	200,990	121	23,437	164	127,515
Hong Kong	262	223,012	—	—	260	140,997	—	—	479	54,182	412	210,393
Japan	253	119,855	500	1,015,653	31	89,793	731	1,338,187	247	26,102	1,343	743,427
Korea, Republic of	4	9,532	(1)	3,200	38	35,132	4	36,269	520	68,024	510	1,509,363
Mexico	513	413,586	341	356,180	534	476,416	267	260,939	1,506	333,222	252	106,578
Netherlands	—	—	347	451,226	10	9,043	182	233,354	—	—	250	200,815
Peru	—	—	1	3,725	177	116,878	1	3,045	—	—	—	—
Saudi Arabia	111	52,539	—	—	145	170,577	19	35,475	778	82,481	—	—
Singapore	—	—	12	14,314	232	119,879	8	11,580	—	—	18	24,043
Taiwan	73	47,440	396	207,383	—	—	29	27,598	32	3,000	4	3,000
United Kingdom	—	—	42	74,759	5	24,603	223	138,424	1,225	182,212	134	104,661
Venezuela	74	51,521	73	44,548	168	104,481	356	208,035	812	198,132	401	246,348
Other countries	126	343,424	220	343,586	340	444,572	204	201,752	1,053	251,100	979	633,595
Total	3,947	3,307,367	2,021	2,586,601	3,517	2,866,761	2,414	2,898,901	9,370	2,021,447	4,678	4,039,446

[1]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 24

U.S. IMPORTS FOR CONSUMPTION OF DIRECT REDUCED IRON (DRI), BY COUNTRY

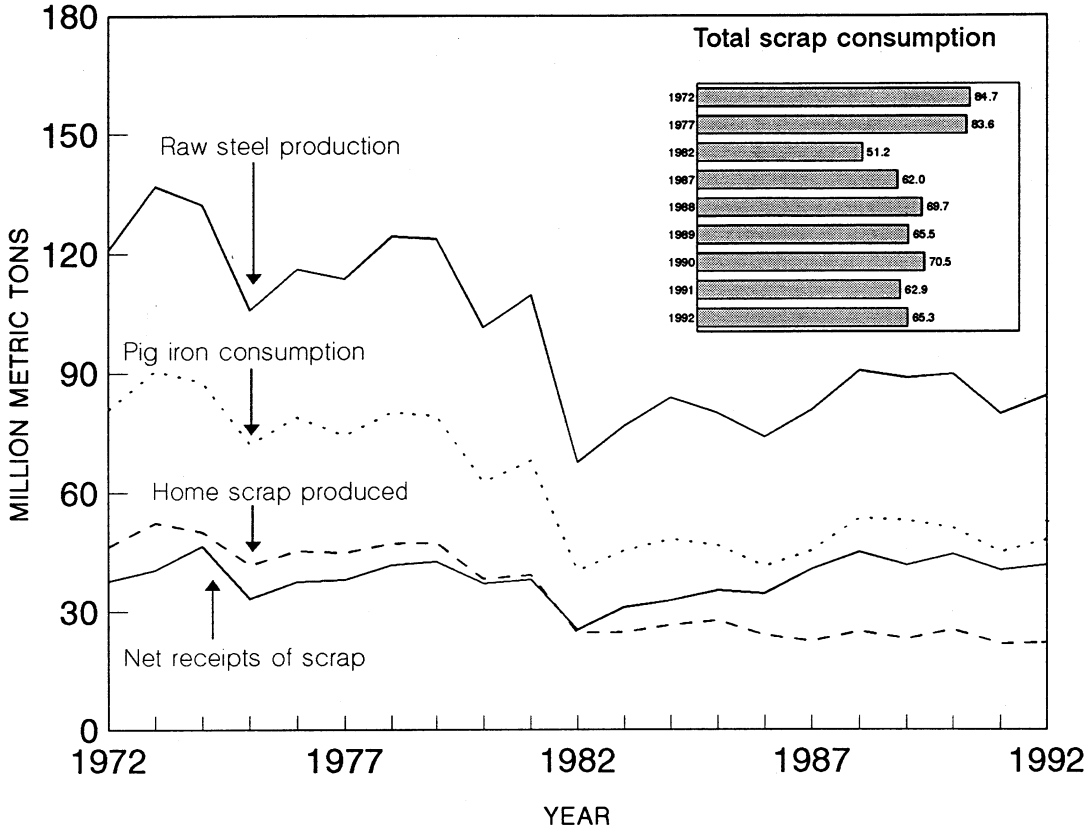
Country	1990				1991				1992			
	Metallic iron content of DRI product, weight percent				Metallic iron content of DRI product, weight percent				Metallic iron content of DRI product, weight percent			
	More than 80%		Minimun of 99.94%		More than 80%		Minimun of 99.94%		More than 80%		Minimun of 99.94%	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Australia	—	—	—	—	—	—	1	$1,678	—	—	1	$2,097
Belgium	—	—	—	—	100	$11,940	38	48,478	—	—	—	—
Brazil	354	$728,769	—	—	—	—	4,301	5,550,936	18	$2,068	—	—
Canada	458	360,927	—	—	—	—	207	101,963	151	16,288	91	68,101
China	—	—	—	—	—	—	9	11,400	—	—	7	9,103
Germany	17,183	1,666,770	1	$1,295	—	—	7	8,622	—	—	3	14,041
Hong Kong	(1)	1,800	—	—	—	—	—	—	—	—	—	—
Italy	20	20,860	—	—	—	—	7	2,155	—	—	—	—
Jamaica	820	278,749	—	—	—	—	—	—	—	—	—	—
Japan	—	—	516	596,015	40	4,270	711	717,235	23,725	2,217,025	200	311,771
Korea, Republic of	—	—	—	—	—	—	1	1,318	—	—	—	—
Mexico	—	—	5	5,359	20	1,986	16	6,694	—	—	2	2,540
Netherlands	—	—	—	—	—	—	—	—	—	—	2	2,870
Peru	—	—	—	—	—	—	7	19,203	—	—	5	24,528
Russia[2]	—	—	—	—	—	—	—	—	22,510	1,800,519	1,238	1,596,650
Spain	—	—	—	—	—	—	273	91,990	—	—	927	299,568
Sweden	—	—	—	—	21	24,360	15	18,017	—	—	—	—
Switzerland	—	—	—	—	—	—	—	—	—	—	1	2,050
Taiwan	—	—	—	—	—	—	—	—	—	—	2	3,170
U.S.S.R.[3]	38,406	6,548,901	24,219	2,536,940	19,345	2,050,634	1,677	2,165,334	—	—	—	—
United Kingdom	—	—	9	45,476	—	—	14	13,803	—	—	147	109,066
Venezuela	212,353	23,730,826	39,303	4,451,445	345,148	38,507,445	7,961	4,264,618	495,685	49,963,448	—	—
Total	269,594	33,337,602	64,053	7,636,530	364,674	40,600,635	15,245	13,023,444	542,089	53,999,348	2,626	2,445,555

[1]Less than 1/2 unit.
[2]Formerly part of the U.S.S.R.
[3]Dissolved in Dec. 1991.

Source: Bureau of the Census.

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



Source: American Iron and Steel Institute and U.S. Bureau of Mines

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, statistical assistants; and 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 with a growth of 700,000 metric tons, from 5.17 million tons in 1982 to the record 5.87 million tons (revised) in 1989, world demand for lead declined for 3 years by about 400,000 tons to an estimated 5.47 million tons in 1992, owing to the worldwide recession. For many years before 1983, primary metal demand represented about 60% of the total, but gradually declined to about 55% in 1988-92. This trend is expected to continue downward in the future as the overall end-use pattern becomes less dissipative, a result of evolving worldwide environmental consciousness, leading also to stronger recycling efforts. Although total refinery production continued fairly strong in 1992, leading to record worldwide yearend metal stocks estimated at 760,000 tons (exclusive of the U.S. National Defense Stockpile), world mine production declined to the lowest level since 1968, the year before Viburnum Trend production in Missouri came fully on-stream. Only in Canada were significant gains reported; significant declines among major producers occurred in China, the United States, and the war-ravaged former Yugoslavia. World and North American average prices at yearend were $0.04 and $0.023 per pound below those at yearend 1991. There was no yearend rally, which is unusual, and prices were expected to continue downward owing to the large inventories. The record average spread between the two prices, $0.106 per pound, forced domestic net metal imports, after 2 very low years, to soar back to the historic levels of recent decades.

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 195 consuming companies to which a survey request was sent, 154 responded, representing 86% of the total U.S. lead consumption shown in tables 1, 6, 7, and 8. Of the 39 companies producing secondary lead, exclusive of copper base, to which a survey request was sent, 29 responded, representing 82% of the total refinery production of secondary lead, shown in tables 1, 5, and 9. Production and consumption for the nonrespondents were estimated using prior-year levels adjusted for general industry trends. *(See table 1.)*

ANNUAL REVIEW

Legislation and Government Programs

Although there was considerable legislative and regulatory investigative activity relative to lead in 1992, only the final drinking water regulations, promulgated under the Safe Drinking Water Act, of June 1991, became effective during the year (June 29). The rules seek to reduce lead levels from an average of 50 parts per billion (ppb) to 15 ppb in at least 90% of monitored households. In addition, water systems must meet a maximum contaminant level goal (MCLG) of "0" for lead under the source water requirements of the

regulation. The effective dates for meeting action levels and for replacing lead service lines are staggered, but the longer lead remains in pipes the less it leaches; thus, newer homes are deemed worst for systems monitoring. All systems with more than 50,000 users must implement corrosion control, which involves simply altering the system chemistry to reduce lead solubility. Systems serving fewer than 500 persons are exempt. The Environmental Protection Agency (EPA) estimates that 95% of lead in drinking water can be reduced through corrosion control and estimates total capital costs to be $630 million with annualized costs of $210 million. All water systems that continue to exceed the lead action level after installing optimal corrosion control, and, if necessary, source water treatment, are required to replace all lead service lines where applicable. The full effect of the staggered corrosion control system mandates will not be achieved until the end of the century in some cases. Because EPA admits that there is limited quantitative information at present regarding the contribution from lead service lines to lead levels at the tap, where "first draw" samples are the standard in all cases, water companies have up to 15 years to replace service lines after completion of corrosion control. Therefore, some service line replacements probably would not begin until after the year 2010.

Water experts differ on how much of a factor lead service lines bear on contamination, but some older lines undoubtably have built up deposits that prevent leaching. However, this would probably not be true if the system had highly corrosive (acidic) water from excessive chlorination and/or fluoridation. That is why the regulations are tied to water quality control, but there are tradeoffs involved, benefits versus risks, in deleading water.

Numerous hearings were held concerning reauthorization of the Resource Conservation and Recovery Act. Other bills in various hearing stages dealt with labeling all lead products, premanufacture notification and approval for any new lead products, comprehensive inventorying of lead products, leaching and content standards in plumbing fixtures, tightening of paint and packaging standards, and excise taxes on all lead produced or imported with the revenue to be applied to a comprehensive lead-base paint abatement program.

Issues

Source reduction is one of four "tiers" for integrated waste management of the EPA's Agenda for Action, published by its Office of Solid Waste (OSW) in February 1989. The other "tiers" are recycling, incinerating, and landfilling. Theoretically, not creating a waste in the first place would be the best option to control solid waste generation. However, in general, source reduction is the least studied, and in some ways the most complex, of the integrated waste management options, involving target reductions of both volume and toxicity, when approached comprehensively. Therefore, in December 1992, EPA organized a forum on source reduction of heavy metals, specifically lead, cadmium, and mercury, in six products commonly found in municipal solid waste (MSW). The goal was to learn more about source reduction on a practical level, how it could be implemented, and what barriers (institutional, technical, economic, etc.) had to be overcome. The lead-containing products of concern were soldered circuit boards and cathode-ray tubes (CRT's).

The workshop for lead soldered circuit boards concluded that the two major uses, solder as an etch-resist in manufacture and as a component connect, must be analyzed separately. For the former, source reduction would entail changing the coating material, changing the manufacturing process (technology), and/or using alternative circuit boards. As a connecting medium the source reduction options are as follows: use adhesives, increase component density of the circuit board to decrease required connections, and implement totally new technologies. Lead-free joining systems currently are being researched. The same basic technology using antimony, bismuth, copper, indium, or silver alloyed with tin would, at the least, require major changes in the manufacturing process, and performance data for decisionmaking at this time are virtually nonexistent.

In the CRT workshop, 11 source reduction options were identified. Evaluation by the panel of a matrix containing reductions achievable, technical feasibility, cost, environmental tradeoffs, and performance yielded only two short-term options and one long-term option that were ranked as having great potential. The two former are zirconium substitution in the faceplate of the CRT's and lower voltage CRT's. The long-term option would be the development of flat panel (liquid crystal) technology that would replace the CRT. Lower voltage with possible lower performance would require implementation of a new worldwide standard, which could result in consumer displeasure. The latter point raises the issue, advanced by many, of the appropriateness of focusing only on the disposal-related impacts associated with products at the expense of not fully recognizing the need for a life-cycle approach to source reduction analysis. All of the economic implications and perturbations over an extended period of time, especially where substitution of materials is concerned, can only be determined by independent, objective, individual life-cycle analyses for each subject material, either before or in parallel with, the source reduction analysis for any given product of concern.

Production

Primary.—The significant decrease in domestic mine production of lead in 1992, more than 50,000 tons in Missouri, was primarily the result of the announcement by The Doe Run Co. about continuing cutback to prevent stock buildup in the depressed market. However, Missouri's share of the total mined lead production remained at 75%, the same as that in 1991, owing mostly to a one-third cutback in Idaho, the result of even worse silver market conditions. Alaska, Idaho, Montana, and Colorado,

in order of output, produced all but 2,200 tons of the balance. The top 12 mines listed in table 3 produced more than 99% of the total, and ASARCO Incorporated, Doe Run, and Cominco (American/Alaska) accounted for almost 90% of the domestic mine production of lead in 1992. *(See tables 2 and 3.)*

Doe Run of St. Louis, the Nation's only fully integrated primary lead producer, operated five mines and four mills in southeast Missouri in 1992. Doe Run's primary smelter-refinery at Herculaneum, MO, apparently produced about 119,000 tons of refined lead in 1992, 38,000 tons less than in 1991. Approximately 65% of Doe Run's ore was 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% on the gross value of concentrates produced. In November, Doe Run's parent company, Fluor Corp., classified Doe Run as a "discontinued operation" for tax purposes. That action resulted in a one-time $79 million offset to net earnings in 1992 and included both the estimated loss on disposal and estimated operating losses through the disposal date. It was hoped that the divestiture would be completed within 1 year of the announcement, but there were no buyers by yearend. Doe Run's Missouri mines produced about 156,000 tons of contained lead in concentrates in 1992.

Asarco operated two mine and mill complexes in southern Missouri that produced slightly more than 97,000 tons of contained lead in 1992 compared with slightly less than 95,000 tons of contained lead in 1991, according to the company's annual report to the stockholders. This represented a gain of 5% for its smelter-refinery at Glover, MO, which had near capacity production of 118,000 tons for the second consecutive year. Asarco's Omaha, NE, refinery, which received the bullion output from its East Helena, MT, custom smelter, produced 68,000 tons of lead in 1992, down slightly from that in 1991 owing to mine closures in the region and in Mexico and Peru. Asarco also received, as operator, 52.5% of the production from the Leadville Mine in Colorado. At yearend, Asarco reported reserves in Missouri of 18.9 million tons grading 4.93% lead at Sweetwater and 6.6 million tons grading 5.65% lead at West Fork. In late 1992, Asarco announced that by May 1993 all of its lead, zinc, silver, and mineral operations would be organized under a single manager headquartered in New York. *(See table 4.)*

The Magmont Mine at Bixby, MO, a 50-50 joint-venture of Cominco American Inc., the operator, and Dresser Industries Inc., dropped a notch to become the third largest domestic lead-producing mine in 1992. According to parent company Cominco Ltd.'s (Canada) annual report to stockholders, the 20% decrease in production from that of 1991 was the result of a decline in average ore grade from 6.5% lead to 6.1% lead and less efficient pillar and salvage mining operations in preparation for final closure in the next 2 years. Surface drilling during the year revealed no new ore extensions. In 1992, Magmont milled 873,000 tons of ore, which yielded 66,000 tons of concentrate grading 7.7% lead (compared with 7.8% in 1991). The mine also produced 7,400 tons of zinc in concentrate from 1.0% ore and 1,500 tons of copper from 0.3% ore. At Cominco Alaska Inc.'s Red Dog Mine, near Kotzebue in northwest Alaska, difficulties were encountered in the mill recoveries in lead and bulk concentrates during the second full year of operations. At yearend, Cominco had published ore reserves (measured and indicated) of 5.2 million tons at Magmont grading 8.5% lead and 1.3% zinc and of 58.2 million tons at Red Dog grading 5.5% lead and 18.4% zinc. It also declared 14.1 million tons of inferred ore reserves grading 2.7% lead and 10.0% zinc for Red Dog.

Secondary.—Domestic secondary production in 1992 was estimated to have nearly achieved 1990's alltime record as capacity utilization for the year was an optimum 88%. This was mainly because a major battery recycler in Alabama was permanently closed by the EPA early in the year.

Operations were indefinitely suspended at a smaller battery recycler in midyear in Tennessee, but this was offset by Refined Metals Corp.'s Memphis plant, which had been shut down at the beginning of the year, coming back on-stream. During the year, several smaller nonbattery recyclers who mainly produced specialty alloys for such uses as solders, brass or bronze ingots, bearing metals, etc., closed permanently, a result of being overcome by very low to nonexistent margins and increasingly enforced environmental emissions and workplace standards.

A new, small, "just-in-time" battery recycler came partially on-stream in Ohio, but was not producing at yearend owing to financial and technical problems. However, at yearend, the secondary lead industry had an estimated production capacity of 1.04 million tons, 1.0 million tons of which resided with 15 battery recycling companies. These 15 companies operated 20 breakers and 22 smelter-refineries with capacities of 10,000 to more than 100,000 tons per year, although two in Ohio and Tennessee were still shut down at yearend and several had curtailed operations. Also operating were five midlevel, nonbattery smelters-refineries, including Asarco's Omaha, NE, refinery, with furnace and kettle capacities of 6,000 to 10,000 tons per year. In addition, 13 small specialty alloy producers were operating, 3 with capacities of 1,000 to 2,000 tons per year; the other 10 had considerably smaller capacities.

Total production from the nonbattery plants in 1992 was 38,000 tons, much of which was from copper-base scrap and/or new scrap. In the first full year of operation, the Doe Run's state-of-the-art secondary plant at Boss, MO, on the site of its former Buick primary smelter-refinery, produced at full capacity. For the year, though, the RSR Corp. of Dallas, TX, the Nation's largest secondary lead producer, out produced both Doe Run's and Asarco's individual total (primary and secondary) outputs of pig lead. *(See table 5.)*

Consumption and Uses

Reported consumption of lead declined only slightly in 1992 compared with that of 1991. Decreases totaling 26,000 tons of lead in gasoline additives (zero), batteries, cable, sheet, and solder were partially offset by 16,000 tons of total gains in bullets/shot, castings and extrusions, and CRT's for television and computer screens. Lead used in construction remained about level for the seventh consecutive year, at 34,000 tons, the same as in 1991 (revised). All other uses increased or decreased marginally.

The Battery Council International (BCI) reported a 1992 starting-lighting-ignition (SLI) battery production of 81.07 million units, compared with 77.81 million units in 1991 and 79.61 million units in 1990. The total includes both original equipment market (OEM) and replacement market automotive-type batteries. Using the BCI estimate of 20.9 pounds per unit, that sector's offtake was 768,600 tons. That total category includes batteries for buses and trucks, tractors, marine, golf carts, motorcycles, aircraft, mine equipment, floor care, and other miscellaneous equipment, including military uses but excluding motive power. The industrial (stationary)-traction (motive power) sector was estimated to have consumed 220,500 tons of lead, a record in quantity and percentage of the total (998,200 tons) battery industry offtake. Consumer batteries; i.e., small, sealed lead-acid cells (SLA) for flashlights, toys, powertools, lawn mowers, floor polishers, etc., less than 25 pounds, were estimated to have consumed the balance of 9,100 tons.

The industrial and traction battery sector includes uninterruptible power supply (UPS) systems designed to ensure constant voltage for large computer systems at hospitals, banks, communication networks, etc., and standby power supply (SBS) systems for emergency lighting and some telenets. The whole sector exhibits great potential for continued future growth as networking of computers of all capacities expands, both externally and internally, and general purpose electric vehicles and electric power load-leveling loom closer to universal application; the latter especially for the customer side of the meter. In 1982, this sector consumed only 67,900 tons of lead and represented less than 10% of total battery lead, compared with more than 22% in 1992. Recently, consumer-type UPS batteries for home and individual office personal computers were introduced to the marketplace.

According to BCI statistics, critical inventories of SLI batteries at yearend stood at a record 9.65 million units, a 1.5-month supply, compared with 8.49 million units at yearend 1991 and 9.49 million units at yearend 1990. *(See tables 6, 7, 8, 9, 12, 13, 14, and 15.*

World Review

According to International Lead and Zinc Study Group (ILZSG) statistics, consumption of soft and antimonial lead in market economy countries (MEC) declined moderately in 1992 to 4.42 million tons compared with 4.47 million tons (revised) in 1991 and 4.48 million tons in 1990. Record MEC consumption of 4.58 million tons was established in 1989, according to ILZSG. Comparable world totals for those years, including about 2% other lead alloys, was estimated by the U.S. Bureau of Mines to be about 5.47, 5.57, 5.73, and 5.87 million tons, respectively. These revised data obviously reflect the continuing general, worldwide recession of recent years. Although MEC consumption and refined metal production were in balance during 1989, MEC production of soft and antimonial lead in 1990, 1991, and 1992 combined was in deficit by more than 120,000 tons. However, during this same 4-year period, net imports of pig metal into the MEC from Eastern European and Asian socialist countries was about 280,000 tons, according to ILZSG, and stocks reached an alltime record. This was primarily attributed to MEC net imports of about 170,000 tons during 1992.[1] Although the London Metal Exchange (LME) average cash price for lead, essentially the world price, was only $0.08 less per pound in 1992 than in 1991 ($0.245 versus $0.253 cents), the price in the last 2 months of the year averaged only $0.207 per pound. This was the result of the metal surplus and weak demand owing to very high battery stocks. Not only was there worldwide excess metal production capacity, but also apparently excess product (battery) manufacturing capacity at yearend. The LME price for the year peaked during the last week of August and first week of September, averaging $0.297 per pound for that 2-week period. That was also the peak in the United States, where the weighted average producer price was $0.388 per pound, delivered, for those 2 weeks. However, the LME price plummeted more than $0.09 to $0.206 per pound by yearend, while the yearend domestic price was $0.324 per pound. That very wide spread encouraged greater importation into the United States in the last quarter than usual.

Mine Capacity.—There was a statistically insignificant net gain of 10,000 tons in world mine capacity in 1992 for a yearend total of 4,010,000 tons. In Europe, the permanent closing of Germany's last two remaining lead mines, which had been producing since the middle of the last century, was offset by the opening of the new Louisa Mine at Lindesberg, Sweden. In the Western Hemisphere, small capacity increases at two large open pits plus the opening of a small new underground mine in Mexico were offset by the closures of the Real de Asientos Mine in Mexico and the Boquira Mine in Brazil. The capacity increase was the result of a new lead-producing gold mine coming on-stream at Cobar, New South Wales, Australia. In Canada, at Faro in the Yukon Territory, the Vangorda open pit started operations as one replacement for the phasing-down Faro Mine to maintain the 120,000-ton-per-year output. In Morocco, the Hajar Mine near Marrakesh, opened in 1991, reached full capacity of more than 20,000 tons per year. World lead-producing mines operated at 81% of capacity in 1992, slightly less than that in 1991 (82%) owing to the 34,000- ton decline in

production. Significant production decreases occurred in Spain, the United States, and the former Yugoslavia, which were not offset by the large increases reported by Canada and Sweden.

Late in the year, MIM Ltd. (72%) announced that it would proceed with development in 1993 of the large McArthur River project in the Northern Territory of Australia. MIM's partner is ANT Minerals, a consortium of Nippon Mining (15%), Mitsui (5%), Mitsubishi (5%), and Marubeni (3%), all of Japan. At a capacity of 1.2 million tons of ore per year, 350,000 tons of bulk concentrate containing 40,000 tons of lead would be produced by 1995 if market conditions warrant. *(See table 10.)*

Metal Capacity.—World primary smelting and refining capacity increased by less than 1% in 1992 (35,000 tons). A new conventional pyrometallurgical plant of 40,000-ton-per-year capacity came on-stream in northern Iran at Zandjan and a new 80,000-ton QSL plant came on-stream at Onsan in the Republic of Korea. Also in Asia, at Karnchanaburi, Thailand, the conventional smelter-refinery built in 1987 was expanded from 12,000 tons to 17,000 tons per year. At Cartegena, Spain, the 90,000-ton conventional smelter-refinery built in 1945 was permanently closed, the cost of environmental upgrading apparently prohibitive. At yearend, world primary smelting capacity stood at 4.6 million tons. In the secondary sector, three expansions and two new small plants totaling 60,000 tons of capacity were offset by the 50,000 tons closed in the United States (previously discussed) and the closure of Holland's largest plant (35,000 tons per year) at Arnhem. At yearend, world secondary capacity was about 3.1 million tons per year and capacity utilization for the year was about 82%. *(See table 11.)*

Reserves.—Worldwide reserves of lead contained in demonstrated resources from both producing and nonproducing deposits estimated to be economically viable at yearend were estimated at 60 million tons by the U.S. Bureau of Mines. For the largest producers among the MEC, Australia and the United States contained about 10 million tons each and Canada 6 million tons, compared to about 15 million tons 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 less than 3% in the United States and about 2.5% for demonstrated resources of all of the MECs, 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 less than 20 years. However, marginal economic deposits, measured and indicated, would extend the "reserve base" to 123 million tons at somewhat less extraction efficiency on average, or about 40 years. In this category, Australia would clearly dominate at an estimated total of 35 million tons, followed by the United States at 22 million tons and Canada at 13 million tons.

In continuing exploration developments, Ibernia West Corp. (47.5%) and Chevron Mineral Corp. (52.5%) of Ireland completed drilling at Europe's second largest zinc-lead deposit at the Lisheen deposit in County Tipperary. That resulted in announced proven and probable reserves of 18.4 million tons grading 13.4% zinc and 2.4% lead. A full feasibility study was then initiated during the year toward the objective of a mine being in production at Lisheen in the late 1990's. In Australia, CRA Ltd. secured a development license for its Century zinc-lead deposit in Queensland, but actual production mining cannot begin until acceptance by the Government of a yet-to-be completed environmental impact report. The resource is estimated to be about 120 million tons averaging 10.3% zinc and 1.5% lead. If an open pit mine were developed, production would be 55,000 tons per year of lead in concentrates, or 35,000 tons per year from an underground mine. In Canada, Curragh Resources secured all required permits for development (18 to 24 months) of its Stronsay Mine in British Columbia. Reserves were estimated to be 50 million tons of more than 10% combined lead and zinc, with a planned production rate for lead of 30,000 tons per year.

Current Research

In lead-acid storage batteries operation, energy efficiency is limited to about 50% of the theoretical value—even less at high discharge rates. One way to obtain high power levels at high discharge rates, a necessity in electromotive applications for example, would be to increase the porosity of the battery grid paste, conventionally 55% to 60%. However, above 60%, a traditional SLI battery pasted plate loses strength. In contract work performed by Johnson Controls Inc. for the Jet Propulsion Laboratory in 1992, an improved new paste formula for positive plates was developed that increased porosity to nearly 70%. This was accomplished by increasing the surface area significantly by creating a much larger fraction of small pores. This was done by utilizing pure tribasic lead sulfate (33% to 39%) and orthorhombic lead oxide (38% to 45%), instead of conventional bulk lead oxide, mixed with about 4% 325-mesh solid potassium persulfate or sodium persulfate, the key ingredient. The pasted grid was conventionally cured and formed, and the resulting new plate had only about 20% surplus of theoretical capacity. The new plate delivered signficant improvements.[2]

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, 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 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 also can 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 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 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 about 2% through 1989 from the low recession year of 1982. Lower growth in U.S. demand, which is about 20% 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 about 60% of world demand is currently 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 changes in response to 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 current downturn.

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 future 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 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 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 investment of primary producers, in many cases through acquisitions and mergers, in secondary lead production to protect existing market share.[3]

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[1]International Lead and Zinc Study Group (London). Lead and Zinc Statistics. Monthly Bull., v. 33, No. 7, July 1993.

[2]High-Performance Positive Paste for Lead-Acid Batteries. NASA Tech Briefs, v. 16, No. 10, Oct. 1992, p. 71.

[3]Woodbury, 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)

		1988	1989	1990	1991	1992
United States:						
Production:						
Domestic ores, recoverable lead content		384,983	410,915	483,704	465,931	397,923
Value	thousands	$315,222	$356,476	$490,771	$343,948	$307,922
Primary lead (refined):						
From domestic ores and base bullion		371,348	379,034	385,637	323,851	283,988
From foreign ores and base bullion		20,739	17,421	18,020	21,863	20,803
Secondary lead (lead content)		736,401	891,341	922,197	r884,624	916,597
Exports (lead content):						
Lead ore and concentrates		20,902	[1]57,038	[1]56,600	[1]87,953	72,323
Lead materials, excluding scrap		29,077	[1]43,837	[1]76,749	[1]113,872	71,733
Imports for consumption:						
Lead in ore and concentrates		20,606	[1]5,122	[1]10,668	[1]12,437	[1]5,310
Lead in base bullion		4,046	[1]5,782	[1]2,713	[1]419	[1]218
Lead in pigs, bars, and reclaimed scrap		155,893	[1]116,358	[1]90,919	[1]116,590	[1]190,959
Stocks, Dec. 31:						
Primary lead[2]		15,398	15,623	25,525	9,089	20,543
At consumers and secondary smelters		89,867	82,356	86,340	r71,685	82,107
Consumption of metal, primary and secondary		1,245,170	1,277,604	1,275,226	r1,246,344	1,236,571
Price: Metals Week average, delivered, cents per pound		37.14	39.35	46.02	33.48	35.10
World:						
Production:						
Mine	thousand metric tons	r3,324.8	r3,244.3	r3,352.8	r3,276.0	e3,242.2
Refinery[3]	do.	r3,206.5	r3,241.1	r3,067.6	r3,016.1	e2,993.5
Secondary refinery	do.	r2,589.1	r2,669.7	r2,694.9	r2,587.1	e2,548.0
Price: London Metal Exchange, pure lead, cash average, cents per pound		29.73	30.63	37.05	25.30	24.50

eEstimated. rRevised.

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export categories for 1989, 1990, 1991 and 1992 are not necessarily comparable with 1988.

[2]American Bureau of Metal Statistics Inc.

[3]Primary 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	1988	1989	1990	1991	1992
Missouri	353,194	366,931	380,781	351,995	300,589
Montana	8,266	W	W	W	W
Nevada	W	—	830	W	—
New Mexico	W	W	W	193	W
South Dakota	—	4	—	—	—
Total[1]	384,983	410,915	483,704	465,931	397,923

W Withheld to avoid disclosing company proprietary data; included in "Total."

[1]Includes, for at least some of the years 1988-92, Alaska, Arizona, Colorado, Idaho, Illinois, Kentucky, New York, Tennessee, and Washington.

TABLE 3

LEADING LEAD-PRODUCING MINES IN THE UNITED STATES IN 1992, IN ORDER OF OUTPUT

Rank	Mine	County and State	Operator	Source of lead
1	Fletcher	Reynolds, MO	The Doe Run Co.	Lead ore.
2	West Fork	do.	ASARCO Incorporated	Lead-zinc ore.
3	Magmont	Iron, MO	Cominco American Inc.	Lead ore.
4	Red Dog	Northwest Arctic, AK	Cominco Alaska Inc.	Zinc ore.
5	Sweetwater	Reynolds, MO	ASARCO Incorporated	Lead ore.
6	Buick	Iron, MO	The Doe Run Co.	Lead-zinc ore.
7	Casteel[1]	do.	do.	Lead ore.
8	Lucky Friday	Shoshone, ID	Hecla Mining Co.	Lead-zinc ore.
9	Viburnum No. 29	Washington, MO	The Doe Run Co.	Lead ore.
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	Van Stone	Stevens, WA	Equinox Resources	Do.
14	Balmat	St. Lawrence, NY	Zinc Corporation of America	Do.
15	Troy Unit	Lincoln, MT	ASARCO Incorporated	Copper ore.
16	Pierrepont	St. Lawrence, NY	Zinc Corporation of America	Zinc ore.
17	Rosiclare	Hardin, IL	Ozark-Mahoning Co.	Fluorspar.
18	Center	Grant, NM	Mount Royal Mining Co.	Gold ore.
19	Truth or Consequences	Hidalgo, NM	Lordsburg Mining Co.	Do.
20	Mission	Pima, AZ	ASARCO Incorporated	Copper ore.
21	Franklin 73	Clear Creek, CO	Franklin Consolidated Mines Inc.	Gold ore.
22	Immel	Knox, TN	ASARCO Incorporated	Zinc ore.
23	Coy	Jefferson, TN	do.	Do.

[1]Includes Brushy Creek Mill.

TABLE 4

REFINED LEAD PRODUCED AT PRIMARY REFINERIES IN THE UNITED STATES, BY SOURCE MATERIAL[1]

(Metric tons unless otherwise specified)

Source material		1988	1989	1990	1991	1992
Refined lead:						
Domestic ores and base bullion		371,348	379,034	385,637	323,851	283,988
Foreign ores and base bullion		20,739	17,421	18,020	21,863	20,803
Total		392,087	396,455	403,657	345,714	304,791
Calculated value of primary refined lead[2]	thousands	$321,039	$343,932	$409,537	$255,174	$235,854

[1]Total refined lead: American Bureau of Metal Statistics Inc.; domestic and foreign ores: U.S. Bureau of Mines calculations.
[2]Value based on average quoted price.

TABLE 5

LEAD RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1991	1992
KIND OF SCRAP		
New scrap:		
Lead-base	r48,338	48,274
Copper-base	r6,629	e7,000
Tin-base	3	3
Total	r54,970	55,277
Old scrap:		
Battery-lead	r756,227	784,269
All other lead-base	r65,105	68,051
Copper-base	r8,322	e9,000
Tin-base	—	—
Total	r829,654	861,320
Grand total	r884,624	916,597
FORM OF RECOVERY		
As soft lead	421,907	452,920
In antimonial lead	426,938	424,535
In other lead alloys	r20,825	23,139
In copper-base alloys	r14,951	e16,000
In tin-base alloys	3	3
Total	r884,624	916,597
Value[1] thousands	r$652,947	$709,283

eEstimated. rRevised.

[1]Value based on average quoted price of common lead.

TABLE 6
U.S. CONSUMPTION OF LEAD, BY PRODUCT

(Metric tons)

SIC Code	Product	1991	1992
	Metal products:		
3482	Ammunition: Shot and bullets	r58,477	64,845
	Bearing metals:		
35	Machinery except electrical	W	W
36	Electrical and electronic equipment	303	310
371	Motor vehicles and equipment	[1]2,624	[1]3,622
37	Other transportation equipment	W	W
	Total bearing metals	3,669	4,785
3351	Brass and bronze: Billets and ingots	r8,987	9,175
36	Cable covering: Power and communication	17,472	15,992
15	Calking lead: Building construction	1,074	1,045
	Casting metals:		
36	Electrical machinery and equipment	W	W
371	Motor vehicles and equipment	W	W
37	Other transportation equipment	2,372	2,884
3443	Nuclear radiation shielding	W	W
	Total casting metals	14,141	17,111
	Pipes, traps, other extruded products:		
15	Building construction	8,975	11,652
3443	Storage tanks, process vessels, etc.	[2]	[2]
	Total pipes, traps, other extruded products	8,975	11,652
	Sheet lead:		
15	Building construction	17,964	16,233
3443	Storage tanks, process vessels, etc.	[2]	[2]
3693	Medical radiation shielding	4,370	4,773
	Total sheet lead	22,334	21,006
	Solder:		
15	Building construction	3,651	3,449
341/371	Motor vehicles, equipment, metal cans and shipping containers	5,013	4,118
367	Electronic components and accessories	4,495	4,539
36	Other electrical machinery and equipment	1,592	1,412
	Total solder	[3]14,750	13,518
	Storage batteries:		
3691	Storage battery grids, post, etc.	591,884	624,998
3691	Storage battery oxides	415,233	373,185
	Total storage batteries	1,007,117	[3]998,184
371	Terne metal: Motor vehicles and equipment	[4]	[4]
27	Type metal: Printing and allied industries	[5]	[5]
34	Other metal products[6]	3,254	3,024
	Total metal products	r1,160,250	1,160,337
	Other oxides:		
285	Paint	W	W
32	Glass and ceramics products	W	W
28	Other pigments and chemicals	11,695	9,922
	Total other oxides	59,617	63,225

See footnotes at end of table.

TABLE 6—Continued
U.S. CONSUMPTION OF LEAD, BY PRODUCT

(Metric tons)

SIC Code	Product	1991	1992
2911	Gasoline additives	(7)	(7)
	Miscellaneous uses	[8]26,478	[8]13,009
	Grand total	[r 3]1,246,344	1,236,571

[r]Revised. W Withheld to avoid disclosing company proprietary data; included in appropriate totals.
[1]Includes "Terne metal: Motor vehicles and equipment."
[2]Included with "Building construction" to avoid disclosing company proprietary data.
[3]Data do not add to total shown because of independent rounding.
[4]Included with "Bearing metals: Motor vehicles and equipment."
[5]Included with "Other metal products" to avoid disclosing company proprietary data.
[6]Includes lead consumed in foil, collapsible tubes, annealing, galvanizing, plating, and fishing weights.
[7]Included with "Miscellaneous uses" to avoid disclosing company proprietary data.
[8]Includes "Gasoline additives."

TABLE 7
U.S. CONSUMPTION OF LEAD IN 1992, BY STATE[1]

(Metric tons)

State	Refined soft lead	Lead in antimonial lead	Lead in alloys	Lead in copper-base scrap	Total[2]
Arizona, California, Oregon, Washington	56,093	37,728	7,291	—	101,112
Florida and Georgia	36,389	11,557	—	—	47,946
Illinois	42,549	53,952	7,725	595	104,821
Missouri	11,221	16,712	—	—	27,933
Ohio and Pennsylvania	111,721	45,557	46,028	2,134	205,440
Texas	63,128	39,806	6,852	—	109,786
Alabama, Arkansas, Louisiana, Mississippi, Oklahoma	25,407	23,881	19,345	2,107	70,740
Colorado, Indiana, Iowa, Kansas, Kentucky, Minnesota, Nebraska, Tennessee, Wisconsin	270,745	79,077	40,941	1,173	391,936
Connecticut, Delaware, Maine, Maryland, Massachusetts, New Jersey, New Hampshire, New York, North Carolina, Rhode Island, South Carolina, Vermont	98,424	58,372	19,792	271	176,859
Total[2]	715,680	366,640	147,974	6,280	1,236,571

[1]Includes lead that went directly from scrap to fabricated products.
[2]Data may not add to totals shown because of independent rounding.

TABLE 8

U.S. CONSUMPTION OF LEAD IN 1992, BY CLASS OF PRODUCT[1]

(Metric tons)

Product	Soft lead	Lead in antimonial lead	Lead in alloys	Lead in copper-base scrap	Total[2]
Metal products	60,217	72,348	23,310	6,280	162,154
Storage batteries	584,339	293,455	120,390	—	998,184
Other oxides	63,225	—	—	—	63,225
Miscellaneous[3]	7,899	837	4,274	—	13,009
Total[2]	715,680	366,640	147,974	6,280	1,236,571

[1]Includes lead that went directly from scrap to fabricated products.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes gasoline additives to avoid disclosing company proprietary data.

TABLE 9

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]
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[r]	33,230	33,599	4,664	191	71,685
1992	38,411	37,594	5,940	162	82,107

[r]Revised.
[1]Data may not add to totals shown because of independent rounding.

TABLE 10

LEAD: WORLD MINE PRODUCTION OF LEAD IN CONCENTRATES, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Algeria[e]	1.9	1.4	1.1	r0.9	0.9
Argentina	28.5	26.7	23.4	23.7	23.6
Australia	465.5	495.0	565.0	571.0	3548.0
Austria	2.3	1.6	1.5	1.2	1.0
Bolivia	12.5	15.7	19.9	20.8	18.0
Bosnia and Herzgovina[4]	—	—	—	—	4.0
Brazil	14.3	r14.0	r9.3	r7.3	7.5
Bulgaria[e]	60.0	357.0	57.0	43.6	35.0
Burma	6.0	5.2	r e4.4	r e4.7	4.8
Canada	368.4	275.0	e232.1	e235.0	3342.5
Chile	1.4	1.2	1.1	1.1	1.1
China[e]	312.0	308.0	364.0	380.0	385.0
Colombia	(5)	.4	.3	r.4	.4
Congo (Brazzaville)	r—	r—	r—	r—	—
Czechoslovakia	e2.8	2.7	3.0	e2.5	2.5
Ecuador[e]	.2	.2	.2	.2	.2
Finland	1.9	2.6	1.7	e1.3	—
France	2.0	1.1	r1.2	1.7	—
Georgia[6]	—	—	—	—	1.0
Germany: Western states	r14.4	r7.4	r7.1	r1.9	1.9
Greece	23.1	22.3	23.5	r27.0	27.0
Greenland	23.1	24.1	16.0	—	—
Honduras	16.9	9.6	5.8	r8.7	8.5
India	30.5	26.5	25.1	25.1	25.0
Iran[e 7]	11.0	r13.0	r11.0	r16.0	30.0
Ireland	32.5	32.1	35.3	r39.9	42.4
Italy	16.5	17.5	16.0	r14.2	12.0
Japan	22.9	18.6	18.7	18.3	318.8
Kazakhstan[6]	—	—	—	—	240.0
Kenya[e 8]	.6	r—	r—	—	—
Korea, North[e]	r90.0	r80.0	r80.0	r80.0	75.0
Korea, Republic of	14.5	16.5	14.9	r12.6	13.0
Macedonia[4]	—	—	—	—	25.0
Mexico	171.3	163.0	179.9	r165.2	174.0
Morocco	72.2	67.3	68.8	r73.7	73.0
Namibia[e]	r25.0	323.7	r18.0	r15.0	15.0
Nigeria	r e.1	r—	r.1	r e.1	.1
Norway	2.8	3.2	3.0	3.5	33.8
Peru	149.0	192.2	r187.8	r199.8	3193.2
Poland[e]	64.0	66.0	361.3	60.0	55.0
Romania[e]	15.0	6.7	6.5	6.5	6.5
Russia[6]	—	—	—	—	75.0
Saudi Arabia[e]	.1	.2	.3	.3	.3
Serbia and Montenegro[4]	—	—	—	—	50.0
Slovenia[4]	—	—	—	—	2.5
South Africa, Republic of	90.2	78.2	69.4	76.3	375.4

See footnotes at end of table.

TABLE 10—Continued

LEAD: WORLD MINE PRODUCTION OF LEAD IN CONCENTRATES, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Spain	74.7	r62.8	r58.5	e60.0	50.0
Sweden	91.6	89.0	r98.3	r91.1	3106.2
Tajakistan[6]	—	—	—	—	2.0
Thailand	29.5	25.1	22.2	r16.7	15.0
Tunisia	3.7	2.7	3.0	r1.3	1.2
Turkey	9.4	10.6	r10.4	r10.5	11.0
U.S.S.R.[9]	440.0	440.0	420.0	r380.0	—
United Kingdom	1.2	r2.2	r1.4	r1.0	.5
United States	394.0	420.2	496.5	476.9	3407.5
Uzbekistan[6]	—	—	—	—	22.0
Yugoslavia[10]	103.3	107.0	99.1	e90.0	—
Zambia[11]	12.1	8.8	9.6	r9.1	9.0
Total[12]	r3,324.8	r3,244.5	r3,352.8	r3,276.0	3,242.2

[e]Estimated. [r]Revised.

[1]Table includes data available through July 6, 1993.

[2]In addition to the countries listed, Uganda may produce lead, but available information is inadequate to make reliable estimates of output levels.

[3]Reported figure.

[4]Formerly part of Yugoslavia; data were not reported separately until 1992.

[5]Less than 1/2 unit.

[6]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[7]Year beginning Mar. 21 of that stated.

[8]Reported for 1988 as galena (not further specified), assumed 78% Pb.

[9]Dissolved in Dec. 1991.

[10]Dissolved in Apr. 1992.

[11]Pb content of ore milled in year beginning Apr. 1 of that stated.

[12]Data may not add to totals shown because of independent rounding.

TABLE 11
LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992e
Algeria:e					
Primary	1.8	1.3	1.0	1.0	1.0
Secondary	2.1	1.4	3.5	3.5	3.5
Total	3.9	2.7	4.5	4.5	4.5
Argentina:					
Primary	r14.8	r11.5	r5.5	r11.0	10.0
Secondary	r14.0	13.0	r14.6	r14.0	13.9
Total	r28.8	r24.5	r2.1	r25.0	23.9
Australia:					
Primary	168.0	r178.0	212.0	220.0	2245.0
Secondarye	17.0	18.0	20.0	r18.0	19.0
Totale	185.0	r196.0	232.0	r238.0	264.0
Austria:					
Primary	8.3	r10.0	r8.4	6.4	5.5
Secondary	r14.1	r12.0	r15.1	16.3	218.4
Total	r22.4	r22.0	r23.5	22.7	223.9
Belgium:					
Primary	83.2	72.7	r74.6	r78.1	80.7
Secondary	43.4	36.8	32.2	r32.6	35.0
Total[3]	126.6	109.4	r106.8	r110.7	115.7
Bolivia: Primary	(3)	(3)	r.1	r.2	.1
Brazil:					
Primary	29.5	32.5	r30.1	r22.0	22.0
Secondary	68.7	53.3	r45.3	r42.0	42.0
Total	98.2	85.8	r75.4	r64.0	64.0
Bulgaria:e					
Primary	83.0	89.0	56.0	r46.0	45.0
Secondary	r18.0	r12.5	r10.6	r10.6	10.0
Total	r101.0	r101.5	r66.6	r56.6	55.0
Burma: Primary	4.4	3.4	r1.7	r2.2	1.8
Canada:					
Primary	179.5	157.3	r87.2	r106.4	151.3
Secondary	89.9	85.5	r96.5	r106.0	103.9
Total[3]	269.4	242.8	r183.6	r212.4	255.2
China:e					
Primary	200.0	245.0	240.0	265.0	265.0
Secondary	45.0	55.0	56.0	65.0	65.0
Total	245.0	300.0	296.0	330.0	330.0
Colombia: Secondarye	4.0	3.5	3.5	3.5	3.6
Czechoslovakia: Secondary	26.0	26.0	23.7	r17.8	17.0
France:					
Primary	146.5	149.3	162.3	r154.5	160.5
Secondary	109.2	118.1	108.2	r139.0	123.6
Total	255.7	267.4	270.5	r293.5	284.1

See footnotes at end of table.

TABLE 11—Continued

LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992e
Germany:					
Primary:					
Eastern states[e]	13.8	14.0	15.8	—	—
Western States	176.6	170.7	162.0	r—	—
Total primary	190.4	184.7	177.8	r160.8	145.0
Secondary:					
Eastern states	25.8	26.1	29.7	r—	—
Western States	168.5	179.1	186.7	r—	—
Total secondary	194.3	205.2	216.4	r201.7	200.0
Total	384.7	389.9	394.2	r362.5	345.0
Greece: Primary	13.1	5.6	r—	r—	—
Guatemala: Secondary	.1	.1	.1	r (3)	2 (3)
Hungary: Secondary[e]	.1	.1	.1	.1	.1
India:					
Primary	18.8	21.3	29.9	e33.1	30.0
Secondary	9.9	13.5	16.8	r e20.3	20.0
Total	28.7	34.7	46.7	r e53.4	50.0
Iran: Secondary[e]	10.0	9.0	10.0	r12.0	12.0
Ireland: Secondary[3]	211.7	12.0	12.0	12.0	12.0
Italy:					
Primary	72.2	74.2	e73.0	r111.1	100.0
Secondary	111.6	112.0	e100.0	r96.5	95.0
Total	183.8	186.2	e173.0	r207.6	195.0
Jamaica: Secondary[e]	1.0	1.0	1.0	1.0	1.0
Japan:					
Primary	217.7	207.7	204.9	r220.3	2218.8
Secondary	r122.3	r124.6	r122.3	r112.1	2111.4
Total[3]	r340.0	r332.4	r327.2	r332.4	2330.2
Kenya: Secondary[e]	r—	r—	r—	r—	—
Kazakhstan:[4]					
Primary	—	—	—	—	260.0
Secondary	—	—	—	—	170.0
Total	—	—	—	—	430.0
Korea, North: Primary[e]	r64.0	r70.0	r70.0	75.0	70.0
Korea, Republic of:[e]					
Primary	r61.0	r60.0	r61.0	40.0	60.0
Secondary	r29.0	r20.9	r14.0	40.0	30.0
Total	90.0	80.9	r75.0	80.0	90.0
Macedonia:[5]					
Primary	—	—	—	—	10.0
Secondary	—	—	—	—	5.0
Total	—	—	—	—	15.0
Malaysia: Secondary	15.0	16.0	16.0	16.0	16.0
Mexico:					
Primary	r168.1	160.0	r167.2	r151.8	2162.7
Secondary[e]	35.0	35.0	35.0	r8.6	9.8
Total[e]	r203.1	195.0	r202.2	r 2160.4	2172.6

See footnotes at end of table.

TABLE 11—Continued

LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992[e]
Morocco:[e]					
Primary	[2]68.4	[r]63.0	64.0	[r]70.0	70.0
Secondary[e]	2.0	2.0	2.0	2.0	2.0
Total	70.4	[r]65.0	66.0	[r]72.0	72.0
Namibia: Primary	44.4	44.2	35.1	33.4	[2]31.7
Netherlands: Secondary	39.5	41.5	44.1	[r]35.9	30.0
New Zealand: Secondary[e]	[r]3.6	[2]5.0	5.0	5.0	5.0
Nigeria: Secondary[e]	[r]—	[r]—	[r]—	[r]—	—
Pakistan: Secondary[e]	2.0	2.0	[r]2.5	[r]2.5	2.5
Peru:					
Primary	56.5	73.4	69.3	75.9	[2]82.5
Secondary[e]	5.0	5.0	5.0	5.0	5.0
Total[e]	61.5	78.4	74.3	80.9	87.5
Philippines: Secondary[e]	[r]11.4	[r]13.6	[r]12.1	[r]17.5	16.8
Poland:					
Primary[e]	61.0	[r]63.2	[r]49.8	[r]35.8	39.8
Secondary[e]	30.0	[r]15.0	[r]15.0	[r]15.0	15.0
Total	91.0	[r]78.2	[r]64.8	[r]50.8	[2]54.8
Portugal: Secondary[e]	6.5	6.5	5.0	5.0	6.0
Romania:[e]					
Primary	[r]27.2	[r]24.9	[r]12.5	[r]13.0	13.0
Secondary[e]	[r]16.0	[r]16.0	[r]15.0	[r]10.0	10.0
Total	[r]43.2	[r]40.9	[r]27.5	[r]23.0	23.0
Russia:[4]					
Primary	—	—	—	—	70.0
Secondary	—	—	—	—	40.0
Total	—	—	—	—	110.0
Serbia and Montenegro:[5]					
Primary	—	—	—	—	20.0
Secondary	—	—	—	—	5.0
Total	—	—	—	—	[2]25.0
Slovenia:[5]					
Primary	—	—	—	—	2.0
Secondary	—	—	—	—	3.0
Total	—	—	—	—	5.0
South Africa, Republic of: Secondary	37.4	36.9	31.2	32.1	31.0
Spain:					
Primary[e]	68.8	[r 2]62.0	60.0	65.0	60.0
Secondary	[e]52.0	51.8	[r]50.0	[e]50.0	50.0
Total	120.8	[r 2]113.8	[r]110.0	115.0	110.0
Sweden:					
Primary	57.8	48.7	[r]40.7	[r]49.2	46.8
Secondary	26.9	22.7	[r]35.4	[r]38.8	[2]44.3
Total	84.7	71.4	[r]76.1	[r]88.0	[2]91.1
Switzerland: Secondary	1.5	1.5	5.7	[r]6.4	[2]6.4
Taiwan: Secondary[e]	67.3	58.2	57.6	40.0	40.0

See footnotes at end of table.

TABLE 11—Continued

LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992e
Thailand: Secondary	15.6	18.7	15.9	r12.8	12.0
Trinidad and Tobago: Secondarye	1.8	1.8	1.8	1.8	1.8
Tunisia:e					
Primary	2.2	2.2	2.2	r.8	.8
Secondary	.5	.5	.5	r.2	.2
Total	2.7	2.7	2.7	r1.0	1.0
Turkey:e					
Primary	7.3	4.6	r5.4	r5.4	6.0
Secondary	3.7	2.4	3.6	3.1	3.2
Total	11.0	7.0	r9.0	r 28.5	9.2
U.S.S.R.:e 6					
Primary	447.0	465.0	420.0	380.0	—
Secondary	280.0	280.0	280.0	250.0	—
Total	727.0	745.0	700.0	630.0	—
United Kingdom:					
Primary	172.2	156.5	r156.5	r164.3	2198.8
Secondary	201.6	r177.8	r177.8	r146.7	2148.0
Total	373.8	r334.3	r334.3	r311.0	2346.8
United States:					
Primary	392.1	396.5	403.7	345.7	304.8
Secondary	736.4	891.3	r922.9	883.7	916.6
Total	1,128.5	1,287.8	r1,326.6	1,229.4	1,221.4
Venezuela: Secondarye	18.0	17.0	17.0	17.0	17.0
Yugoslavia:					
Primary	70.9	99.6	82.0	e70.0	—
Secondarye	39.0	18.0	17.0	18.0	—
Total	109.9	117.6	99.0	e88.0	—
Zambia: Primary8	6.3	r3.7	r3.7	r2.7	3.0
Grand total:9	r5,795.7	r5,910.8	r5,762.5	r5,603.3	5,541.6
Of which:					
Primary	r3,206.5	r3,241.1	r3,067.6	r3,016.1	2,993.5
Secondary	r2,589.1	r2,669.7	r2,694.9	r2,587.1	r2,548.0

eEstimated. rRevised.

[1]Table includes data available through July 22, 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.

[2]Reported figure.

[3]Less than 1/2 unit.

[4]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[5]Formerly part of Yugoslavia; data were not reported separately until 1992.

[6]Dissolved in Dec. 1991.

[7]Dissolved in Apr. 1992.

[8]Data are for fiscal year beginning Apr. 1 of that stated.

[9]Data may not add to totals shown because of independent rounding.

TABLE 12

PRODUCTION AND SHIPMENTS OF LEAD PIGMENTS[1] AND OXIDES IN THE UNITED STATES

(Metric tons unless otherwise specified)

Product	1991				1992			
	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	86,870	80,614	82,529	$59,881,085	75,895	70,355	70,569	$56,715,831
Leady oxide	r428,475	r407,051	NA	NA	280,899	266,854	NA	NA
Total[3]	r515,346	r487,664	NA	NA	356,794	337,209	NA	NA

rRevised. NA Not available. W Withheld to avoid disclosing company proprietary data.

[1]Excludes basic lead sulfate; withheld to avoid disclosing company proprietary data.

[2]At plant, exclusive of container.

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

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF LEAD PIGMENTS AND COMPOUNDS, BY KIND

Kind	Quantity (metric tons)	Value (thousands)
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
Total[1]	23,946	29,967
1992		
White lead carbonate	88	146
Red and orange lead	154	292
Chrome yellow and molybdenum orange pigments and lead-zinc chromates	4,685	10,789
Litharge	17,119	10,919
Leady litharge	423	324
Glass frits (undifferentiated)	7,769	13,726
Total[1]	30,239	36,197

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

Source: Bureau of the Census.

TABLE 14
U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ore and concentrates (lead content):				
Australia	11,412	$5,342	—	—
Bahamas	4	3	—	—
Belgium	44,411	10,595	24,327	$8,110
Canada	3,454	2,042	4,692	3,134
Germany	—	—	16,799	4,082
Haiti	29	16	—	—
Italy	—	—	5,727	1,002
Japan	11,943	2,714	—	—
Korea, Republic of	—	—	1,078	810
Mexico	5,339	1,263	2,139	631
Morocco	—	—	3,451	567
Russia[1]	—	—	5,129	1,334
Spain	10,420	2,892	—	—
Taiwan	29	9	—	—
Ukraine[1]	—	—	8,981	2,532
United Kingdom	603	187	—	—
Venezuela	310	96	—	—
Total[2]	87,953	25,159	72,323	22,202
Ash and residues (lead content):				
Belgium	6,807	2,511	1,925	857
Canada	2	2	36	100
India	4,899	1,572	—	—
Mexico	91	8	—	—
United Arab Emirates	—	—	180	74
United Kingdom	30	14	—	—
Total[2]	11,828	4,106	2,141	1,031
Unwrought lead and lead alloys (lead content):				
Australia	5	18	38	35
Belgium	—	—	100	217
Brazil	40	103	49	108
Canada	4,819	4,437	5,865	4,221
Chile	485	485	454	450
China	710	539	—	—
France	32	66	18	20
Germany	13	18	54	285
Haiti	56	27	23	18
Hong Kong	83	89	224	182
Indonesia	2,288	1,507	3,506	2,022
Israel	1,002	805	1,617	1,044
Italy	16	26	2	3
Jamaica	31	19	3	3
Japan	8,270	7,556	7,292	4,305
Korea, Republic of	38,033	26,491	28,672	20,054
Malaysia	4,900	3,762	3,208	2,026

See footnotes at end of table.

TABLE 14—Continued

U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Unwrought lead and lead alloys (lead content)—Continued:				
Mexico	569	$691	225	$182
Netherlands	101	149	48	57
New Zealand	—	—	45	35
Philippines	297	191	27	70
Saudia Arabia	17	14	49	50
Singapore	1,228	1,059	365	263
Taiwan	27,737	19,304	12,264	7,939
Thailand	124	115	97	592
United Kingdom	3,518	2,198	4	5
Venezuela	51	245	10	29
Other	3	68	81	411
Total[2]	94,428	69,982	64,340	44,624
Wrought lead and lead alloys (lead content):				
Argentina	1	6	5	39
Australia	11	127	47	215
Bahamas	26	46	6	12
Barbados	14	18	—	—
Belgium	17	23	9	41
Brazil	5	10	(3)	3
Canada	1,114	2,726	1,176	2,861
Chile	1,518	2,478	1	19
China	1	11	135	263
Dominican Republic	(3)	7	—	—
Ecuador	3	4	2	5
Egypt	36	129	—	—
France	105	216	26	718
Germany	107	326	62	180
Guatemala	3	25	21	28
Guyana	—	—	75	146
Haiti	122	496	46	269
Hong Kong	37	379	461	1,188
India	167	101	3	3
Indonesia	—	—	33	26
Israel	216	210	—	—
Italy	8	103	—	—
Jamaica	95	350	—	—
Japan	152	990	209	745
Korea, Republic of	316	1,093	147	821
Malta	4	7	—	—
Mexico	1,853	6,855	1,485	7,198
Netherlands	82	308	131	373
New Zealand	—	—	59	176
Nigeria	—	—	375	442
Panama	—	—	41	30

See footnotes at end of table.

TABLE 14—Continued

U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Wrought lead and lead alloys (lead content)—Continued:				
Philippines	311	$424	36	$160
Saudia Arabia	44	110	69	116
Singapore	43	329	56	247
South Africa, Republic of	269	60	1	17
Spain	(3)	6	(3)	25
Sweden	10	21	6	32
Taiwan	219	809	155	1,560
Thailand	32	210	2	26
Trinidad and Tobago	—	—	41	45
United Arab Emirates	—	—	152	705
United Kingdom	458	879	17	135
Venezuela	93	225	70	109
Other	r124	r497	91	663
Total[2]	7,615	20,614	5,251	19,637
Grand total[2]	201,824	119,860	144,056	87,494
Scrap (gross weight):				
Antigua and Barbuda	8	14	39	14
Argentina	42	4	2	32
Austria	(3)	5	26	6
Bahamas	7	29	23	68
Belgium	185	r621	135	384
Brazil	4,457	959	2,392	417
Canada	54,488	10,105	48,771	8,386
China	3,286	2,522	820	500
Colombia	—	—	471	105
France	274	83	168	69
Germany	1,011	278	269	117
Ghana	—	—	174	38
Hong Kong	1,431	918	109	37
India	1,706	1,093	1,379	292
Indonesia	4,764	1,023	126	20
Ireland	186	128	192	74
Isreal	—	—	59	10
Italy	47	104	—	—
Japan	1,386	1,275	111	461
Jordan	350	35	—	—
Korea, Republic of	2,267	1,108	1,457	949
Malaysia	—	—	68	36
Mexico	5,399	1,895	2,381	833
Netherlands	211	120	30	27
Panama	17	14	(3)	4
Philippines	3,525	660	1,337	74
Singapore	(3)	10	3	104
South Africa, Republic of	274	77	23	5

See footnotes at end of table.

TABLE 14—Continued

U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Scrap (gross weight)—Continued:				
Spain	2,583	$481	314	$42
Taiwan	2,290	1,397	572	584
Thailand	993	459	104	571
Trinidad and Tobago	96	20	—	—
United Kingdom	1,773	729	648	482
Venezuela	75	23	921	160
Other	r130	r384	88	265
Total[2]	93,262	26,574	63,212	15,165

rRevised.
[1]Formerly part of the U.S.S.R.; data were not reported separately until 1992.
[2]Data may not add to totals shown because of independent rounding.
[3]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 15

U.S. IMPORTS FOR CONSUMPTION OF LEAD, BY COUNTRY

Country	1990		1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ore and concentrates (lead content):[1]						
Australia	1,478	$534	—	—	—	—
Canada	2,137	515	4,961	$1,384	370	$125
Germany	—	—	254	101	—	—
Honduras	—	—	(2)	9	639	156
Italy	234	297	—	—	—	—
Mexico	968	1,052	7,177	2,910	1,969	2,062
Peru	5,778	2,751	—	—	2,332	1,079
Switzerland	73	18	45	62	—	—
Total	10,668	5,167	12,437	4,466	5,310	3,422
Base bullion (lead content):						
Canada	38	30	19	11	58	31
China	91	43	17	7	150	54
Mexico	2,584	1,563	364	252	11	9
Other	—	—	19	13	—	—
Total[3]	2,713	1,636	419	283	218	94
Pigs and bars (lead content):						
Australia	—	—	7,995	4,018	—	—
Belgium	—	—	21	12	(2)	3
Brazil	—	—	12	7	—	—
Canada	70,662	58,099	83,627	50,960	124,715	70,480
Germany	66	253	25	79	2	1
India	330	223	—	—	—	—
Italy	—	—	—	—	38	48
Mexico	18,055	14,005	22,614	12,688	56,102	30,709
Panama	—	—	79	29	58	25
Peru	1,000	822	500	228	9,797	5,124
Sweden	—	—	1,204	666	—	—
United Arab Emirates	239	646	113	342	11	43
United Kingdom	269	332	274	304	—	—
Venezuela	13	11	—	—	—	—
Other	—	—	11	16	—	—
Total[3]	90,638	74,395	116,473	69,351	190,723	106,433
Reclaimed scrap, including ash and residues (lead content):[4]						
Canada	165	72	117	28	216	54
Mexico	116	30	—	—	—	—
Other	—	—	—	—	20	11
Total	281	102	117	28	236	65
Grand total[3]	104,300	81,299	129,446	74,128	196,487	110,013
Wrought lead, all forms, including wire and powders (gross weight):						
Belgium	1	86	1	17	(2)	14
Canada	1,152	2,068	r1,302	1,839	1,822	2,303
China	278	771	136	367	145	445
France	21	140	111	370	1	68

See footnotes at end of table.

TABLE 15—Continued

U.S. IMPORTS FOR CONSUMPTION OF LEAD, BY COUNTRY

Country	1990		1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Wrought lead, all forms, including wire and powders (gross weight)—Continued:						
Germany	258	$1,167	210	$836	269	$1,318
Hong Kong	—	—	—	—	164	534
Italy	330	448	817	982	379	620
Japan	37	399	r47	539	66	1,149
Mexico	2,769	2,061	2,628	1,556	2,122	1,563
Namibia	—	—	—	—	1,002	454
Netherlands	55	241	46	131	19	159
Panama	—	—	—	—	64	26
Peru	735	628	133	100	765	436
Spain	4	96	—	—	2	114
Taiwan	178	495	160	469	151	399
Thailand	30	120	(2)	2	2	7
United Arab Emirates	40	101	60	128	20	42
United Kingdom	88	513	r177	548	70	687
Venezuela	709	366	26	16	—	—
Other	40	245	108	561	34	209
Total[3]	6,723	9,944	r5,962	8,460	7,094	10,548

rRevised.

[1]Also 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.

[2]Less than 1/2 unit.

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

[4]Also includes other lead-bearing materials containing greater than 10% by weight of copper, lead, or zinc (any one).

Source: Bureau of the Census.

LIME

By M. Michael Miller

Mr. Miller, a physical scientist with 15 years of minerals experience with the U.S. Department of the Interior, has been the commodity specialist for lime since 1989. Domestic survey data were prepared by Tonya Hardin, statistical assistant; and the world production table was prepared by Harold D. Willis, international data coordinator.

Lime is an important chemical with hundreds of chemical, industrial, and environmental uses in the United States. Its history probably dates back at least 4,000 to 6,000 years. The ancient Egyptians utilized lime as an ingredient in mortar and plaster. The Greeks, Romans, and Chinese utilized lime for construction, agriculture, bleaching, and tanning. Its uses began expanding with the advent of the industrial revolution, but it remained primarily a construction commodity until the rapid growth of the chemical process industries at the beginning of the 20th century. At the turn of the century, more than 80% of lime consumed in the United States was for construction uses, but now more than 90% of lime is consumed for chemical and industrial uses.

Lime is a basic chemical that ranked sixth in total production in the United States in 1992. It is produced in 32 States and Puerto Rico; its major markets are the steel industry, the utility power industry, the pulp and paper industry, the construction industry, and municipal water- and sewage-treatment facilities.

Total lime sold or used by domestic producers, excluding that from Puerto Rico, increased by about 587,000 short tons to nearly 17.9 million short tons in 1992. Production included the commercial sale or captive consumption of quicklime, hydrated lime, and dead-burned refractory dolomite. These products were valued at more than $949 million. Merchant sales increased by 504,000 tons to a record high of nearly 15.8 million tons, while captive consumption increased by 82,000 tons from 1991 levels. *(See table 1.)*

DOMESTIC DATA COVERAGE

To comply with Federal law and Executive Order 12770, the U.S. Bureau of Mines has decided on the following transition plan for the mandated conversion of the remaining commodity publications not currently being reported in metric units. It was decided that for the 1992 Commodity Annual Reports and 1993 Mineral Industry Surveys, all tables containing measures of weight will be published in English units with an additional total line showing metric units. For the 1993 Commodity Annual Reports and 1994 Mineral Industry Surveys, all data will be published in metric units with an additional total line showing English units. Beginning with the 1994 Commodity Annual Reports and the 1995 Mineral Industry Surveys, all data will be published in metric units only. As a result, the 1992 Lime Annual Report has been published in English units with an additional total line showing metric units. That will be reversed for the 1993 report, and the 1994 report will be entirely in metric units.

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 115 operations to which the annual survey request was sent, 101 responded, representing 80% of the total sold or used by producers shown in table 2. Production for 12 nonrespondents was provided based on the monthly lime survey. Production for two nonrespondents was estimated using reported prior-year production figures. Three plants were idle or shut down.

BACKGROUND

Definitions and Specifications[1]

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 it 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, railcars, 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.

Technology[2]

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 CO_2 (carbon dioxide) are formed. This process is performed in a kiln, of which there are a 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 sold. 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 in 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 with 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 values 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 values over the past 20 years, based on constant 1992 dollars, two trends become evident. From 1973 to 1979, they increased every year and were up a total of 49%. From 1979 to 1991, they decreased every year and were down a total of 30%. This long downward spiral finally stopped in 1992, when the average value increased, albeit by only 0.4%, over that of 1991. *(See figure 1.)*

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 2522.10.0000, 2522.20.0000, and 2522.30.0000, 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 to all 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

The Environmental Protection Agency (EPA) began testing the drinking water in 660 large public water systems for lead, in compliance with the Safe Drinking Water Act regulations. The initial sampling found excessive levels of lead in the drinking water of 130 cities. EPA's lead standard is 15 parts per billion (ppb), and they found samples in 10 cities with levels above 70 ppb. These levels do not represent average lead levels but rather were taken from "high-risk" homes defined as those homes served by lead service lines or that contained lead piping or copper piping with lead solder.

All water systems serving more than 50,000 users must implement corrosion control, regardless of the test results. The 15 ppb standard will be utilized for systems serving fewer than 50,000 users. Corrosion control measures consist of treating the water with chemicals such as calcium phosphate, zinc orthophosphate, or lime. Corrosion control measures for large systems must be in place by January 1, 1997.

EPA, under a court-mandated deadline, finally released its rule on treatment standards for municipal sewage sludge (Part 503 of Clean Water Act) in December 1992. The final rule sets management standards for the use and disposal of municipal sewage sludge. The rule encourages recycling and reuse of sludge, rather than incineration or landfilling. Following removal of toxic contaminants, sludge can be recycled as soil compost or fertilizer. At present, approximately 30% of sewage sludge is being recycled; the rule encourages an increase in that level.

Lime stabilization is a recognized means of treating municipal sludge before land application. EPA had previously included lime stabilization in its list of "Processes to Significantly Reduce Pathogens." The standard lime stabilization process involves the addition of lime slurry to liquid sludge to meet the EPA standard of a pH $\geq$ 12, 2 hours after treatment. A more cost-effective process for large treatment plants involves adding dry quicklime to the dewatered sludge.

The Department of Transportation regulations covering the transportation of hazardous materials (HMR-181), 49 CFR 171-180, were revised. The regulations were revised to comply with the U.N. Recommendations List of Dangerous Goods Most Commonly Carried. As a result, quicklime's listing was changed to "UN 1910 - Class 8, Packaging Group 3." Class 8 stands for corrosive material and Group 3 means minor danger. Based on these regulations, quicklime shipments would have to be placarded and manifested as corrosive materials. However, it was judged that these revisions were in error, and the regulations were revised again. An "A" symbol was added to the quicklime listing, stipulating that the provisions of the regulation applied only to shipments by "air only." No placards or manifests are required for shipment by truck or rail; only the description "UN 1910, Quicklime, Calcium Oxide" is required on shipping documents.[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, increased by 3.4% compared with that of 1991. Merchant lime sales increased by 3.3%, and captive lime used by producers increased by 4%.

In 1992, 69 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 each in

Idaho and Utah; Continental Lime Inc., with one plant each in Montana, Nevada, Utah, and Washington; APG Lime Co., with one plant each in Texas and Virginia; Allied Lime Co., with two plants in Alabama; Martin Marietta Corp. in Ohio; Chemical Lime Inc., with two plants in Texas; and Wimpey Minerals PA Inc., with two plants in Pennsylvania. These 10 companies operated 29 plants and accounted for 59% 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 unavailable for all commercial lime plants. Based on the data available, the commercial lime industry operated at about 75% of capacity in 1992. *(See tables 2 and 3.)*

The industry reported some consolidation and new plant construction in 1992. Mississippi Lime Co. acquired Virginia Lime Co. (Ripplemead, VA) from Scottish Heritable Inc. and renamed the company Eastern Ridge Lime Co. LP. No capacity increases were planned, but equipment upgrades were planned to increase reliability. Continental Lime Inc. completed 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 went on-line in September 1992. Basin Electric Power Cooperative's subsidiary Dakota Coal Co. completed construction of a lime plant near Frannie, WY, to operate as Wyoming Lime Producers. The plant will operate a 400-ton-per-day Kennedy Van Saun preheater rotary. Plant operations will be run by Pete Lien & Sons, Rapid City, SD. Operational start was scheduled for January 1993. Western Lime & Cement Co. started installation of a second preheater rotary kiln at its lime plant in Green Bay, WI. The new kiln was expected to go on-line during the summer of 1993.

Chemstar's parent holding company, Chemical Lime Co., Ft. Worth, TX, purchased the Texada Lime Division of BP Resources Canada Ltd. The lime plant is at Fort Langley, British Columbia, and has two calcimatic (rotary hearth) kilns producing high-calcium quicklime. Texada will operate separately but will report to Chemstar. Chemical Lime Co. also acquired the idle M.E.R.R. Corp. lime plant located near Grantsville, UT. Chemstar's plans for a new lime plant at Cosgrave, NV, were put on hold while the company reviewed the markets. It applied for a permit extension and plans to do more drilling of the limestone reserves in the permit area.

Chemstar Lime Inc. completed construction of its Tenmile lime plant near Soda Springs, ID. The plant went on-line in September 1992. The quarry is operated under contract by Conda Mining Inc., which is responsible for supplying material to Chemstar's crushing plant. The operation is on Federal land, and a mining plan with concurrent reclamation was required. Chemstar constructed a 600-ton-per-day Maerz vertical shaft kiln on the site. A Maerz kiln is more energy efficient than straight rotary kilns or preheater rotary kilns. It consumes about 3.5 million Btu's per ton of lime compared with about 4.5 to 5.0 million Btu's for a preheater rotary and 6.0 million Btu's for a straight rotary. The selection of a Maerz kiln was made, in part, to facilitate permitting, as the kiln is more environmentally friendly than conventional rotary kilns.[5] *(See table 4.)*

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 as a component in tar-bonded refractory brick used in basic oxygen furnaces. Lime consumption for raw steel production (from basic oxygen and electric arc furnaces) was essentially unchanged at 5.1 million tons and accounted for about 29% 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 thus 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 alkalies. 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.

As a result of the expansion of certain markets and in an effort to disseminate as much data as possible, the end-use table has been expanded to include several end uses formerly included under "other." These newly listed end uses include petrochemicals, argon oxygen decarburization, ladle desulfurization, asphalt paving, industrial solid waste treatment, industrial wastewater treatment, and scubber sludge solidification. *(See table 5.)*

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, increased by $1.57 per ton over the previous year to $53.30 per ton. Average values were $51.56 per ton for chemical and industrial lime, $52.17 for environmental lime, $63.11 for construction lime, $65.28 for agriculture lime, and $75.87 for refractory dolomite.

The average value of quicklime sold increased to $50.33 per ton. Average values per ton were $50.23 for chemical and industrial lime, $49.34 for environmental lime, $50.30 for construction lime, $79.32 for agricultural lime, and $74.62 for refractory dead-burned dolomite.

The average value of hydrated lime sold increased to $65.45 per ton. Average values were $60.49 for chemical lime, $65.41 for environmental lime, $68.29 for construction lime, and $64.88 for agricultural lime.

Foreign Trade

According to the Bureau of the Census, exports of lime increased by 25% to 64,500 tons. Imports of lime increased by 22% to 212,520 tons. Most U.S. trade was with Canada and Mexico, which together accounted for nearly 100% of the U.S. imports and exports of lime. Canada was the major trading partner, receiving 80% of U.S. exports and shipping 90% of U.S. imports.

The import statistics were revised to include lime classified as "hydraulic lime." Almost all U.S. lime imports came from Canada, and because Canada did not produce hydraulic lime it is believed that the material was actually hydrated lime. *(See tables 6 and 7.)*

World Review

Australia.[6]—Dennis Mitchell Ltd. (DML) and Dennis Mitchell-Melcann Pty. Ltd. (DMMPL) own a number of limestone and lime operations across Australia. In the State of Tasmania, DML operated a 33,000-ton-per-year lime plant at Mole Creek. Its major market was the mining industry, which has been solid despite a poor local economy. DML's largest lime operation is located at Lilydale in the State of Victoria. The company produced limestone, quicklime, and hydrate for local markets. DML also operated lime plants in the State of Queensland at Calcium and Ootann, where markets include the sugar and gold industries. The Calcium plant added a hydrator as a result of strong demand for hydrated lime by the gold industry. DMMPL is a joint venture operating several operations in the States of New South Wales and Queensland. The joint-venture company operated lime plants at Tamaree, Queensland, and Attunga, New South Wales. DML took a 50% equity interest and management role in

Loongana Lime Pty. Ltd., a producer in the State of Western Australia serving the gold industry.

Canada.—Shipments of lime were essentially unchanged from 1991 levels at 2.6 million tons valued at $182.8 million, based on preliminary data. In 1992, the Canadian lime industry was composed of 13 companies that operated 19 plants. Capacity utilization was estimated at 60% in 1992. More than 90% of output was quicklime, which was consumed predominantly by the steel, environmental, and pulp and paper industries.

Although there was no new plant construction in 1992, there were a number of ownership changes. Canadian steel producer Dofasco Inc. sold its lime subsidiary, Beachvilime Ltd., to Calcitherm Nederland BV of the Netherlands in August 1992. Beachvilime's lime plant is located at Ingersoll, Ontario, and had a reported annual capacity of about 518,000 tons of quicklime and 75,000 tons of hydrate. Calcitherm is a holding company for a number of limestone and lime producers in the Belgium, Italy, and United States. Canadian steel producer Stelco Inc. also sold its lime operation, Chemical Lime Works, to Global Stone Corp. of British Columbia. The Chemical Lime Works lime plant, located at Ingersoll, Ontario, had a reported annual capacity of 248,000 tons.[7]

BP Resources Canada Ltd. sold its Texada Lime Division (Fort Langley, British Columbia) to Chemical Lime Co. of the United States. Texada operated two calcimatic kilns and produced high-calcium quicklime. Texada Lime will operate as a separate company but will report to Chemical Lime Co.'s subsidiary, Chemstar Lime Inc. Chemstar operated lime plants in five Western states. Koch Minerals of Canada Ltd. purchased the Reiss Lime Co. at Spragge, Ontario.

Germany.—Bundesverband der Deutchen Kalkindustrie (German Lime Association) celebrated its 100th anniversary. It was formed in 1892 from a larger lime and cement association. The German Lime Association is currently host for the International Lime Association, which transfers between member nations periodically.

United Kingdom.—Redland, PLC, agreed to sell the manufacturing plants of its subsidiary Steetley Refractories, Ltd. to J. E. Baker Co. of the United States. Steetley has two facilities located in Dudley and Worksop, about 130 miles northwest of London. Steetley Refractories Ltd. is a well-known producer and supplier of refractory products, including magnesite-carbon brick, basic brick, slide grate refractories, and heat storage blocks. The additional product line will complement J. E. Baker's line and strengthen Baker's international business. *(See table 8.)*

Current Research

Chemstar Lime Inc. has been busy in the research and development of new lime-based products designed for specific markets. They patented a new lime-based agglomeration product designed to decrease leaching times and increase the recovery rate of gold from its ore. The product is intended for use in the heap-leaching process for extracting gold from low-grade ores. The product is a combination of inorganic minerals that when agglomerated with fine particles create dendritic crystalline structures allowing greater contact of oxygen and cyanide with the ore. The material is utilized in the same fashion as lime and portland cement and provides the pH control necessary for maximum gold recovery. The company also patented a new lime-based dust-control agent. The material is a cost effective semipermanent and permeable sealant designed to last 6 months. It is combined with water and then sprayed over dust sources such as construction and landfill sites, tailing piles, and open-air transport vehicles. Chemstar is also conducting research on a lime product designed to compete with caustic soda in the water- and sewage-treatment market. Much of the potential success of such a product depends on the development of a form with easier use and handling characteristics.[8]

OUTLOOK

Lime has dozens of end uses in the chemical, industrial, and construction industries. Steelmaking is still the largest single end use for lime; the steel industry's consumption of lime in basic oxygen and electric arc furnaces was essentially unchanged compared with 1991 levels. Consumption by the steel industry has been relatively flat in recent years. Steel output is expected to increase modestly in the short term. Demand should increase for steel for highway and transit construction resulting from the Intermodal Surface Transportation Efficiency Act (ISTEA), from improved auto sales resulting from an improved economy, and in general construction. If the economy continues to improve, these factors should translate into increased lime consumption for the next few years.

Construction markets, which showed a healthy increase in 1992, should continue a strong showing. The passage of ISTEA and the lime industry push to market more lime to the asphalt paving industry should be the driving forces in the construction markets. Unfortunately, the construction markets tend to be dependent on the weather, and prolonged periods of rainy weather can damage regional markets, as was the case in 1991.

Environmental markets as a whole should show growth, led by the FGD market. FGD consumption is expected to show significant growth, despite the small decrease reported in 1992. The deadline for phase 1 compliance with the Clean Air Act Amendments is January 1, 1995, which means utility companies will be forced to make decisions on their compliance strategies in the near future. Because individual utility powerplants are large consumers, often requiring hundreds of thousands of tons per year, even a small percentage of utilities installing new lime scrubbers would translate into significant long-term increases in demand for lime. Longer

term increases could materialize from the use of lime in dry scrubbers used with small boilers.

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 polychlorinated biphenyls and dioxins, and on the use of lime as a binder and desulfurizing additive in refuse-derived fuels. Lime's traditional use as a neutralizing agent should remain relatively stable. It could, however, lose some market share in the acid mine drainage market, as there is increasing research and development of cheaper alternative processes such as the use of anaerobic bacteria and wetlands or the use of fly ash.

Consumption by the pulp and paper industry decreased by 10% in 1992. Lime is used in the sulfate process pulp mills to recausticize sodium carbonate into caustic soda. Consumption of caustic soda for pulping and bleaching is expected to decline by about 5% in 1993, and then remain essentially flat through 1996. Consumption of lime by the pulp and paper industry is expected to follow a similar trend.

Total U.S. paper demand is projected to increase by 2.4% annually through the 1990's. The outlook depends on the health of the economy and the strength of the U.S. dollar against foreign currencies. Increased consumption of paper products, driven by a stronger U.S. economy, should translate into greater consumption of lime for precipitated calcium carbonate production. Increases in exports are expected, assuming there isn't substantial strengthening of the U.S. dollar against foreign currencies.

Regionally, gold production will continue to provide a solid market in the West for lime consumed in the cyanide heap-leaching process. The gold boom may be over owing to the changed political climate and growing antimining sentiments, but current mining and mines in development should fuel the lime market for decades.

When caustic soda prices escalated in recent years, Western soda ash producers constructed facilities for the lime-soda production of caustic soda, termed chemical caustic. Chemical caustic was deemed a cost-attractive substitute to traditional "electrolytic" caustic soda, which at the time was priced between $250 and $290 per ton. Unfortunately, recent spot prices for caustic have been as low as $100 per ton. This eliminates any cost value advantage the chemical caustic producers might have. The chemical caustic industry could still develop into a significant regional market for lime, but it will depend entirely on the price of caustic.

The price of caustic soda and availability of supply could delay or even eliminate a potential new regional market. A major manufacturer of propylene oxide was considering switching from the use of caustic soda to hydrated lime for the dehydrochlorination stage of the manufacturing process. If the manufacturer proceeded with the substitution, the company would consume about 500,000 tons of hydrated lime per year. The current caustic situation is likely to have put any plans for switching to hydrated lime on the back burner, at least until caustic supplies tighten and prices rise.

[1]National Lime Association. Chemical Lime Facts. Bull. 214, 5th ed., 1988, 44 pp.

[2]Boynton, R. S. Chemistry and Technology of Lime and Limestone. Wiley, 1980, 578 pp.

[3]Pages 316-319 of work cited in footnote 2.

[4]Francis, H. L. Revision of Department of Transportation Regulations Covering the Transportation of Hazardous Materials (HMR-181), 49 CFR 171-180. Notice to National Lime Association members, Oct. 2, 1992; available upon request from H. L. Francis, National Lime Association, Arlington, VA.

[5]Weaver, B. Tenmile, Idaho—The Latest in Lime Plants. Pit and Quarry, v. 85, No. 11, May 1993, pp. 26-28.

[6]Griffiths, J. Australia's White Minerals—Finding More Exports. Ind. Miner. (London), No. 298, July 1992, pp. 55-56.

[7]Industrial Minerals (London). Canada: Steel Producers Sell Lime Facilities. No. 300, Sept. 1992, p. 10.

[8]Chemical Marketing Reporter. Lime is Special. V. 242, No. 9, Sept. 1, 1992, pp. 5 and 11.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

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Other Sources

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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)

		1988	1989	1990	1991	1992
United States:[1]						
Number of plants		115	115	113	112	112
Sold or used by producers:						
Quicklime		14,066	14,500	14,762	14,541	14,798
Hydrated lime		2,531	2,249	2,313	2,390	2,726
Dead-burned dolomite		455	402	377	339	333
Total[2]		17,052	17,152	17,452	17,270	17,857
Total	thousand metric tons	15,469	15,560	15,832	15,667	16,200
Value[3]	thousands	$817,893	$852,113	$901,549	$890,482	$949,674
Average value per ton		$47.96	$49.68	$51.66	$51.56	$53.18
Lime sold		14,736	15,016	15,448	15,265	15,769
Lime used		2,317	2,135	2,004	2,005	2,087
Exports[4]		15	32	r54	r52	65
Imports for consumption[4]		210	218	173	174	213
Consumption, apparent[5]		17,248	17,337	r17,571	r17,392	18,005
World: Production		r147,663	r153,492	r149,508	r145,742	e141,901

eEstimated. rRevised.
[1]Excludes regenerated lime. Excludes Puerto Rico.
[2]Data may not add to totals shown because of independent rounding.
[3]Selling value, f.o.b. plant, excluding cost of containers.
[4]Bureau of the Census.
[5]Calculated by sold or used plus imports minus exports.

TABLE 2

LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

State	1991					1992				
	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	149	1,361	1,510	$75,506	4	172	1,431	1,603	$82,619
Arizona, Nevada, Utah	9	189	1,304	1,493	81,113	9	185	1,488	1,674	88,889
California	10	49	258	307	20,389	10	51	229	280	18,072
Colorado, Montana, Wyoming	9	—	280	280	14,313	9	—	400	400	21,709
Idaho, Oregon, Washington	7	26	435	461	31,994	8	70	464	535	35,672
Illinois, Indiana, Missouri	8	529	2,961	3,490	169,687	8	540	2,977	3,518	174,560
Iowa, Nebraska, South Dakota	5	W	W	287	15,153	5	W	W	274	15,222
Kentucky, Tennessee, West Virginia	5	124	1,922	2,047	102,565	5	120	1,862	1,981	100,963
Michigan	8	32	581	613	30,959	8	30	606	636	31,253
North Dakota	3	—	98	98	5,360	3	—	111	111	4,288
Ohio	9	W	W	1,783	85,976	9	W	W	1,841	96,739
Pennsylvania	10	309	1,386	1,695	95,328	9	282	1,378	1,660	94,543
Puerto Rico	1	30	—	30	4,440	1	30	—	30	3,717
Texas	7	481	892	1,373	69,400	7	546	928	1,474	83,359
Virginia	5	150	675	825	39,612	5	137	705	842	40,271
Wisconsin	4	149	387	536	23,226	4	121	400	521	26,579
Other[3]	9	r203	r2,340	r473	r29,901	9	208	2,417	507	34,936
Total[2]	113	2,420	14,880	r17,300	894,922	113	2,492	15,396	17,887	953,391
Total thousand metric tons	XX	2,195	13,499	15,694	XX	XX	2,261	13,967	16,227	XX

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Other." XX Not applicable.

[1]Excludes regenerated lime. Includes Puerto Rico.

[2]Data do not add to total shown because of independent rounding.

[3]Includes Arkansas, Louisiana, Massachusetts, Minnesota, Oklahoma, and data indicated by the symbol W.

TABLE 3

LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES,[1] BY SIZE OF PLANT

Size of plant	1991			1992		
	Plants	Quantity (thousand short tons)	Percent of total	Plants	Quantity (thousand short tons)	Percent of total
Less than 10,000 tons	10	70	(2)	11	81	(2)
10,000 to 25,000 tons	22	357	2	21	387	2
25,000 to 50,000 tons	15	562	3	14	541	3
50,000 to 100,000 tons	15	1,159	7	14	1,003	6
100,000 to 200,000 tons	19	2,579	r15	23	3,188	18
200,000 to 400,000 tons	24	6,050	r15	21	5,978	33
More than 400,000 tons	8	6,523	38	9	6,709	38
Total	113	17,300	100	113	17,887	100
Total thousand metric tons	XX	15,694	XX	XX	16,227	XX

rRevised. XX Not applicable.

[1]Excludes regenerated lime. Includes Puerto Rico.

[2]Less than 1/2 unit.

TABLE 4

DESTINATION OF SHIPMENTS OF LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

(Thousand short tons)

State	1991			1992		
	Quicklime	Hydrated lime	Total[2]	Quicklime	Hydrated lime	Total[2]
Alabama	624	32	656	639	24	663
Alaska	1	1	2	—	2	2
Arizona	271	59	329	333	45	378
Arkansas	149	26	175	122	25	147
California	475	96	571	367	97	464
Colorado	77	27	104	156	31	187
Connecticut	21	7	28	21	4	25
Delaware	13	5	19	9	2	11
District of Columbia	17	37	54	21	26	46
Florida	376	25	401	426	22	449
Georgia	278	77	355	241	79	320
Idaho	167	3	170	119	44	162
Illinois	603	176	779	546	182	728
Indiana	1,420	35	1,455	1,455	34	1,488
Iowa	73	26	99	65	29	94
Kansas	75	19	94	81	31	112
Kentucky	388	40	428	392	42	434
Louisiana	250	95	345	253	108	362
Maine	—	1	1	—	—	—
Maryland	183	20	203	118	14	133
Massachusetts	120	12	132	175	15	190
Michigan	1,037	76	1,112	957	39	996

See footnotes at end of table.

TABLE 4—Continued

DESTINATION OF SHIPMENTS OF LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

(Thousand short tons)

State	1991			1992		
	Quicklime	Hydrated lime	Total[2]	Quicklime	Hydrated lime	Total[2]
Minnesota	258	15	274	323	19	341
Mississippi	196	9	205	190	15	205
Missouri	162	67	228	155	69	224
Montana	200	18	218	175	14	190
Nebraska	61	14	75	63	13	76
Nevada	294	36	330	380	27	407
New Hampshire	2	—	2	—	—	—
New Jersey	197	26	223	135	18	153
New Mexico	176	28	203	143	32	175
New York	80	37	117	86	27	112
North Carolina	198	43	241	199	46	245
North Dakota	218	5	223	254	8	262
Ohio	1,581	148	1,729	1,834	132	1,966
Oklahoma	131	20	152	125	12	137
Oregon	128	27	155	155	25	180
Pennsylvania	1,740	201	1,941	1,680	227	1,908
Rhode Island	7	2	9	7	1	8
South Carolina	175	26	201	204	26	230
South Dakota	31	2	33	23	2	25
Tennessee	207	55	262	211	62	273
Texas	932	469	1,401	930	557	1,487
Utah	140	16	156	291	19	311
Vermont	—	2	2	—	—	—
Virginia	153	58	211	190	45	235
Washington	205	16	221	237	19	256
West Virginia	444	61	505	515	66	581
Wisconsin	154	52	206	149	48	197
Wyoming	106	25	131	159	20	179
Total	14,794	2,373	17,166	15,309	2,444	17,754
Puerto Rico	(3)	23	23	(3)	24	24
Canada	57	15	72	54	16	70
Other[4]	29	7	36	33	8	41
Total[2]	86	47	132	87	48	135
Grand total[2]	14,880	2,420	17,300	15,396	2,492	17,887
Grand total thousand metric tons	13,499	2,195	15,694	13,967	2,261	16,227

[1]Excludes regenerated lime.

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

[3]Less than 1/2 unit.

[4]Includes other countries and U.S. possessions.

TABLE 5

LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE[1]

(Thousand short tons and thousand dollars)

Use	1991				1992			
	Sold	Used	Total[2]	Value	Sold	Used	Total[2]	Value
Agriculture	53	—	53	3,741	29	—	29	1,867
Chemical and industrial:								
Alkalies	W	W	88	4,372	W	W	172	8,249
Aluminum and bauxite	160	—	160	8,459	173	—	173	9,314
Copper ore concentration	W	W	409	19,691	W	—	W	23,086
Food products, animal or human	22	—	22	1,224	22	—	22	1,516
Glass	168	—	168	8,389	120	—	120	5,639
Magnesia from seawater or brine	W	W	577	28,873	W	W	W	W
Oil well drilling	12	—	12	633	13	—	13	737
Oil and grease	W	W	W	W	39	—	39	3,107
Ore concentration, other	378	—	378	18,135	405	—	405	20,341
Paper and pulp	W	W	1,240	59,509	W	W	1,127	57,706
Petrochemicals	61	—	61	3,490	62	—	62	4,366
Precipitated calcium carbonate	W	W	298	15,370	W	W	426	21,253
Steel:								
Basic oxygen furnaces	W	W	4,156	198,486	W	W	4,225	206,648
Electric arc furnaces	920	—	920	47,651	887	—	887	47,001
Open-hearth furnaces	48	—	48	2,300	—	—	—	—
Argon oxygen decarburization	73	—	73	3,669	97	—	97	4,827
Ladle desulfurization, iron or steel	105	—	105	5,287	105	—	105	5,308
Other	184	—	184	8,742	200	—	200	9,438
Sugar refining	29	737	675	44,476	30	672	702	37,408
Tanning	21	—	21	1,374	20	—	20	1,279
Other[3]	r7,421	1,083	r1,825	88,740	7,725	1,243	3,018	145,113
Total	9,602	1,820	11,420	568,870	9,898	1,915	11,813	612,336
Construction:								
Asphalt paving	116	—	116	6,450	108	—	108	5,661
Finishing lime	106	—	106	7,840	56	—	56	3,901
Mason's lime	(4)	(4)	185	10,404	(4)	(4)	150	10,018
Soil stabilization	714	—	714	39,714	944	—	944	53,280
Other	r181	—	r181	r16,058	331	—	193	18,726
Total	1,117	(4)	1,302	80,466	(4)	(4)	1,451	91,586
Environmental:								
Acid water, mine or plant	r344	r2	r346	20,756	308	2	310	17,027
Flue gas sulfur removal	1,725	—	1,725	84,390	1,703	—	1,703	86,770
Industrial solid waste treatment	41	—	41	2,213	45	—	45	2,399
Industrial wastewater treatment	61	—	61	3,429	56	—	56	3,047
Scrubber sludge solidification	57	—	57	2,791	60	—	60	3,031
Sewage treatment	521	—	521	28,435	(4)	(4)	516	29,548
Water purification	1,138	—	1,138	58,890	1,169	—	1,169	60,995
Other	r291	5	r296	15,208	917	—	403	19,554
Total	r4,178	r7	4,185	216,112	4,258	(4)	4,262	222,371

See footnotes at end of table.

TABLE 5—Continued

LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE[1]

(Thousand short tons and thousand dollars)

Use	1991				1992			
	Sold	Used	Total[2]	Value	Sold	Used	Total[2]	Value
Refractory lime (dead-burned dolomite)	(4)	(4)	339	25,736	(4)	(4)	333	25,230
Grand total[2]	15,295	2,005	17,300	894,922	15,800	2,087	17,887	953,391
Grand total thousand metric tons	13,875	1,819	15,694	XX	14,334	1,893	16,227	XX

[r]Revised. W Withheld to avoid disclosing company proprietary data. XX Not applicable.
[1]Excludes regenerated lime. Includes Puerto Rico.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes briquetting, brokers, calcium carbide, chrome, citric acid, commercial hydrators, desiccants, ferroalloys, fiberglass, glue, insecticides, magnesium metal, metallurgy, pelletizing, pharmaceuticals, rubber, silica brick, soap, and uses indicated by symbol W in "Chemical and industrial" lime only.
[4]Withheld to avoid disclosing company proprietary data; included in "Grand total."

TABLE 6

U.S. EXPORTS OF LIME

	Quantity (short tons)	Value[1] (thousands)
1988	14,908	$3,113
1989	32,241	3,893
1990	[r]53,839	[r]6,145
1991	[r]51,688	[r]6,058
1992	64,500	7,540

[r]Revised.
[1]Customs value.

Source: Bureau of the Census.

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF LIME

	Quicklime		Hydrated lime		Total	
	Quantity (short tons)	Value[1] (thousands)	Quantity (short tons)	Value[1] (thousands)	Quantity (short tons)	Value[1] (thousands)
1989	150,824	$7,841	[r]66,832	[r]$4,127	217,656	$11,968
1990	108,826	6,222	[r]64,371	[r]4,171	173,197	10,392
1991	121,678	7,227	[r]52,248	[r]3,841	173,927	11,068
1992	167,461	11,322	45,059	3,661	212,520	14,983

[r]Revised.
[1]Customs value.

Source: Bureau of the Census.

TABLE 8

QUICKLIME AND HYDRATED LIME, INCLUDING DEAD-BURNED DOLOMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1988	1989	1990	1991	1992[e]
Algeria	r35	r30	r35	r68	66
Australia[e]	1,210	1,650	1,650	1,650	1,650
Austria	1,703	1,788	1,804	r e1,760	1,760
Belgium	r2,090	r2,169	r2,288	r2,228	3 1,211
Bosnia and Herzegovina[4]	—	—	—	—	220
Botswana	(5)	—	r(5)	r(5)	(5)
Brazil	6,063	6,316	r e6,300	r e6,100	6,100
Bulgaria	1,570	1,581	r1,452	e1,430	1,320
Burundi	(5)	(5)	(5)	(5)	(5)
Canada	2,776	r2,813	r2,581	r2,575	3 3,178
Chile[e]	1,320	1,430	1,430	1,320	1,430
China[e]	14,300	17,600	18,700	20,400	21,000
Colombia[e]	1,430	1,430	1,430	1,430	1,430
Congo	e(5)	(5)	(5)	(5)	(5)
Costa Rica[e]	11	r11	r13	r 3 10	10
Croatia[4]	—	—	—	—	440
Cuba[e]	3 197	200	r200	200	180
Cyprus	8	8	8	r7	7
Czechoslovakia	3,650	3,688	3,439	r3,560	3,300
Denmark (sales)[e]	3 148	149	140	150	150
Dominican Republic[e]	40	r20	r5	r—	—
Egypt	e105	e105	r75	r826	830
Ethiopia	r e3	r(5)	r(5)	r 3 (5)	(5)
Fiji	—	e2	—	—	—
Finland (sales)	287	247	r e250	e250	250
France[e]	3,405	3,400	3,300	3,300	3,300
Germany:					
Eastern states	r3,670	r3,756	e3,300	—	—
Western states	7,497	7,753	7,598	—	—
Total	r11,167	r11,509	e10,898	r8,303	8,500
Guatemala	79	87	e83	r e77	77
Hungary	938	968	916	r616	500
India[e]	830	870	880	940	940
Iran[e]	700	700	700	700	700
Ireland	107	123	r123	r121	110
Israel	143	r198	r254	r229	230
Italy[e 6]	4,300	4,300	r4,244	r3,968	3,970
Jamaica[e]	3 88	100	100	r105	105
Japan (quicklime only)	8,516	9,354	9,902	r9,970	9,400
Jordan	3	3	6	r5	5
Kenya	r30	35	r15	r15	15
Korea, Republic of[e]	250	250	250	260	260
Kuwait[e]	72	72	55	r6	33
Lebanon[e]	11	11	11	11	17
Libya[e]	290	290	290	290	290
Macedonia[4]	—	—	—	—	44

See footnotes at end of table.

TABLE 8—Continued

QUICKLIME AND HYDRATED LIME, INCLUDING DEAD-BURNED DOLOMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1988	1989	1990	1991	1992[e]
Malawi	e3	r4	r5	r4	4
Malta[e]	6	6	6	6	6
Martinique[e]	6	6	6	6	6
Mauritius[e]	8	8	8	8	8
Mexico[e]	r6,610	6,610	6,610	7,170	7,170
Mongolia[e]	r24	105	r114	r110	110
Mozambique[e]	r—	r—	r—	r—	—
Nepal	23	45	e50	r27	28
New Zealand[e]	165	110	110	100	110
Nicaragua[e]	4	4	r2	r e2	2
Norway[e]	110	110	110	110	110
Paraguay	94	114	e110	e110	110
Peru[e]	14	14	14	r15	15
Philippines	4	e5	14	r8	11
Poland	4,883	4,873	r3,521	e3,420	3,300
Portugal[e]	220	220	220	220	220
Romania[e]	3,900	3,600	r3,500	r3,300	2,800
Saudi Arabia[e]	13	13	13	13	13
Serbia and Montenegro[4]	—	—	—	—	770
Slovenia[4]	—	—	—	—	550
South Africa, Republic of (sales)	2,112	2,138	2,018	1,946	1,900
Spain[e]	1,300	1,380	r1,300	r1,300	1,300
Sweden[e]	e740	740	720	r720	720
Switzerland	r35	r33	r29	e44	44
Taiwan	117	r678	r610	r677	660
Tanzania	e3	3	r2	r1	1
Tunisia[e]	720	720	r720	720	660
Turkey[e]	1,600	1,500	1,800	1,800	1,800
Uganda[e]	1	1	r2	r2	2
U.S.S.R.[7]	33,705	33,486	r e30,900	e28,700	25,400
United Arab Emirates[e]	50	50	50	50	50
United Kingdom[e]	3,100	3,100	r2,900	r2,900	2,800
United States including Puerto Rico (sold or used by producers)	17,077	17,178	17,481	r17,300	e17,887
Uruguay	11	13	e13	e13	13
Venezuela[e]	2	2	2	2	2
Yugoslavia[8]	2,754	2,653	2,340	r e1,764	—

See footnotes at end of table.

TABLE 8—Continued

QUICKLIME AND HYDRATED LIME, INCLUDING DEAD-BURNED DOLOMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1988	1989	1990	1991	1992[e]
Zaire	111	110	[r]101	[r]91	[3]71
Zambia	263	353	[r e]280	[r e]203	220
Total	[r]147,663	[r]153,492	[r]149,508	[r]145,742	141,901
Total thousand metric tons	[r]133,962	[r]139,247	[r]135,649	[r]132,083	128,731

[e]Estimated. [r]Revised.

[1]Table includes data available through June 21, 1993.

[2]Lime 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.

[3]Reported figure.

[4]Formerly part of Yugoslavia; data were not reported separately until 1992.

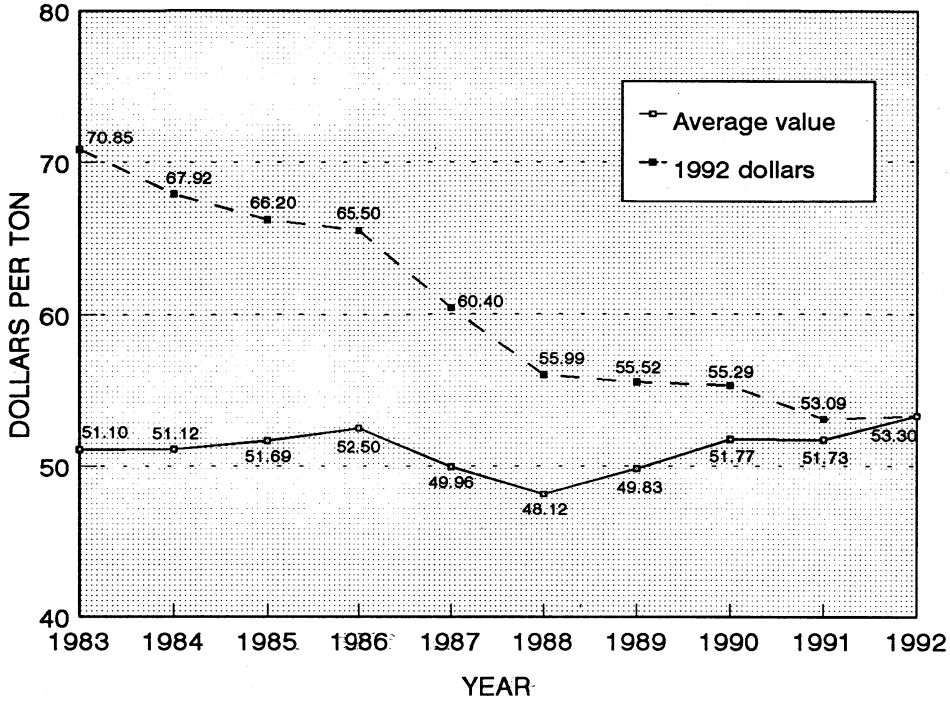
[5]Less than 1/2 unit.

[6]Includes hydraulic lime.

[7]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

[8]Dissolved in Apr. 1992.

FIGURE 1
TIME-VALUE RELATIONSHIPS FOR LIME



LITHIUM

By Joyce A. Ober

Mrs. Ober, a physical scientist with 15 years industry and U.S. Bureau of Mines experience, has been the commodity specialist for lithium since 1986. Domestic survey data were prepared by Pamela G. Shorter, statistical assistant; and the world table was prepared by Theodore Spittal, international data coordinator.

The United States has been the leading producer and consumer of lithium and its compounds for many years. Chile, as a leading and low cost producer of lithium carbonate, is now challenging the United States; production in Chile is conducted by one of the two U.S. lithium companies, the world's largest producer of lithium carbonate. The other U.S. producer is vigorously pursuing opportunities to develop a similar low-cost operation in South America.

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) held a 36-million-kilogram stock of lithium hydroxide monohydrate that had been on the list for disposal for the past several years. DOE had planned to offer the lithium hydroxide in 1989, but delayed the disposal until an environmental impact study was complete. A final decision about disposal was delayed, and no material was offered for sale in 1992. DOE was planning to sell at least a portion of the material in 1993.

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.

Production

The two companies that produced lithium in the United States in 1992 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. Lithium was recovered from geothermal brine deposits in Nevada. Spodumene is the most common form of lithium ore, but petalite and lepidolite are other types of lithium ores that are mined in different parts of the world. These three types of ore are beneficiated to produce lithium ore concentrates that can be consumed directly in certain applications. Spodumene and brines are converted to lithium carbonate and then other compounds for consumption in other end uses.

Lithium carbonate is the most important lithium compound produced from brine and ore 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 the 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 1 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.

Cyprus Foote Mineral Co. produced lithium carbonate from its brine deposit in Silver Peak, NV, and spodumene concentrate at its mine in Kings Mountain, NC. It operated processing facilities for downstream lithium products and metal in Kings Mountain, 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.

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 also operated a butyllithium plant in Bayport, TX.

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 12% in 1992. Ceramics and glass production and aluminum smelters were the largest consumers of lithium carbonate and lithium concentrates in the United States, comprising 20% and 18% of the lithium market, respectively. Other consuming industries were synthetic rubber and pharmaceuticals, 13%; chemical manufacturing, 13%; miscellaneous chemicals, 12%; lubricants, 11%; batteries, 7%; and air treatment, 4%.[1]

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 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 third largest end use for lithium compounds is as catalysts in the production of synthetic rubbers and plastics and pharmaceuticals. N-butyllithium initiates the reactions between styrene and butadiene that form abrasion-resistant synthetic rubber and thermoplastic rubbers that require no vulcanization. Other organic lithium compounds are catalysts for the production of plastics like polyethylene. Lithium metal and compounds also are used by drug manufacturers in the production of a number of drugs, including Vitamin A, some steroids, an anticholesterol drug, an analgesic, antihistamines, tranquilizers, sleep inducers, and contraceptives. Pharmaceutical-grade lithium carbonate is approved directly for the treatment for manic-depressive psychosis. This is the only treatment approved by the U.S. Food and Drug Administration in which lithium is consumed by the patient.

The multipurpose grease industry was another of the important end uses for lithium in 1992. 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, and new battery configurations continue to be developed. Renewed interest in electrically powered vehicles spurred additional interest in battery research and new, more efficient types of rechargeable (secondary) lithium batteries were developed and improved to meet the needs for this market. Special interest was shown for a lithium polymer battery developed in Japan.

Nonrechargeable (primary) lithium batteries offer improved performance over alkaline batteries at a slightly higher cost and have been commercially available for more than 10 years. 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.

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. 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 sixth consecutive year. Prices averaged about 3% higher in 1992 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, the 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 12% lower in 1992 than they were in 1991. The majority of U.S. exports of lithium compounds were to Germany, Japan, and the United Kingdom. Imports of lithium compounds reported by the Bureau of the Census increased 31%. Cyprus Foote Mineral Co. owns a lithium brine operation in Chile; nearly 100% of all lithium carbonate imports was from this source. Lithium ore concentrates from Australia, 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 and Chile were the leading producers of lithium carbonate; significant quantities of lithium compounds and ore concentrates also were produced in Australia, Canada, Chile, China, Portugal, the former U.S.S.R. (probably Russia), 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, Germany, Japan, and the United Kingdom produced downstream lithium compounds from imported lithium carbonate.

Capacity.—Lithium presents special problems when compiling estimates 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 contain 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.

Lithium carbonate production capacity has been established at about 6,300 tons contained lithium in the United States and Chile, the world's largest producers. Additional capacity at Cyprus Foote's Kings Mountain plant has been idle since mid-1986, and it is not expected to reopen in the near future. For this reason, 1,500 tons of lithium capacity was not included in U.S. figures. The plant has not been dismantled, and this capacity could be available if required.

An estimated 1,800 tons of lithium contained in lithium carbonate may be produced in China and the former U.S.S.R., but these estimates denote only an approximate order of magnitude. No basis for more exact estimates is available; output for China and the former U.S.S.R. has never been reported, but production in those countries is known to occur.

Worldwide production capacity for lithium ore concentrates, which are used directly in the ceramics and glass applications and are not converted to any other lithium compound, is estimated to be about 2,900 tons, contained lithium.

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.—The Gwalia Group mined high-grade, low-iron spodumene at its mine in Greenbushes, Western Australia. Gwalia 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.

Bolivia.—A lithium brine deposit identified in Bolivia may be the world's largest salt flat. 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.[3]

FMC had been negotiating for 4 years with the Government of Bolivia for the rights to develop 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 the recovery of lithium carbonate from the evaporated brines. Extreme political pressures in 1990 delayed the ratification of the contract that defined FMC's development of the project to produce 10,000 tons per year of lithium carbonate over 40 years at an investment of at least $92 million.[4] After FMC signed the contract, the Bolivian Congress changed four major conditions of the contract, including raising the value-added tax rate. FMC informed the Government of Bolivia that the company could not accept the changes to the contract, and it is unlikely that FMC will follow through with the project.[5]

Brazil.—Brazil has produced small quantities of lithium minerals for almost 30 years. Companhia Brasileira de Litio 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.[6] Although 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 Litio Ltda., having bought the remaining interest from the Chilean Government in 1989. Cyprus Foote produced lithium carbonate from the brines at 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 has 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.[7]

Sociedad Quimica y Minera de Chile (SQM) bought AMAX's interest in the project in the second half of 1992. SQM is a Chilean fertilizer producer, and its interest in the MINSAL project is for the potash that would be produced as a raw material for its potassium nitrate plant. For the project to be economically feasible as a potassium nitrate operation, production and sales of byproduct lithium carbonate are essential. Reports indicate that FMC would contribute to the development costs and receive the exclusive rights to the lithium that would be recovered, and in this way would acquire the low-cost lithium deposit for which the company has been seeking.[8]

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 Germany, Japan, and the Netherlands.

France.—Lithium metal is produced by Metaux Speciaux SA in Plombieres 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.[9]

Germany.—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 Langelsheim.

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 operated a 100-ton-per-year battery-grade lithium metal operation in Kagawa to meet the demands of the large lithium battery industry in Japan. 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 hand picked. Small amounts of two other lithium minerals, lepidolite (lithia mica) and amblygonite (lithia alumina phosphate), were other products. Germany imported most of these concentrates. High-grade lepidolite was hand picked at the company's Helicon Mine for export to Western Europe and Japan.[10]

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 had been lepidolite.

Former U.S.S.R.—Lithium ores, compounds, and metal were produced in the former U.S.S.R., but no details were available. The majority of lithium production is believed to be from the Kola Penninsula in Russia.

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.

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 by 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.[11] *(See table 5.)*

OUTLOOK

The health of the lithium industry is closely tied to the performance of the primary aluminum industry. Reduced consumption of lithium in the aluminum industry has once again had a negative effect on lithium consumption. Demand for lithium compounds and minerals in the ceramics and glass industry continues to grow modestly. Similar increases are expected for the near 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 to some extent for alloys should increase, but total consumption of metal will remain small in comparison to the demand for lithium compounds for the short term. The fate of the lithium battery market will be largely dependant on the success of electric vehicles and whether the best type of battery for powering them finally is determined to be some form of lithium battery.

Other markets should remain relatively stable with slight growth. 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.

The United States should remain the largest producer of lithium carbonate until FMC begins production of lithium carbonate from a brine deposit in South America. Although no official announcement concerning a formal agreement for actual production in any South American country has been announced, FMC's continued pursuit of such an operation is not in doubt, only the timing is in question. Chances are very good that FMC will be producing lithium carbonate at the Salar de Atacama within the next few years. At that time, Chile will become the leading producer of lithium compounds in the world.

[1]Cyprus Minerals Company Annual Report. 1992, p. 14.

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TABLE 1
SALIENT LITHIUM STATISTICS

(Metric tons of contained lithium)

	1988	1989	1990	1991	1992
United States:					
Production[1]	W	W	W	W	W
Producers' stock changes[1]	W	W	W	W	W
Imports[2]	1,000	630	790	590	770
Shipments of Government stockpile surplus[3]	2	—	—	—	—
Exports[4]	2,300	2,600	2,600	2,400	2,100
Consumption:					
Apparent	W	W	W	W	W
Estimated	2,700	2,700	2,700	2,600	2,300
Rest of world: Production[1]	r4,800	r5,400	5,400	r5,200	e5,200

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.
[1]Mineral concentrate and carbonate.
[2]Compounds, concentrate, ores, and metal.
[3]Lithium hydroxide monohydrate.
[4]Compounds.

TABLE 2
DOMESTIC YEAREND PRODUCERS' AVERAGE PRICES OF LITHIUM AND LITHIUM COMPOUNDS

	1991		1992	
	Dollars per pound	Dollars per kilogram	Dollars per pound	Dollars per kilogram
Lithium bromide, 54% brine: Truckload lots, delivered in drums	5.31	11.71	5.47	12.06
Lithium carbonate, technical: Truckload lots, delivered	1.91	4.21	1.96	4.32
Lithium chloride, anhydrous, technical: Truckload lots, delivered	4.53	9.99	4.67	10.30
Lithium fluoride	6.67	14.70	6.87	15.15
Lithium hydroxide monohydrate: Truckload lots, delivered	2.44	r5.37	2.51	5.53
Lithium metal ingot, standard-grade: 1,000-pound lots, f.o.b.	31.50	69.46	32.45	71.54
Lithium sulfate, anhydrous	3.51	r7.73	4.16	9.17
N-butyllithium in n-hexane (15%): Truckload lots, delivered	18.78	41.40	19.34	42.64

rRevised.

Source: U.S. lithium producers and Chemical Marketing Report, v. 240, No. 1, Jan. 3, 1993, p. 34.

TABLE 3

U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY

Compound and country	1991		1992	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium carbonate:				
Argentina	7,994	$33,566	30,000	$122,430
Australia	889	8,722	38,901	194,364
Belgium	158	4,537	3,556	33,866
Brazil	1,000	4,224	9	6,110
Canada	1,128,763	4,189,644	591,758	2,228,129
France	1,059	3,795	—	—
Germany	3,067,698	9,286,896	1,678,751	5,256,754
India	29,847	123,564	51,594	229,176
Italy	1,885	10,029	—	—
Japan	1,263,050	4,574,933	1,263,792	4,415,657
Korea, Republic of	109,819	355,154	75,962	285,503
Mexico	124,349	448,041	123,426	486,590
Netherlands	108,121	390,521	436,975	1,444,464
Singapore	2,173	16,638	16,000	57,553
Taiwan	15,957	53,023	66,258	243,776
United Kingdom	1,471,587	4,051,112	1,704,699	4,612,190
Venezuela	617,106	2,070,566	696,847	2,420,900
Total[1]	7,951,455	25,624,965	6,778,526	22,037,462
Lithium carbonate U.S.P.[2]				
Austria	15	4,655	—	—
Australia	83,144	329,769	49,381	149,432
Colombia	2,289	24,911	—	—
Germany	2,794	37,622	500	10,407
India	11,498	49,524	16,928	87,249
Italy	20	3,750	363	4,800
Japan	932,004	3,233,933	357,831	1,161,580
Korea, Republic of	151,296	505,023	174,283	587,652
Mexico	38,043	77,160	—	—
New Zealand	—	—	1,383	23,086
South Africa, Republic of	3,554	17,220	—	—
Taiwan	181,560	653,922	46,764	159,329
Venezuela	207,003	710,560	799,998	2,786,616
Total[1]	1,613,219	5,648,049	1,447,431	4,970,151
Lithium hydroxide:				
Argentina	111,268	498,430	135,649	580,933
Australia	104,684	500,579	61,506	258,358
Bahamas	—	—	157	6,039
Belgium	—	—	8,613	16,142
Brazil	302,289	1,414,466	212,057	908,391
Canada	34,168	168,448	41,830	202,272
Chile	22,400	105,892	33,177	160,020
Colombia	41,779	193,388	36,379	162,452
Dominican Republic	—	—	998	7,400

See footnotes at end of table.

TABLE 3—Continued

U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY

Compound and country	1991		1992	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium hydroxide—Continued:				
Ecuador	7,000	$33,860	5,000	$19,000
Egypt	8,800	40,066	5,000	24,120
Finland	17,500	47,740	—	—
Germany	321,523	1,372,859	360,548	1,642,567
Honduras	—	—	1,850	8,717
Hong Kong	100,802	186,480	—	—
India	225,016	988,190	63,034	270,639
Indonesia	37,196	190,476	36,651	229,179
Israel	26,901	141,752	33,867	149,399
Japan	743,435	3,530,724	739,862	3,831,787
Korea, Republic of	216,723	906,048	280,032	1,163,886
Malaysia	—	—	1,000	4,639
Mexico	79,973	387,949	180,462	751,109
Morocco	359	12,103	14,968	67,735
Netherlands	5,017	29,053	74,000	338,451
New Zealand	—	—	4,500	23,270
Norway	24	9,177	—	—
Pakistan	32,622	66,690	27,051	122,236
Peru	7,000	31,640	648	2,970
Philippines	9,580	42,543	45,888	195,680
Poland	201	10,695	451	26,110
Saudi Arabia	55,321	111,504	15,000	65,851
Singapore	58,069	233,704	64,721	339,141
South Africa, Republic of	26,146	119,563	20,973	126,520
Taiwan	25,001	118,225	24,944	111,352
Thailand	76,490	288,979	78,000	353,331
United Kingdom	343,849	1,046,082	275,275	889,475
Venezuela	37,784	170,635	27,027	124,209
Total[1]	3,078,922	12,997,940	2,911,116	13,183,380
Lithium metal:[3]				
Belgium	6,788	NA	—	NA
Brazil	48	NA	—	NA
Colombia	—	NA	168	NA
Germany	4,190	NA	—	NA
Gabon	39	NA	—	NA
Japan	46,035	NA	62,064	NA
Netherlands	132	NA	—	NA
Nigeria	39	NA	—	NA
South Africa, Republic of	103	NA	—	NA
Total[1]	57,373	NA	62,232	NA

NA Not available.

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

[2]Pharmaceutical-grade lithium carbonate.

[3]According 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			
	1991		1992	
	Quantity (kilograms)	Value[1]	Quantity (kilograms)	Value[1]
Lithium carbonate:				
Canada	170	$5,451	60	$8,454
Chile	3,108,820	7,363,384	4,051,286	10,561,787
Germany	200	7,303	100	3,001
Japan	645	43,126	602	43,564
Total	[2]3,109,834	7,419,264	4,052,048	10,616,806
Lithium hydroxide:				
Canada	50	3,975	125	7,847
China	16,422	64,080	17,000	64,600
Germany	200	13,155	771	18,086
Japan	5	15,768	16,862	170,752
Netherlands	—	—	200	23,521
Switzerland	—	—	2	1,539
United Kingdom	3,698	31,499	1,470	7,215
Total	20,375	128,477	36,430	293,560

[1]Customs value.

[2]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 5

LITHIUM MINERALS AND BRINE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992e
Argentina (minerals not specified)	119	104	e120	e110	100
Australia, spodumene	e30,000	e40,000	e40,000	r 3 40,376	3 4 42,516
Brazil:e					
Amblygonite	4 25	25	25	25	25
Petalite	4 1,115	1,200	1,200	1,200	1,200
Spodumene	4 331	350	350	350	350
Canada, spodumene e 5	14,000	14,000	12,000	r12,000	4 18,500
Chile, carbonate from subsurface brine	7,332	7,508	r9,082	r8,575	8,600
China (minerals not specified)e 6	15,000	15,000	15,000	15,500	15,500
Namibia:					
Amblygonite	147	131	54	r20	20
Lepidolite	18	41	80	r33	30
Petalite	1,477	1,226	1,134	r1,139	1,150
Portugal, lepidolite	14,109	18,264	10,614	e12,000	10,000
Russia (minerals not specified) 6 7 8	—	—	—	—	45,000
U.S.S.R.e 8 9	55,000	55,000	55,000	50,000	—
United States, spodumene and subsurface brine	W	W	W	W	W
Zimbabwe (minerals not specified)	15,073	20,647	19,053	r9,186	10,000

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.

[1]Table includes data available through Apr. 23, 1993.

[2]In 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.

[3]Data are for year ending June 30 of that stated.

[4]Reported figure.

[5]Estimates based on imports by the United States.

[6]These estimates denote only an approximate order of magnitude; no basis for more exact estimates is available.

[7]Formerly part of the U.S.S.R.

[8]All production in the former U.S.S.R. from 1988 through 1991 came from Russia.

[9]Dissolved in Dec. 1991.

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 9 years. Domestic survey data were prepared by Lillian Wood, statistical assistant, and Renaldo Summerset, management assistant; international data tables were prepared by Doug Rhoten, international data coordinator, and Ron Hatch, international data coordinator.

U.S. magnesium metal production increased slightly in 1992, but imports decreased, and producers drew down their inventories to meet demand. Partially as a result of the drop in inventories, U.S. transaction prices for primary magnesium trended up from midyear.

One of the areas that has continued growing is the use of magnesium diecastings in automobile components. Many U.S. automakers planned to add more magnesium components to future models, and as a result, several North American diecasters increased their production capacities or planned new facilities.

Antidumping and countervailing duties were assessed against the largest Canadian magnesium producer, and as a result, 1992 imports from Canada, which had been the largest U.S. import source since 1990, dropped dramatically. The newly independent States of the former U.S.S.R. were granted most-favored-nation status midyear, and Russia became the United States' largest import source for primary magnesium.

As in the United States, world magnesium inventories decreased as several companies in Italy, Japan, and the United States closed all or part of their plants. New capacity was planned for construction in Australia, Israel, and Saudi Arabia by the end of the decade. If all these plants are constructed, world production capacity would increase by 120,000 metric tons.

Total demand for magnesium compounds increased slightly in 1992. Refractory applications, although still the primary end use, remained at lower levels than in the past. Producers were investigating environmental applications, such as water treatment and flue gas desulfurization, as potential growth markets for magnesium compounds. Imports of magnesia increased, particularly dead-burned magnesia from China, which was the principal source of U.S. imports. Net import reliance for magnesium compounds increased to 23% for 1992 from 18% in 1991.

Mine and plant closures occurred in Canada, Germany, Greece, and the United Kingdom during the year. These closures were partially offset by additional magnesium compounds capacity that came on-stream in Australia, Israel, and Mexico.

DOMESTIC DATA COVERAGE

Data for magnesium metal are collected from two voluntary surveys of U.S. operations. Of the 115 companies canvassed for magnesium consumption data, 76% responded, representing 47% of the primary magnesium consumption shown in tables 4 and 6. Data for the 28 nonrespondents were estimated based on prior year consumption levels and other factors.

Data for magnesium compounds were collected from one voluntary survey of U.S. operations. Of the 19 operations canvassed, 74% responded, representing 63% of the magnesium compounds shipped and used shown in table 13. Data for the five 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; Olivine operates one mine and one processing plant in Washington.

Electrolytic plants in Canada, Kazakhstan, Norway, Russia, Ukraine, and the United States represent 68% of the world magnesium metal production capacity (excluding the capacity in Kazakhstan, Russia, and Ukraine that is used exclusively for titanium metal production). Smaller thermal plants are in Brazil, Canada, China, France, India, Italy, Japan, the United States, and Yugoslavia.

The largest magnesite production facilities in the world are in China, North Korea, and Russia. Together, these three countries account for 58% of the world magnesite production capacity. Japan and the United States account for 61% of the world's magnesium compounds production capacity from seawater or

brines. Fused magnesia is produced in Australia, Canada, France, Israel, Japan, Mexico, 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 is 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]

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 ton, with energy costs as the largest component of the total operating cost. A weighted average operating cost was estimated to be $1,122 per ton. 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. The weighted average operating cost for magnesium compounds production from all sources was $288 per ton. Energy costs also represent the largest component of total operating costs.[7]

Analysts at Commodities Research Unit (CRU) evaluated the direct operating costs of magnesium plants that operated during 1991. The operating cost curve showed that about one-half of the producers had direct operating costs less than $1.00 per pound of magnesium, and about 20% of the production was at direct operating costs above $1.25 per pound. In their cost estimates, CRU evaluated capital and operating costs for a 60,000-ton-per-year greenfield magnesium plant constructed in Australia. Capital costs were estimated at $470 million, with a 20% rate of return on investment over a 10-year life of the loan. In addition, operating costs were estimated to be $1.76 per pound in constant 1990 dollars, with most of the costs being capital charges resulting from the rate of return on investment and loan life. If the rate of return was lowered to 10% and the life of the loan was extended to 20 years, capital change would drop by one-half.[8]

Tariffs for magnesium and magnesium compounds are shown in table 3. 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 July 7, 1992, the International Trade Administration (ITA) made a final determination on countervailing and antidumping duties assessed on magnesium imported into the United States from Canada. The final countervailing duty for primary and alloy magnesium was 21.61% ad valorem, and the final antidumping duty was 31.33% ad valorem for primary magnesium only. These duties affect Norsk Hydro Canada Inc., but do not affect material imported from either Norsk Hydro in Norway or Timminco Ltd. in Canada.[9] These duties were affirmed by the International Trade Commission, which voted on the determinations on August 11. As a result, the U.S. Customs Service was required to collect both countervailing and antidumping duties on imports of magnesium from Norsk Hydro Canada.

On November 16, the Department of Commerce announced a final decision concerning Canadian Provincial government subsidies of Norsk Hydro Canada's electric power contract for its Becancour, Quebec, primary magnesium plant. According to Commerce, the amended power contract between Norsk Hydro and Hydro Quebec, the power supplier, which was approved on August 5 and made retroactive effective to January 1, no longer conferred a subsidy. As a result of this determination, the countervailing duty for pure and alloy magnesium dropped from 21.61% ad valorem to 7.61% ad valorem.[10] The 14% difference in the margin is the quantity assigned to the power contract; in its original investigation, ITA found that Norsk Hydro received a 60% discount when compared to Hydro Quebec's other customers. Antidumping duties, which were levied on pure magnesium only, were not affected.

In an effort to eliminate all countervailing and antidumping duties, Norsk Hydro filed a request for review with the United States Section of the Binational Secretariat of the United States-Canada Free Trade Agreement on September 25. When a request for review is made, a panel is formed to review the final determination and to determine whether it conforms to the antidumping or countervailing duty laws in the country that imposed the duty. The reviews were scheduled to take place in 1993.

With the signing of trade agreements

on June 17, the Russian Federation officially received most-favored-nation status. As a result, the tariff on U.S. primary magnesium imports from the former U.S.S.R. was reduced from 100% ad valorem to 8% ad valorem, making imports of the metal competitive in U.S. markets.

Production.—Total U.S. primary production increased by 4% from that in 1991. Producers operated at 86% of their rated capacity.

After resolving some furnace problems, Northwest Alloys Inc. reported that its primary magnesium plant in Addy, WA, was operating five out of nine furnaces at the end of August. After its announced cutback in December 1991, Northwest Alloys was operating only three furnaces because of the problems. The company planned to increase capacity while operating the same number of furnaces to satisfy some of Alcoa's magnesium requirements that had been met by Norsk Hydro Canada. *(See table 4.)*

Consumption and Uses.—Automobile manufacturers continue to specify magnesium in some of their new models. Ford Motor Co. began using magnesium in some radio components in the 1993 models of cars built in North America and overseas; this is part of a program that is expected to consume about 500 tons of magnesium annually. Ford's new radio applications involved two-piece amplifier housings. The magnesium was expected to be purchased in North America, and in addition to being used in North American plants, it will be used in vehicles manufactured in Portugal and perhaps in Brazil. In addition, Chrysler Corp. announced that it would use die-cast magnesium steering column support brackets in the 1994 models of its standard-size T300 pickup trucks. This application could consume up to 250 tons of magnesium annually. Chrysler also planned to use magnesium valve covers on the largest engines in the T300 truck; this application was expected to consume more than 70 tons of magnesium annually.

Significant quantities of magnesium also were to be used in new models of minivans, one of the most popular types of vehicles. General Motors Corp. (GM) was evaluating magnesium instrument panel support beams for two of its minivans, for introduction in 1996. Annual consumption of magnesium for this application was estimated to be 1,360 tons. Chrysler also planned to install magnesium steering column assemblies in a new model of its minivans, scheduled to be out in 1996. The company was considering magnesium steering column support brackets for use in these minivans. An article reviewed new applications for magnesium in the automotive industry and properties of magnesium that make it attractive for these uses.[11]

Although Ford's electric vehicle is still a concept vehicle, the company planned to use magnesium in some components, including the transmission housings. Magnesium, along with aluminum and plastic components, was expected to minimize the effect of the vehicle's heavy battery pack on performance.

A firm in the United Kingdom, Hawtal Whiting Holdings Plc, constructed an ultralight car door structure from aluminum and magnesium. The new door, weighing 12.3 pounds as compared with a steel door, which weighs between 35 and 50 pounds, was made to fit a Swedish-built Volvo 240. The main door structure and attached mirror bracket were made of magnesium alloy; the intrusion beam and window frame were aluminum. The door was said to meet U.S. Federal safety requirements for direct and side impacts, but the cost of a mass-produced door was not known.

GM was studying magnesium alloy AE42 for potential applications in transmission cases. Engineers at the company were studying the casting characteristics, performance, and machinability for transmission cases for rear-wheel-drive vehicles. The Chevrolet Corvette would be the first candidate for the new transmission cases, if tests prove successful.

Because of increased demand for large die-cast magnesium components, Lunt Manufacturing planned to begin construction of a second 6,000-square-meter magnesium casting facility near Chicago, IL, in 1993. The company currently operates an 7,900-square-meter facility with 12 diecasting machines. In addition, Magnesium Products Ltd., a subsidiary of Canada's Meridian Technologies Inc., announced that it would construct a new 6,000-square-meter diecasting plant in Eaton Rapids, MI. Completion was scheduled for 1994.

Consumption of secondary magnesium was 7,515 tons. Of this consumption, 56% was from old scrap and 44% was from new scrap. *(See tables 5 and 6.)*

Stocks.—Producers' stocks of primary magnesium at yearend 1992 dropped to 5,863 tons, which was significantly lower than the yearend 1991 stocks of 21,294 tons. Although there was not a large increase in domestic demand, the sharp dropoff in imports required producers to draw down their stocks to replace demand that was met by imported material in 1991. Consumer stocks of secondary magnesium increased slightly to 356 tons at yearend 1992 from 337 tons at yearend 1991.

Markets and Prices.—Throughout most of the year, published U.S. producer prices of primary magnesium and diecasting alloy continued to be significantly higher than estimates of actual transaction prices. U.S. producers announced several price increases in the first half of 1992, but did not state what their actual prices were. Although both Dow and MagCorp had announced that they would increase primary magnesium prices by 10% in January 1992, the published list price of $1.43 per pound did not change. Press reports estimated that the actual transaction price was about $1.22 per pound. In mid-June, Dow and MagCorp announced price increases of $0.10 per pound for primary magnesium, but neither company increased its published $1.43-per-pound quotation. The estimated transaction price was $1.32 per pound. In September, both

companies reported that they had increased the primary magnesium price to $1.43 per pound, their published price quotations. By mid-December, Dow and MagCorp reportedly increased their primary magnesium price to $1.53 per pound, but Dow announced a temporary voluntary allowance of $0.07, which reduced its actual transaction price to $1.46 per pound. At yearend, U.S. producers' price for magnesium was $1.46 to $1.53 per pound.

In April, both Dow and MagCorp announced increases in diecasting alloy prices. Dow increased its published price by $0.06, from $1.34 to $1.40 per pound. MagCorp also announced a price increase of $0.06 per pound, but its published price of diecasting alloy remained at $1.43 per pound. In mid-November, both companies announced price increases for diecasting alloy to $1.54 per pound; Dow increased its price by $0.14 per pound, and MagCorp increased its price by $0.10 per pound. At yearend the diecasting alloy AZ91D was quoted at $1.54 per pound. This was the first time in many years that the price of diecasting alloy was higher than the primary metal price.

Two trade publications, Metals Week and Metal Bulletin, began publishing estimated transaction prices for primary magnesium. Metals Week began publishing a U.S. transaction price and a European free market price in May, and Metal Bulletin began quoting a free market price in February.

Metals Week's U.S. transaction price was quoted at $1.22 per pound at the beginning of May. It rose steadily throughout the year and closed at $1.46 to $1.53 per pound by yearend. Metals Week's European free market price was quoted at $1.02 to $1.07 per pound at the beginning of May and rose to a high of $1.27 to $1.29 per pound by mid-June. This price generally trended down through the remainder of 1992 to end the year at $1.16 to $1.20 per pound. The free market price quoted in Metal Bulletin followed essentially the same pattern as the European free market price. The free market price was quoted at $0.88 to $0.93 per pound in February, rose to a high of $1.27 to $1.29 per pound by the end of June, and decreased to $1.18 to $1.20 per pound by the end of 1992.

Norsk Hydro began publishing a European indicator price at the beginning of 1992. This price was quoted at 3.85 Deutchemarks per kilogram on January 1 and was raised on a quarterly basis to 5.35 Deutchemarks per kilogram by yearend.

Foreign Trade.—Exports of magnesium were 6% less than those in 1991. The Netherlands (31%), Japan (24%), and Canada (15%) were the principal destinations.

The effects of the antidumping and countervailing duty determinations against Norsk Hydro in Canada were reflected in the U.S. import statistics in 1992. Imports of primary magnesium from Canada fell from more than 21,000 tons in 1991 to about 500 tons in 1992. In addition, granting most-favored-nation status to the Russian Federation led to a significant quantity of primary magnesium imported from the former U.S.S.R.; Russia and Ukraine became the largest single sources of primary magnesium in 1992. Total U.S. imports in 1992 were 63% less than those in 1991. *(See tables 7 and 8.)*

World Review.—According to the International Magnesium Association, world inventories of magnesium at the end of 1992 were nearly one-half the level at yearend 1991. Total world inventories stood at 29,500 tons at the end of December 1992, compared with 55,100 tons at the end of 1991. Temporary and permanent closures of several facilities throughout the world led to a tight supply situation during 1992, and producers drew down their inventories to meet demand. *(See tables 9, 10, and 11.)*

Australia.—In Australia, the Commonwealth Scientific, Industrial and Research Organization (CSIRO), the Government research and development organization, and Japan's Ube Industries Ltd. signed an agreement with the owners of the Kunwarara magnesite deposit to develop new electrolytic magnesium metal production technology that will be internationally competitive. Current plans were for Ube Industries, along with Queensland Metals Corp. and MIM Holdings Ltd., to construct a 700- to 1,000-ton-per-year pilot plant by 1994 or 1995. If the technology proves successful, the three companies plan to build a 60,000-ton-per-year plant in Australia using magnesite from the Kunwarara deposit as raw material.

Brazil.—Brasmag's parent company, Rima Group, announced in December that the two companies completed their debt repayment under the Brazilian law equivalent to the U.S. chapter 11 bankruptcy law. The companies had filed for bankruptcy in November 1990, citing high interest rates, shortage of credit lines, and the startup of Brasmag's capacity expansion as some of the reasons for the filing.

Canada.—At the end of May, Noranda Minerals reportedly signed an agreement with Benvest Capital (formerly Lavalintech) to purchase its 50% interest in the Magnola magnesium project in Canada. This purchase made Noranda the sole owner of the project, and the company said that it was seeking financing from additional partners before proceeding with project development. The Magnola project was designed to recover magnesium from asbestos mine tailings in Quebec.

Magnesium Products announced that it would expand its diecasting facility in Strathroy, Ontario, in response to new business from North American automobile manufacturers. The 370-square-meter addition, with a 2,200-ton diecasting machine, was expected to be completed by June 1993.

France.—Pechiney announced that it would shut down its 18,000-ton-per-year magnesium plant in Marignac, France, during January and February 1993. Because of energy costs, which are highest during these 2 months, Pechiney may decide to continue this practice

during the next few years.

Israel.—Dead Sea Works Ltd. (DSW), a subsidiary of Israel Chemicals Ltd., announced that it planned to construct a 50,000-ton-per-year magnesium production plant in Israel that could begin production as early as 1995. Construction and final financing decisions were expected in the fall. Initially, the company planned a two-stage construction; construction of a 25,000-ton-per-year facility by 1995 and an additional 25,000 tons of annual capacity by 1998. DSW planned to use technology that has been used in the former U.S.S.R. to recover magnesium from carnallite, which is said to be easier than magnesium chloride to dehydrate. DSW currently produces bromine, chlorine, magnesium compounds, potash, salt, and sodium hydroxide from brines in Israel.

Italy.—The primary magnesium producer in Italy announced in March that it would cease production at its plant in Bolzano for at least a few months. Because of inventories that have built up at the plant, the company had enough magnesium to meet the demands of its current contract customers, but would not renew the contracts when they expire. In addition, there were sufficient stocks to continue the current production levels for magnesium alloys for anode production. According to a company spokesperson, the low price of magnesium resulting from exports from the former U.S.S.R. influenced the company's decision to discontinue primary magnesium production. Approximately 220 to 230 of the plant's work force of 250 were expected to be laid off.

Japan.—Japan Metals and Chemicals Corp. temporarily stopped production of primary magnesium at its 5,000-ton-per-year plant, although the company planned to maintain its remelt production.

Canada-based Meridian Technologies reportedly signed an agreement with Kobe Steel Ltd. of Japan under which Kobe Steel will market Meridian's diecastings in Japan, mainly for the automotive industry. Kobe Steel currently produces magnesium sand castings, primarily for the aircraft industry. Magnesium diecasting in Japan has been limited to low volumes of small castings, and Kobe Steel does not have the equipment necessary to produce castings for the automotive industry. If demand increases sufficiently, Kobe Steel and Meridian plan to form a joint venture to produce magnesium diecastings in Japan.

Saudi Arabia.—British Aerospace International reportedly was evaluating construction of a magnesium metal plant in Saudi Arabia. The proposed plant initially would have an annual capacity of 10,000 tons, with a potential for expansion to 30,000 tons. Magnesium would be recovered from salt water by electrolysis, which would take advantage of low-cost electrical power available in Saudi Arabia. British Aerospace stated that the decision whether to go ahead with a feasibility study would not be made until mid-1993.

Current Research.—In Japan, Mitsui Mining & Smelting Co. Ltd. reportedly developed three new magnesium alloys with a wide range of potential applications. Two of the new alloys combine magnesium with rare-earth metals—one with terbium and one with gadolinium. These alloys are highly heat-resistant, which make them candidates for applications in pistons of automobile engines. The third alloy is a magnesium-lithium alloy that possesses high specific strength and superplasticity. Potential applications for the magnesium-lithium alloy are in office automation equipment and other industrial products.

Researchers at Magnesium Elektron Ltd. in the United Kingdom announced the development of a process for making metal-matrix composites that blends liquid magnesium alloy with ceramic particles, such as alumina or silicon carbide. These magnesium metal-matrix composites were lightweight and demonstrated significant increases in modulus and tensile strength, compared to unreinforced material, at both ambient and elevated temperatures. The process for making the magnesium metal-matrix composites was essentially a direct mixing process, and the company claimed that this was a cost-effective process to make metal-matrix composites for cast and wrought applications.[12]

Magnesium Compounds

Production.—Production of all magnesium compounds in 1992 dropped slightly from 1991 levels, except for magnesium sulfate production, which increased by about 9%. Martin Marietta Specialties Inc. announced plans to increase its merchant capacity for producing magnesium hydroxide at its Manistee, MI, facility in mid-1994. Annual production capacity was scheduled to increase to 50,000 to 70,000 tons from current levels of a few thousand tons. Martin Marietta has been a significant producer of magnesium hydroxide for internal use; the company calcined the magnesium hydroxide to magnesium oxide, which it marketed. *(See table 12.)*

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, representing about 60% of the total U.S. demand for magnesium compounds. Harbison-Walker Refractories Inc. introduced magnesia-alumina spinel refractories for use in lime and cement kilns as replacements for magnesia-chrome refractories. According to the company, magnesia-alumina spinel bricks have demonstrated an improved service life in many plants and may reduce the need for hazardous waste disposal of bricks that contain traces of soluble chrome.[13]

In 1992, agricultural applications (animal feed and fertilizer) were the dominant use for caustic-calcined magnesia, accounting for 32% of U.S. shipments. Chemical processing was the next largest segment, with 21% 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, and stack-gas scrubbing), 16%; manufacturing (rayon, fuel additives, rubber, and pulp and paper), 14%; construction (oxychloride and oxysulfate cements and general construction), 5%; pharmaceuticals and nutrition (medicinal and pharmaceutical, sugar, and candy), 3%; and unspecified uses, 8%. A review of magnesium oxide compounds applications in acid neutralization was published, reflecting the growing interest in minerals for environmental applications.[14]

Magnesium carbonate was used principally as a chemical intermediate and in medicines and pharmaceuticals. Magnesium hydroxide was used mainly in pulp and paper, chemical industries, and in water treatment.

Magnesium sulfate was used mostly in pharmaceuticals and animal feed. According to a review article on agricultural applications of kieserite ($MgSO_4 \cdot H_2O$), using kieserite-containing fertilizers increases both the available magnesium and sulfur to crops. Depending on soil type, kieserite may be used in conjunction with magnesium carbonate in carbonate-deficient soils.[15]

Magnesium chloride was used mainly in oxychloride cements. Magnesium chloride brines were used principally for road dust and ice control.

Refractory and foundry uses were the largest applications for olivine in the United States, each accounting for 44% of consumption of domestically produced material. Sand blasting and other abrasive applications accounted for 7%, and slag control accounted for the remaining 5% of U.S. olivine consumption. *(See table 13.)*

Markets and Prices.—Yearend 1992 prices for most magnesium compounds did not change from those of 1991. The only exceptions were dead-burned magnesium, which decreased by $62 per short ton, and synthetic magnesia, which increased by $36 per short ton. *(See table 14.)*

Foreign Trade.—Trade data for olivine are not reported separately by the Bureau of the Census. Some data on olivine are available from a computer service, the Port Import/Export Reporting Service (PIERS). PIERS reports data on materials that are transported by ship. According to this source, the United States imported 123,249 tons of olivine from Norway in 1992. Exports of olivine from the United States totaled 2,744 tons. Chile, with 56% of the total, and Peru, with 25% of the total, were the principal recipients. Australia, Italy, the Republic of Korea, New Zealand, and Taiwan were the other destinations. *(See tables 15, 16, 17, and 18.)*

World Review.—A review article of the world magnesia industry discussed the status of all the principal world magnesia producers, including a review of magnesia products, changes in product quality, and development of new markets.[16] *(See tables 19 and 20.)*

Australia.—Devex Ltd. reportedly signed a Heads of Agreement with Toyota Tsushi Corp. and Mitsubishi Materials Corp. for further development of its magnesite mining and processing operations at Thuddungra, New South Wales. In the proposed joint-venture agreement, Devex will own 50% of the operations and Toyota Tsushi and Mitsubishi Materials together will own 50%. Expanding the mine's facilities will include installation of calcining equipment to produce 43,000 tons per year of calcined magnesia and electric arc furnaces to produce 13,000 tons per year of high-grade fused magnesia. A construction schedule for the $21 million facilities was expected to be set by early 1993.

The Queensland Magnesia Project Joint Venture (QMAG) commissioned additional furnaces at its magnesite processing operation in Queensland. A second 10-ton-per-hour, multiple-hearth Herreshoff furnace was installed in February for the initial magnesite calcination step; the first furnace was installed in October 1991. Calcined magnesite from these furnaces was used as feed for QMAG's dead-burning and fusion operations. A second 50,000-ton-per-year shaft kiln was commissioned in the dead-burning plant in February 1992, and a third kiln is scheduled to be installed sometime in 1993.

In addition to dead-burned and fused magnesia, QMAG is in several joint ventures to market other products derived from magnesite. These joint ventures include one with ICI Australia to evaluate market potential and technical requirements for calcined magnesia and magnesium hydroxide to the environmental market (Enviromag); Cemag, with Queensland Cement Ltd., to develop magnesia cements and building products; and Flamemag, a joint venture with CSIRO, to produce specially formulated flame-retardant fillers for plastics. The company is also in a joint venture with Japan's Ube Industries, MIM Holdings, and CSIRO to construct a 1,000-ton-per-year pilot plant to produce magnesium metal.[17]

Austria.—Radex-Heraclith Industriebeteilgungs AG announced a restructuring of its organization. This restructuring involved a noncash capital contribution of 70% of Radex Austria AG to Veitscher Magnesitwerke AG as part of a capital increase; acquisition of 30% of Radex Austria by Veitscher Magnesitwerke from Österreichische Magnesit AG; renaming Veitscher Magnesitwerke to Veitsch-Radex AG für feuerfeste Erzeugnisse; and the dissolution of Österreichische Magnesit. As a result of this restructuring, Radex-Heraclith holds controlling interest in 610,000 tons per year of magnesia production capacity in Austria and has interests in magnesia operations in Australia, Greece, Italy, and Turkey.

Canada.—Canadian Refractories Dresser Canada Inc., a subsidiary of U.S.-based Harbison-Walker, announced that it planned to close its underground dolomitic magnesite operation in Kilmar, Quebec, by May. After the mine was closed, the company planned to rely on accumulated aboveground stocks for 4 to

5 years of feed supply for its 15,000-ton-per-year dead-burned magnesia plant.

China.—Construction of a 10,000-ton-per-year magnesium sulfate plant reportedly was completed in Laizhou, Shandong, in 1992. The plant was expected to use locally produced magnesite and sulfuric acid as feedstock. This was reported to be the largest magnesium sulfate plant in China.

Germany.—Kali und Salz AG reportedly ceased production of magnesium chloride flake at its Salzdetfurth plant in March. According to a company spokesperson, magnesium chloride flake was no longer a profitable business. At one point, Kali und Salz was supplying Norsk Hydro with magnesium chloride flake as a feed for its magnesium metal plant in Norway, but Norsk Hydro had switched to a different supplier. Supplies of magnesium chloride that were lost from the closure of Kali und Salz's plant were expected to be replaced by production at DSW's new magnesium chloride plant in Israel, with a capacity of 100,000 tons per year, which began operating in early April. In addition to magnesium metal, magnesium chloride is used by the artificial seawater industry; in textiles, adhesives, and special oxychloride cements; and as an alternative deicer.[18]

Greece.—Fimisco and its affiliated company Macedonian Magnesite SA reportedly will be sold through a public auction. The companies, which had a combined magnesia production capacity of 365,000 tons per year, cited depletion of ore reserves and falling prices and revenues as reasons for the liquidation. Fimisco stopped production at the end of November 1991 after several years of financial problems and went into liquidation in January 1992.

India.—Tamilnadu Magnesite Ltd. (Tanmag) announced plans to produce high-quality dead-burned magnesia at its plant in Salem by the end of 1993. Tanmag was expected to install technology based on Sulzer Brothers Ltd.'s Sulmag process to produce 26,000 tons per year of dead-burned magnesia from domestically mined silica-rich cryptocrystalline magnesite. The company also planned to produce 10,000 tons per year of magnesia-chrome clinker.

Italy.—At the beginning of 1992, Cogema SpA, a subsidiary of Sardamag SpA with a 65,000-ton-per-year seawater magnesia plant in Sicily, was dissolved as a separate entity, and its plant was operated under the Sardamag name. Sardamag also operated a 65,000-ton-per-year plant in Sant Antioco. Because of depressed prices, the Sant Antioco plant was closed from November 1991 until April 1992, but the company supplied its customers from inventories.

Mexico.—In September, Industrias Peñoles SA de CV announced the opening of a 5,000-ton-per-year fused magnesia plant to be operated by a new subsidiary Magnelec SA de CV. The new $5 million plant is in Ramos Arizpe, Coahuila, and its output is expected to be consumed primarily by the Mexican refractory industry. Feedstock for Magnelec's fusion process was supplied by dead-burned magnesia from Quimíca del Rey Sa de CV's brine operation, also in Coahuila.

United Kingdom.—Steetly Magnesia Products Ltd. reportedly closed its 35,000-ton-per-year facilities for the production of high-purity pelletized magnesia. Instead, the company planned to concentrate on production of magnesium-aluminum spinels and magnesium hydroxide for environmental applications. Spinel production capacity was estimated to be 12,000 tons per year, but Steetly planned to increase this to 30,000 tons per year.

A review of refractories consumption in the United Kingdom showed some of the same patterns occurring as in the United States. Overall refractories consumption has declined as open-hearth steel furnaces were replaced by electric arc furnaces, basic-oxygen steelmaking, and continuous casting. Refractories consumption per ton of steel produced dropped from 250 kilograms to less than 5 kilograms just by changing production technologies. In addition, the refractories were being replaced less often as improved refractory products are developed.[19]

OUTLOOK

Growth areas for magnesium metal consumption in the United States in the next few years are likely to be in automotive components and iron and steel desulfurization, with the largest growth in automotive components. To meet more stringent requirements for fuel economy, manufacturers have essentially two choices—make the vehicles smaller or reduce weight. To satisfy consumer preferences for larger vehicles, automakers are using magnesium components to reduce the total weight. The average magnesium content of a typical U.S. vehicle has doubled from 1.1 kilograms in 1987 to 2.3 kilograms in 1991. Many auto manufacturers continue to specify new magnesium components in vehicles to be built throughout the rest of the decade.

Iron and steel desulfurization in the United States is expected to continue to grow, but at slower rates than in the past. Magnesium has already been substituted for calcium carbide; in the United States, almost all hot metal already is desulfurized with magnesium. Growth in the desulfurization market will come as additional metal requires desulfurization, not by replacing currently used desulfurization agents as was done in the past. This factor would lead to slower growth rates in this market.

Recent political changes in the former U.S.S.R. have begun to affect the world supply of magnesium metal. Normally, most of the magnesium produced in the former U.S.S.R. was used in the production of titanium for defense applications. With the shift of emphasis away from defense applications and because of the country's need for hard currency, this magnesium has begun to appear on the world market at prices less than prevailing world prices. This is

likely to continue to affect future supplies.

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 continue to decrease. Technological changes in steel production have had a deleterious effect on the consumption of specific refractories. Open-hearth furnaces have disappeared in the United States and been replaced by electric arc furnaces and basic-oxygen steelmaking. Although the trend to electric arc furnaces has reduced the overall demand for refractories, high-quality basic refractories (including magnesia-base refractories) are needed for the body of the furnace. In addition, the use of continuous casting has increased at the expense of ingot casting. At the same time, improvements in refractories technology resulted in increased longevity. As a result of these changes, in the past 15 years, there has been a threefold to fourfold decline in refractories consumption per ton of steel produced to about 14 to 15 kilograms of refractories per ton. This figure is projected to drop to 10 to 11 kilograms per ton by 2000.[20] The decline in use of magnesia-base refractories, however, has not been as great as declines for other materials, such as firebrick. Although refractories are the principal use for magnesia, environmental applications, such as flue gas desulfurization and water treatment, are being investigated as growth areas for magnesia and other magnesium compounds. Any increase in demand for other magnesium compounds is expected to be offset by the decline in refractories demand, leading to a stagnant demand for magnesium compounds in the United States.

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TABLE 1

U.S. MAGNESIUM METAL PRODUCERS, BY LOCATION, RAW MATERIAL, AND PRODUCTION CAPACITY IN 1992

Company	Plant location	Raw material	Annual capacity (metric tons)
The Dow Chemical Co.	Freeport, TX	Seawater	90,000
Magnesium Corp. of America	Rowley, UT	Lake brines	35,000
Northwest Alloys Inc.	Addy, WA	Dolomite	35,000
Total			160,000

TABLE 2

U.S. MAGNESIUM COMPOUND PRODUCERS, BY RAW MATERIAL SOURCE, LOCATION, AND PRODUCTION CAPACITY IN 1992

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) Jan. 1, 1992	Non-MFN Jan. 1, 1992
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)

	1988	1989	1990	1991	1992
United States:					
Production:					
Primary magnesium	141,983	152,066	139,333	131,288	136,947
Secondary magnesium	50,207	51,200	r54,808	r50,543	57,045
Exports	49,802	56,631	51,834	55,160	51,952
Imports for consumption	14,407	12,289	26,755	31,863	11,841
Consumption, primary	100,793	105,226	96,108	91,872	93,827
Price per pound	$1.58-$1.63	$1.63	$1.43-$1.63	$1.43	$1.46-$1.53
World: Primary production	r334,365	344,448	r353,537	r339,596	e303,619

eEstimated. rRevised.

TABLE 5

MAGNESIUM RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1988	1989	1990	1991	1992
KIND OF SCRAP					
New scrap:					
Magnesium-base	2,641	3,951	3,992	4,867	4,539
Aluminum-base	19,926	19,278	r19,432	r18,192	21,652
Total	22,567	23,229	r23,424	r23,059	26,191
Old scrap:					
Magnesium-base	3,882	4,269	4,277	4,443	4,220
Aluminum-base	23,758	23,702	r27,107	r23,041	26,634
Total	27,640	27,971	r31,384	r27,484	30,854
Grand total	50,207	51,200	r54,808	r50,543	57,045
FORM OF RECOVERY					
Magnesium alloy ingot[1]	3,930	4,494	4,290	4,604	W
Magnesium alloy castings	438	795	857	1,043	923
Magnesium alloy shapes	1,065	635	301	158	329
Aluminum alloys	43,827	43,125	r46,807	r41,606	48,619
Zinc and other alloys	W	W	W	3	3
Chemical and other dissipative uses	943	W	W	W	W
Cathodic protection	W	W	W	W	W
Total	50,207	51,200	r54,808	r50,543	57,045

rRevised. W Withheld to avoid disclosing company proprietary data; included in "FORM OF RECOVERY: Total."
[1]Includes secondary magnesium content of both secondary and primary alloy ingot.

TABLE 6
U.S. CONSUMPTION OF PRIMARY MAGNESIUM, BY USE

(Metric tons)

Use	1988	1989	1990	1991	1992
For structural products:					
Castings:					
Die	4,383	5,627	7,479	7,532	8,920
Permanent mold	943	811	875	750	853
Sand	1,743	1,017	724	575	450
Wrought products:					
Extrusions	6,907	6,712	7,848	6,387	6,435
Other[1]	3,231	2,941	3,096	2,415	2,408
Total	17,207	17,108	20,022	17,659	19,066
For distributive or sacrificial purposes:					
Alloys:					
Aluminum	53,671	53,821	45,060	45,809	41,003
Other	7	9	8	9	10
Cathodic protection (anodes)	6,234	5,474	5,421	4,976	4,852
Chemicals	780	594	800	695	739
Iron and steel desulfurization	W	10,463	9,853	10,895	13,611
Nodular iron	2,037	1,635	1,424	1,074	W
Reducing agent for titanium, zirconium, hafnium, uranium, beryllium	8,467	10,798	8,989	6,071	8,209
Other[2]	12,390	5,324	4,531	4,684	6,337
Total	83,586	88,118	76,086	74,213	74,761
Grand total	100,793	105,226	96,108	91,872	93,827

W Withheld to avoid disclosing company proprietary data; included in "Other."
[1]Includes sheet and plate and forgings.
[2]Includes scavenger, deoxidizer, and powder.

TABLE 7

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:								
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
Germany	—	—	1	28	3	10	35	722
Ghana	—	—	224	605	—	—	—	—
Hong Kong	—	—	546	1,549	19	259	(1)	3
India	—	—	505	1,330	—	—	59	636
Iran	—	—	—	—	—	—	—	—
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
Spain	—	—	774	2,684	—	—	1	25
Taiwan	—	—	613	1,572	21	83	47	150
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	r90	r305	r544	r3,972	r153	r1,264	r500	r2,680
Total	919	2,304	42,859	119,848	3,233	10,132	8,149	18,046
1992:								
Argentina	—	—	384	906	—	—	70	420
Australia	7	15	2,975	5,447	—	—	117	517
Bahrain	—	—	133	400	—	—	—	—
Brazil	—	—	338	718	—	—	41	104
Canada	2,097	4,797	4,041	9,967	1,035	2,766	819	4,067
Germany	—	—	—	—	—	—	—	—
Ghana	—	—	138	360	—	—	—	—
Hong Kong	—	—	5	20	1	12	8	93
India	—	—	124	335	—	—	45	388
Iran	—	—	450	1,496	—	—	—	—
Japan	11	22	10,996	26,690	59	289	1,174	4,928
Korea, Republic of	—	—	444	1,084	103	715	6,749	2,049
Mexico	295	668	354	949	58	212	201	741
Netherlands	76	240	13,940	41,108	43	129	1,907	5,591
Spain	—	—	14	297	—	—	(1)	5
Taiwan	—	—	349	758	10	33	42	570
United Arab Emirates	—	—	—	—	1	4	23	11
United Kingdom	10	164	91	592	28	295	139	563
Venezuela	—	—	481	913	1	7	2	5
Other	(1)	1	567	4,181	134	903	821	4,315
Total	2,496	5,907	35,824	96,221	1,473	5,365	12,158	24,367

rRevised.

[1]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 8

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)
1991:								
Canada	3,035	$3,484	21,234	$50,849	4,037	$12,611	173	$502
China	—	—	—	—	—	—	—	—
France	19	27	159	418	5	180	—	—
Germany	387	440	—	—	—	—	(1)	2
Italy	122	169	—	—	11	9	—	—
Kazakhstan[2]	—	—	—	—	—	—	—	—
Mexico	89	53	120	338	—	—	1,147	4,129
Netherlands	255	247	—	—	—	—	—	—
Norway	—	—	245	581	371	1,295	(1)	2
Russia[2]	—	—	—	—	—	—	—	—
South Africa, Republic of	27	39	—	—	—	—	—	—
Ukraine[2]	—	—	—	—	—	—	—	—
United Kingdom	20	28	—	—	168	1,684	32	208
Yugoslavia[3]	—	—	—	—	—	—	—	—
Other	r196	r166	—	—	4	124	7	23
Total	4,150	4,653	21,758	52,186	4,596	15,903	1,359	4,866
1992:								
Canada	1,049	722	548	1,514	3,144	11,312	344	913
China	—	—	370	930	57	248	—	—
France	—	—	111	291	1	58	(1)	3
Germany	83	86	—	—	(1)	11	(1)	35
Italy	—	—	—	—	—	—	—	—
Kazakhstan[2]	—	—	—	—	209	486	—	—
Mexico	87	63	97	289	—	—	988	3,247
Netherlands	137	120	—	—	—	—	(1)	—
Norway	—	—	—	—	(1)	2	1	2
Russia[2]	561	1,179	1,930	5,122	77	209	—	—
South Africa, Republic of	139	125	—	—	—	—	—	—
Ukraine[2]	—	—	692	1,871	—	—	—	—
United Kingdom	274	442	(1)	4	324	1,787	3	70
Yugoslavia[3]	—	—	372	707	—	—	—	—
Other	95	84	124	302	27	432	(1)	11
Total	2,425	2,821	4,244	11,030	3,839	14,545	1,336	4,281

rRevised.
[1]Less than 1/2 unit.
[2]Formerly part of the U.S.S.R.; data were not reported separately until 1992.
[3]Dissolved in Apr. 1992.

Source: Bureau of the Census.

TABLE 9

WORLD ANNUAL PRIMARY MAGNESIUM PRODUCTION CAPACITY,[1] DECEMBER 31, 1992, BY CONTINENT AND COUNTRY

(Metric tons)

Continent and country	Capacity
North America:	
Canada	49,000
United States	160,000
Total	209,000
South America: Brazil	10,600
Europe:	
France	17,000
Italy	10,000
Kazakhstan	[2]65,000
Norway	41,000
Russia	[2]95,000
Serbia and Montenegro	7,000
Ukraine	[2]54,000
Total	289,000
Asia:	
China	9,000
India	600
Japan	13,000
Total	22,600
World total	531,200

[1]Includes capacity at operating plants as well as at plants on standby basis.

[2]Includes magnesium production capacity that is used exclusively for titanium production as follows: Kazakhstan, 40,000 metric tons; Russia, 35,000 metric tons; and Ukraine, 15,000 metric tons.

TABLE 10
MAGNESIUM: WORLD PRIMARY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1988	1989	1990	1991	1992e
Brazil e	2 5,865	6,200	6,500	7,800	7,300
Canada	e 7,600	e 7,200	26,726	r 35,512	25,700
China e	3,200	3,600	5,800	6,000	6,500
France	13,776	14,600	14,600	e 14,000	12,000
Italy	5,436	5,469	r 5,725	r 5,115	3,000
Japan	9,012	8,381	12,843	11,559	2 7,768
Kazakhstan e 3	—	—	—	—	20,000
Norway	r 50,317	49,827	48,222	44,322	2 30,404
Russia e 3	—	—	—	—	40,000
Serbia and Montenegro 4 5	—	—	—	—	4,000
Ukraine e 3	—	—	—	—	10,000
U.S.S.R. e 6	91,000	91,000	88,000	80,000	—
United States	141,983	152,066	139,333	131,288	2 136,947
Yugoslavia 5 7	6,176	6,105	5,788	e 4,000	—
Total	r 334,365	344,448	r 353,537	r 339,596	303,619

eEstimated. rRevised.
[1]Table includes data available through July 1, 1993.
[2]Reported figure.
[3]Formerly part of the U.S.S.R.; data were not reported separately until 1992.
[4]Formerly part of Yugoslavia.
[5]All production in Yugoslavia 1988-91 came from Serbia and Montenegro.
[6]Dissolved in Dec. 1991.
[7]Dissolved in Apr. 1992.

TABLE 11
MAGNESIUM: WORLD SECONDARY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1988	1989	1990	1991	1992e
Brazil e	2 1,519	2 1,500	1,600	1,600	1,600
Japan	15,099	20,270	23,308	17,158	2 12,978
U.S.S.R. e 3	8,000	8,000	7,500	7,000	6,500
United Kingdom e	1,000	1,000	1,000	1,000	800
United States	50,207	51,200	r 54,806	r 50,543	2 57,045
Total	75,825	81,970	r 88,214	r 77,301	78,923

eEstimated. rRevised.
[1]Table includes data available through July 1, 1993.
[2]Reported figure.
[3]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

TABLE 12
SALIENT MAGNESIUM COMPOUND STATISTICS

(Thousand metric tons and thousand dollars)

	1988	1989	1990	1991	1992
United States:					
Caustic-calcined and specified magnesias:[1]					
Shipped by producers:[2]					
Quantity	124	135	135	154	130
Value	$36,500	$39,529	$37,850	$48,074	$37,131
Exports, value[3]	$13,322	$2,263	$1,406	$2,289	$2,404
Imports for consumption, value[3]	$2,371	$13,657	$13,957	$15,891	$12,309
Refractory magnesia:					
Shipped by producers:[2]					
Quantity	371	348	335	296	291
Value	$103,400	$97,673	$94,962	$85,292	$80,756
Exports, value	$9,262	$10,685	$19,709	$25,038	$22,257
Imports for consumption, value	$42,885	$38,555	$32,858	$30,209	$37,928
Dead-burned dolomite:					
Sold and used by producers:					
Quantity	413	365	342	308	333
Value	$30,182	$28,294	$26,988	$25,736	$25,230
World production (magnesite)	r11,989	r11,879	r10,985	r11,166	e11,129

eEstimated. rRevised.
[1]Excludes caustic-calcined magnesia used in the production of refractory magnesia.
[2]Includes magnesia used by producers.
[3]Caustic-calcined magnesia only.

TABLE 13
U.S. MAGNESIUM COMPOUNDS SHIPPED AND USED

	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined[1] and specified (USP and technical) magnesias	153,655	$48,074	130,118	$37,131
Magnesium hydroxide [100% $Mg(OH)_2$][1]	302,244	82,768	267,087	67,203
Magnesium sulfate (anhydrous and hydrous)	34,872	12,229	37,889	13,919
Precipitated magnesium carbonate[1]	3,360	746	2,162	547
Refractory magnesia	296,173	85,292	290,558	80,756

[1]Excludes material produced as an intermediate step in the manufacture of other magnesium compounds.

TABLE 14
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 15

U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined magnesia:				
Canada	256	$514	—	—
Germany	521	350	546	$353
Mexico	123	62	359	103
Netherlands	699	407	1,482	801
United Kingdom	158	158	81	131
Venezuela	1,530	475	2,135	694
Other	35	323	659	322
Total	3,6403	2,289	5,262	2,404
Dead-burned and fused magnesia:				
Argentina	194	137	—	—
Belgium	4,468	1,965	—	—
Brazil	334	342	685	764
Canada	41,632	14,919	38,605	14,595
France	255	65	1,887	508
Germany	971	439	2	525
Israel	1,460	1,213	1,457	756
Japan	7,441	1,672	532	101
Korea, Republic of	302	196	286	138
Mexico	2,454	1,306	1,251	459
Switzerland	—	—	1,000	368
Taiwan	416	177	307	136
Thailand	16	6	4,257	1,594
Venezuela	6,107	2,483	5,956	2,011
Other	r242	r118	533	302
Total	66,292	25,038	56,758	22,257
Other magnesia:				
Australia	152	210	296	369
Canada	5,185	2,884	5,545	2,687
Colombia	219	347	204	354
France	805	306	86	115
Germany, Federal Republic of	142	100	138	140
Italy	150	123	52	64
Korea, Republic of	135	113	191	174
Mexico	13,416	6,010	9,684	5,326
Netherlands	158	128	116	54
Spain	1,592	864	1,753	952
Taiwan	187	99	317	122
United Kingdom	1,561	1,161	82	105
Venezuela	1,058	632	227	113
Other	r389	r1,008	384	965
Total	25,149	13,985	19,075	11,540

See footnote at end of table.

TABLE 15—Continued

U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Crude magnesite:				
Australia	99	$99	81	$86
Brazil	325	621	169	242
Canada	1,173	310	726	145
Germany	836	1,037	795	898
Hong Kong	136	112	18	20
Italy	612	719	450	545
Japan	108	128	55	75
Korea, Republic of	320	198	789	316
Mexico	1,391	476	884	277
Netherlands	936	712	940	736
New Zealand	122	123	209	249
Spain	221	206	96	74
Taiwan	54	74	317	29
Venezuela	1,349	301	43	26
Other	r279	r451	354	496
Total	7,961	5,567	5,926	4,214
Calcined dolomite:				
Canada	2,350	464	2,695	529
Colombia	775	111	212	39
Mexico	9,461	2,199	5,761	1,290
Saudi Arabia	2,014	295	1,810	252
Trinidad and Tobago	355	43	3,887	507
Venezuela	1,653	189	5,037	642
Other	r94	r48	182	55
Total	16,702	3,349	19,584	3,314

rRevised.

Source: Bureau of the Census.

TABLE 16

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)
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
1992	2,280	4,411	3,941	2,348	436	333	2,929	1,161

Source: Bureau of the Census.

TABLE 17

U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined magnesia:				
Canada	51,209	$10,654	48,206	$9,507
China	41,997	3,124	29,423	1,798
Greece	8,249	1,018	2,747	445
Japan	3,962	741	2,595	547
Mexico	2,331	317	—	—
Turkey	—	—	80	12
Other	100	37	—	—
Total	107,848	15,891	83,051	12,309
Dead-burned and fused magnesia:				
Austria	—	—	10,199	4,127
Brazil	—	—	3,000	360
Canada	2,384	1,233	2,976	1,599
China	74,358	9,610	132,500	13,807
Czechoslovakia	3,706	364	8,537	789
France	—	—	2,000	404
Germany	1	1	2,145	884
Greece	21,687	2,805	12,767	1,615
Ireland	2,101	750	—	—
Israel	7,932	3,244	12,168	5,121
Italy	2,000	455	2,500	558
Japan	5,087	2,284	2,465	2,152
Mexico	27,128	9,300	17,525	6,030
Other	r144	r163	1,633	482
Total	r146,528	30,209	210,415	37,928
Other magnesia:				
Brazil	58	48	122	98
Canada	15	28	280	204
China	596	1,264	168	938
Germany	128	202	13	40
Israel	682	1,282	526	942
Japan	2,386	4,631	1,918	3,384
Tajikistan[1]	—	—	107	219
United Kingdom	135	172	(2)	7
Other	109	85	150	328
Total	4,109	7,712	3,284	6,160
Crude magnesite:				
China	37	11	804	83
Germany	59	23	—	—
Italy	632	211	2,163	230
Japan	1,117	414	338	249
Other	111	r54	102	61
Total	1,956	r713	3,407	623
Calcined dolomite:				
Austria	—	—	220	159

See footnotes at end of table.

TABLE 17—Continued

U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Calcined dolomite—Continued:				
Canada	27,261	$3,282	23,610	$3,069
Germany	590	83	54	12
Other	1	r6	20	4
Total	27,852	r3,371	23,904	3,244

rRevised.
[1]Formerly part of the U.S.S.R.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 18

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)
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
1992	1,750	2,461	4,594	1,447	16,902	754	36	36	5,193	1,119

Source: Bureau of the Census.

TABLE 19

WORLD MAGNESIUM COMPOUNDS ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1992

(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	191	—
Europe:		
Austria	665	—
Czechoslovakia	726	—
France	—	30
Greece	240	—
Ireland	—	100
Italy	—	130
Netherlands	—	100
Norway	—	25
Poland	10	—
Russia	2,100	—
Serbia and Montenegro	240	—
Spain	205	—
Turkey	309	—
Ukraine	—	100
United Kingdom	—	200
Total	4,495	685
Africa:		
Kenya	170	—
South Africa, Republic of	119	—
Zimbabwe	2	—
Total	291	—
Asia:		
China	1,050	10
India	273	—
Israel	—	70
Japan	—	650
Korea, North	2,000	—
Korea, Republic of	—	50
Nepal	50	—
Total	3,373	780
Oceania: Australia	200	—
Grand total	8,810	2,500

[1]Includes capacity at operating plants as well as at plants on standby basis.

TABLE 20
MAGNESITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1988	1989	1990	1991	1992e
Australia e	[2]56,446	55,000	60,000	r100,000	820,000
Austria	1,121,585	1,024,942	1,179,162	r958,000	950,000
Brazil[3] (beneficiated)	404,126	259,508	257,159	r242,256	250,000
Canada e [4]	150,000	150,000	150,000	r e180,000	180,000
China e	2,610,000	2,600,000	2,600,000	2,600,000	2,600,000
Colombia	17,760	20,425	r19,300	r18,768	19,000
Czechoslovakia	630,786	642,000	561,000	r328,000	350,000
Greece	847,911	903,593	r696,900	r590,188	250,000
India	507,873	479,530	r544,000	r e539,000	550,000
Iran[5]	2,777	6,967	1,405	r [6]29,291	30,000
Korea, North e	1,500,000	1,500,000	1,500,000	1,600,000	1,600,000
Mexico	r6,228	r4,510	r5,863	r5,587	5,600
Nepal	45,000	27,978	e25,000	e25,000	25,000
Pakistan	3,081	8,750	4,274	r5,191	5,500
Philippines	—	4,796	e700	e700	700
Poland	23,867	24,133	r23,300	e22,000	22,000
Russia[7] [8]	—	—	—	—	1,100,000
Serbia and Montenegro[9] [10]	—	—	—	—	195,000
South Africa, Republic of	74,088	75,695	r114,182	92,634	[2]53,344
Spain	624,216	r596,759	r603,178	r e600,000	500,000
Turkey	1,125,844	r1,343,893	812,660	r1,595,818	1,600,000
U.S.S.R. e [8] [11]	1,825,000	1,825,000	1,600,000	1,400,000	—
United States	W	W	W	W	W
Yugoslavia[10] [12]	382,606	292,302	194,119	210,000	—
Zimbabwe	30,121	33,423	32,639	r23,295	23,000
Total	r11,989,315	r11,879,204	r10,984,841	r11,165,728	11,129,144

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]Figures 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 11, 1993.

[2]Reported figure.

[3]Series reflects output of marketable concentrates. Production of crude ore was as follows, in metric tons: 1988—810,837; 1989—1,385,565; 1990—1,432,741; 1991—879,477 (revised), and 1992—880,000 (estimated).

[4]Magnesitic dolomite and brucite. Figures are estimated on the basis of reported tonnage dollar value.

[5]Year beginning Mar. 21 of that stated.

[6]Includes 3,336 tons of huntite, ($Mg_3Ca(CO_3)_4$.)

[7]Formerly part of the U.S.S.R.

[8]All production in U.S.S.R. from 1988-91 came from Russia.

[9]Formerly part of Yugoslavia.

[10]All production in Yugoslavia from 1988-91 came from Serbia and Montenegro.

[11]Dissolved in Dec. 1991.

[12]Dissolved in Apr. 1992.

TABLE 21

MAGNESIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons of contained magnesium)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
WORLD PRODUCTION											
United States:											
Nonmetal	512	567	574	420	412	464	573	513	499	442	427
Metal	93	104	144	136	125	124	142	152	139	131	137
Total	605	671	718	556	537	588	715	665	638	573	564
Rest of world:											
Nonmetal	4,371	4,777	4,676	4,807	5,009	4,905	r4,756	r4,724	r4,466	r4,518	e4,508
Metal	161	156	184	189	196	200	192	192	r214	r208	e167
Total	4,532	4,933	4,860	4,996	5,205	5,105	r4,948	r4,916	r4,680	r4,726	e4,675
World total	5,137	5,604	5,578	5,552	5,742	5,693	r5,663	r5,581	r5,318	r5,299	e5,239
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
U.S. production:											
Nonmetal	512	567	574	420	412	464	573	513	499	442	427
Primary metal	93	104	144	136	125	124	142	152	139	131	137
Secondary metal (old scrap)	21	23	24	24	23	23	28	28	31	r27	31
Imports:											
Nonmetal	39	61	115	134	160	164	198	171	147	156	179
Metal	5	5	9	8	8	11	14	12	27	32	12
Industry stocks, metal, Jan. 1	57	42	25	32	39	39	28	25	26	26	27
Total U.S. supply	727	802	891	754	767	825	983	901	869	r814	813
Distribution of U.S. supply:											
Exports:											
Nonmetal	20	15	27	25	25	20	34	26	59	57	49
Metal	36	43	44	36	40	44	50	57	52	55	52
Industry stocks, metal, Dec. 31	42	25	32	39	39	28	25	26	26	27	13
Industrial demand[1]	629	719	788	654	663	733	874	792	732	r675	699
U.S. DEMAND PATTERN											
Nonmetal:											
Chemicals	85	105	131	127	171	155	202	188	174	187	180
Refractories	446	508	531	402	376	453	535	470	413	354	377
Total	531	613	662	529	547	608	737	658	587	541	557
Metal:											
Cans and containers	17	19	23	23	22	39	39	42	45	r42	40
Chemicals	6	7	8	5	3	2	1	1	1	1	1
Iron and steel desulfurization	NA	NA	10	12	12	13	15	15	16	13	20
Iron and steel foundries	4	3	4	3	3	2	3	2	1	1	2
Machinery	33	34	29	22	27	19	20	17	20	21	25
Nonferrous metal production	7	6	9	12	9	5	11	12	11	7	9
Transportation	25	31	36	38	33	38	38	36	38	37	34
Other	6	6	7	10	7	7	10	9	13	12	11
Total	98	106	126	125	116	125	137	134	145	r134	142
Total industrial demand	629	719	788	654	663	733	874	792	732	r675	699
Total U.S. primary demand[2]	608	696	764	630	640	710	846	764	701	648	668
Total U.S. demand for primary metal[3]	77	83	102	101	93	102	109	106	114	107	111

eEstimated. rRevised. NA Not available.

[1]Sum of total nonmetal and total metal demands.

[2]Total U.S. demand less U.S. recovery from secondary metal.

[3]U.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 of 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 Ivette Torres, Chief, Section of International Data.

Manganese (Mn) 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 with 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.

In the United States in 1992, ironmaking and steelmaking continued to account for about 90% of domestic manganese demand. Reported data indicated that the overall rate of usage of manganese in steelmaking was about 6% less than in 1991 because of a decline to a somewhat greater extent in the rate of usage of ferromanganese. Foreign trade in silicomanganese was relatively brisk. Imports of silicomanganese, which included a significant amount of material from Ukraine, were only slightly less than the 1991 record quantity, and exports were the greatest ever. The Government's stockpile policy underwent a major change that implied that most holdings of manganese materials would gradually be eliminated. The Government inventory of manganese, all forms, declined only marginally and at yearend still represented more than 2 years of apparent consumption.

Price trends were negative. On the international market, price decreases for metallurgical-grade manganese ore were in the range of 12% to 14%. In the United States, year-average prices for ferroalloys declined by about 15% for high-carbon ferromanganese and by more than 8% for silicomanganese.

World manganese ore production as listed in table 1 was estimated to have decreased to somewhat less than two-thirds of estimated capacity. The decline in output of the Republic of South Africa was particularly significant among declines indicated for a number of major producing countries. Revival of production in Egypt and Panama made a small addition to supply.

The level and nature of manganese use by the United States is expected to remain much the same in the near future. The rate of adaptation of the manganese producing and consuming industries of the Republics of the former U.S.S.R. to their new political environments continued to have an important influence on the rate of stabilization of the global manganese industry.

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 manganese that are in compliance with Public Law 100-418, will begin to report data in metric units.

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. By means of this survey, approximately 15 firms were canvassed that process ore by such methods as grinding and roasting or consume it in the manufacture of manganese ferroalloys, metal, and chemicals. In 1992, 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 4 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 1992, 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, 3.5 for medium-carbon ferromanganese, and 7.1 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 that typically contain 75% Mn, 25% Al and that are made by compacting manganese and aluminum powders. 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 Comércia 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); Georgia, mining of the Chiatura Basin; 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 Ukraine, mining of the Nikopol' Basin. 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 international ore market mainly has been supplied by a group of countries consisting of Australia (GEMCO), Brazil (ICOMI and CVRD), Gabon (COMILOG), and the Republic of South Africa (AMMOSAL and Samancor) acting in the manner of an oligopoly. In addition, Georgia and Ukraine in the former U.S.S.R. together had been supplying more than 1 million tons[3] of ore annually to Eastern Europe. However, the total of such exports was not much more than 700,000 tons in 1987 and dropped precipitously to average about 150,000 tons in 1990-91. The radical political changes that have taken place in Eastern Europe and the former U.S.S.R. cast considerable uncertainty on the pattern of manganese ore exports and imports in this region in the future.

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, about 10 main plants; France, Société du Ferromanganèse de Paris-Outreau (SFPO); 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 Ukraine, Nikopol' Ferroalloy Works. As with ore production, the output of Georgia combined with the much larger production from Ukraine had made the former U.S.S.R. by far the world's largest producer of manganese ferroalloys.

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, Georgia, and Ukraine produced metal, including that obtained metallothermically in the former U.S.S.R. World productive capacity for metal was given as 76,000 tons annually as of 1985[4] and would be approximately the same in 1992.

Annual world capacity for EMD was assessed as 198,000 tons in 1989, including capacities of 71,000 tons for Japan and 36,000 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 18,000 tons. The principal producer of CMD is Belgium's Sedema S.A., with an annual capacity of about 36,000 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 330 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. In a recent study, the world total for manganese in land-based resources was assessed as about 9 billion tons each in actually minable manganese deposits and in potentially minable accumulations.[8] 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.

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, commonly 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

A study by the Minerals Availability Program (MAP) of the U.S. Bureau of Mines has identified transportation as the most significant cost element in the production of manganese concentrates.[13] In a later MAP assessment of costs for most major mines in MEC's, transportation was found to account for about two-thirds of concentrate cost.[14] 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, more than 80% had estimated production costs within 20% of the lowest cost.

Operating Factors

Environmental Issues.—Manganese is an essential element for people, animals, and plants.[15] 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.[16] In excess, manganese can be harmful to the respiratory and nervous systems.[17] Thus, manganese can be an industrial poison, but normally is not a hazard. According to a review published in 1991, no environmental damage was known to be caused by manganese nor did manganese exposure pose a general risk to the environment.[18]

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.

ANNUAL REVIEW

Legislation and Government Programs

On January 3, EPA denied Ethyl Corp.'s July 12, 1991, request for a waiver to permit sale of methylcyclopentadienyl manganese tricarbonyl (MMT, "HiTEC 3000") as an

additive for use in unleaded gasoline (57 FR 2535). In doing so, the Agency stated it was unable to conclude that Ethyl had established that MMT would not lead to the failure of a significant number of vehicles to meet emissions standards. Shortly thereafter, Ethyl filed an appeal of EPA's denial with the U.S. Court of Appeals for the District of Columbia Circuit; action on the appeal was still pending at the end of 1992. The 1991 request for a waiver for MMT, an octane enhancer, was the fourth such application by Ethyl. Previous applications had been submitted on March 17, 1978; May 26, 1981; and May 9, 1990.

Strategic Considerations

Security of Supply.—Manganese, for which there is no economical substitute, is essential to steelmaking. Steel producers in the United States, Japan, and Western Europe have shared a common concern about lack of economically minable domestic manganese deposits. Also, the ore supply of these countries has come 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 the supply of manganese ferroalloys. The domestic manganese ferroalloy industry has declined well below self-sufficiency, and its continued existence has been uncertain for some years.

Stockpile.—The authority of the Defense Logistics Agency (DLA), U.S. Department of Defense, to dispose of excess manganese materials in the National Defense Stockpile was increased considerably on October 23 when the President approved the FY93 Defense Authorization Bill, which then became Public Law 102-484. As shown in table 2, the new levels of disposal authority corresponded at yearend to total inventories of synthetic manganese dioxide and all varieties of ore and most of the inventory of high-carbon ferromanganese. Other provisions of the law were that dispositions previously authorized should be completed by September 30, 1997, unless doing so would cause an undue market disruption; and that before October 1, 1993, metallurgical-grade ore could be disposed of only for processing within the United States and no ferromanganese could be disposed of. DLA subsequently indicated it expected the overall program of disposals authorized for manganese and other stockpile materials would take place over 10 to 14 years.

On December 4, DLA released the Annual Materials Plan for FY93, which specified maximum amounts of materials available for sale but not necessarily to be offered for sale in FY93. For manganese materials, the quantities were, in tons, natural battery-grade ore, 27,216; synthetic manganese dioxide, 2,732; chemical-grade ore, 36,287; and metallurgical-grade ore, 67,132.

In 1992, cash disposals consisted of 20,775 tons of natural battery ore, including any nonstockpile-grade material, and 10,668 tons of nonstockpile-grade metallurgical ore. Payment-in-kind disposals toward the ferroalloy upgrading program consisted, in tons, of metallurgical ore, stockpile-grade, 43,908 and nonstockpile-grade, 11,449; high-carbon ferromanganese, 2,268; medium-carbon ferromanganese, 907; and silicomanganese, 10,597. At 1.7 million tons, the reserve of contained manganese being held by the Government was only marginally diminished from that at yearend 1991.

DLA contracted with Elkem Metals Co. on September 30 to continue the program of upgrading stockpile metallurgical-grade ore into high-carbon ferromanganese. In a contract valued at $43.7 million, about 142,000 tons of ore was to be converted into 76,100 tons of ferromanganese by December 31, 1994. Upgrading of about 115,000 tons of ore into about 70,000 tons of ferromanganese in 1992 at a cost of $45.4 million had been authorized on April 1, 1991, when DLA exercised an option on a then-existing contract. The site of all conversions was Elkem Metals' Marietta, OH, plant.

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.[19] In so doing, OTA discounted ocean mining for the present, a view shared by most participants at a December 1989 conference on marine mining.[20]

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 recent years and reappraisal of stockpile needs have led to the view that the size of the stockpile can be considerably reduced. DLA has signaled its intention to dispose of the large majority of the manganese items in the stockpile, an action deemed likely to require a decade or more.

Production

Ore and Concentrate.—Production and shipments continued to consist 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%. Shipments 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 3. The only producer of manganese ferroalloys, Elkem Metals, suffered a major disruption early in December at its Marietta, OH, plant, when the electric furnace exploded that was being used to upgrade manganese ore into high-carbon ferromanganese for the Government stockpile. Four workers were injured, and the damaged furnace was put out of service indefinitely. Subsequent investigation indicated that zinc in the ore being smelted contributed to the cause of the accident.

In midyear, Chemetals Inc. announced that the annual capacity of its New Johnsonville, TN, plant for EMD was being increased by 4,500 tons. The expansion, scheduled for completion by July 1993, would raise Chemetals' annual capacity for EMD to more than 16,000 tons. The expansion program was designed to allow for additional incremental expansion if warranted by demand. Kerr-McGee Chemical Corp., one of the two other domestic producers of EMD, reported that its plant at Henderson, NV, was operating at its capacity of 14,500 tons per year.

Consumption, Uses, and Stocks

Metallurgical applications accounted for most manganese consumption, almost 90% of the total for steelmaking. This can be deduced from the data relating to manganese end use that form the basis of tables 4 and 5 plus certain other information. Industry averages are presented in table 6 for kilograms of manganese used in ironmaking and steelmaking (including for castings) per ton of raw steel produced, on the basis of the reported data in tables 4 and 5. (Note: Multiply by 2.0 to convert data in terms of kilograms per metric ton to pounds per short ton, the unit previously used in manganese annual reports.) Although somewhat increased, unit consumption of manganese in ironmaking was still roughly at the comparatively low level reached in 1991. Manganese unit consumption in steelmaking declined 6% overall because of a drop in the rate of usage of ferromanganese. Relatively small quantities of manganese were used for alloying with nonferrous metals, chiefly as manganese-aluminum briquets for alloying with aluminum.

Nonmetallurgical applications for manganese included animal feed, brick coloring, dry cell batteries, manganese chemicals, and plant fertilizers.[21] One report raised the possibility that potassium permanganate, an oxidizer used in water treatment, could be used in the future to control water line blockages from zebra mussels now invading the Great Lakes.[22]

Domestic companies engaged in the manufacture and marketing of manganese-containing dry cells reported that the key growth component was the alkaline type of battery based on use of synthetic manganese dioxide. One company observed that, in terms of units, the compound growth rate during the past 5 years was 3% for dry cells overall and 8% for alkaline cells.

The international affiliations of the Eveready Battery Co. were expanded in July through acquisition of Ever Ready Ltd. in the United Kingdom, a firm that Eveready Battery had been associated with before Ralston Purina Co.'s purchase of the battery business of Union Carbide Corp. in 1986. Further international battery activities of Ralston Purina included establishment of the Beijing Eveready Battery Co. in China and acquisition of a battery business in Portugal and Spain.

Attention continued to be focused on two environmentally related aspects of the dry battery industry, mercury elimination and recycling. According to one source, battery manufacturers in the United States, Europe, and Japan may have achieved by the end of 1992 the goal of adding no mercury in production of all dry cells commonly in household use. As of January 1992, the various battery recovery operations of Texas' Basalt Industries Inc. were made into a separate company, Recovery & Reclamation Inc. (R&R), located in Pecos. R&R was using physical methods to recover materials in dry cell batteries in facilities having annual capacities of more than 2,000 tons for processing carbon-zinc cells and about 4,500 tons each for alkaline cells, with or without mercury. In Switzerland, Recytec S.A. (as of late 1991) and Batrec AG (as of mid-1992) were processing dry cells collected under a Swiss program in which recycling was being aided by taxes on batteries. Pyrolysis was a part of the processing sequence at both Swiss plants. According to technology developed by Japan's Sumitomo Heavy Industries Ltd., at Batrec the manganese content of batteries was being converted into low-grade ferromanganese that was to be used in steelmaking in Switzerland.

Markets and Prices

Manganese Ore.—For the second successive year, the price of metallurgical manganese ore decreased from the peak reached in 1990. Agreements between Japanese consumers and their traditional suppliers were reached comparatively early. For the benchmark of high-grade lumpy ore containing 48% manganese, Australia's Broken Hill Pty. Co. Ltd. (BHP) agreed as of mid-December 1991 to an f.o.b. price of $2.95 per metric ton unit (mtu) for material from GEMCO, a decrease of 11.9% from the 1991 contract price. As of early February 1992, South African suppliers accepted a decrease of 14.4% to an f.o.b. price of $2.85 per mtu for similar ore. In mid-January, Portman Mining Ltd. had settled for delivery at $2.70 per mtu, f.o.b., for its lumpy ore containing 46% manganese from Western Australia, which has been a factor contributing to the downward trend in ore price. In May, Metal Bulletin of London revised downward by about 14% its c.i.f. price for delivery of ore to European ports.

The average price, c.i.f. U.S. ports, for metallurgical ore containing 48% manganese was assessed as $3.25 per mtu, for a decline similar to that in other international ore markets. Contracts were made at prices both above and below this average, and significantly lower prices were available late in 1992. The metric

ton unit is 1% of a metric ton; that is, 10 kilograms of contained manganese. The price of manganese in ore in 1992 and 1991 thus can be expressed in cents per kilogram as 32.5 and 37.2, respectively. The price of a metric ton of ore is obtained by multiplying the metric ton unit price by the percentage of 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. The price trend for metallurgical ore during the past two decades is given in table 7, in which constant dollar prices were calculated using Implicit Price Deflators for GDP.

Manganese Ferroalloys.—Again as in 1991, price trends in the United States for manganese ferroalloys, as given by quotations for imports, were negative, both for average price in comparison with that for the prior year and for change during the year. Declines in price were more pronounced for high-carbon ferromanganese than for silicomanganese. The decrease in year-average price was more than 15% for high-carbon ferromanganese and somewhat more than half that for silicomanganese.

According to one study of trends in Western countries during 1985-90, fluctuations in the prices of high-carbon ferromanganese and silicomanganese approximately followed the crude steel production trend.[23] For 1992, the influence on ferroalloy prices of an increase of about 4% in crude steel production in the United States apparently was overridden by a decrease in crude steel production in Western countries of only about 1%. However, crude steel production in Western countries was estimated as the least since 1988. English units continued to be used for price quotes in the United States as given in sources such as Metals Week. For high-carbon ferromanganese containing 78% manganese, the price range of imported material, f.o.b. Pittsburgh or Chicago warehouse, was $555-$560 per long ton of alloy at the start of 1992. The level of the price range generally decreased throughout the year, most strongly in March. The yearend range of $485-$490 signified again as in 1991 a decrease for the year of about 13%.

The change in price range for imported silicomanganese with 2% carbon, in cents per pound of alloy, f.o.b. Pittsburgh or Chicago warehouse, from 23.8-24.25 at the start of 1992 to 23-23.25 at yearend represented a decrease that approached 4%. The price trend for silicomanganese was moderately downward at the beginning and end of the year and firmer in between.

Domestic producer prices given by Metals Week for high-carbon ferromanganese and silicomanganese remained 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.—Trade journal listings again remained the same throughout the year as those already published effective mid-November 1990: a price range of $1.04-$1.05 per pound according to Metals Week and $1.05 per pound according to American Metal Market. These were for bulk shipments of domestic material, f.o.b. shipping point.

Foreign Trade

The total of manganese units exported in 1992 was about seven-tenths that in 1991 after adjusting for transshipments of ore from Gabon to Mexico that were included in the data for 1991. Ore exports in 1992 were almost 70% less than the adjusted total for 1991 and were the least since 1965. Ore reexports in 1992 were only 85 tons, all to Mexico, and appeared to have been transshipments.

Among exports of ferroalloys and metal, those of ferromanganese and metal decreased, by 8% overall and 5%, respectively. Exports of ferromanganese containing less than 2% carbon decreased by about one-eighth to 8,766 tons whereas the quantity remained about the same for those containing more than 2% carbon. Exports of silicomanganese were principally to Canada and more than tripled to become the greatest since a separate reporting category for silicomanganese was set up effective as of 1978. Reexports of ferromanganese and silicomanganese, all to Canada, consisted of 3,227 tons of ferromanganese and 1,432 tons of silicomanganese. Those of ferromanganese were about equally divided between higher and lower carbon grades. Exports of 2,235 tons of spiegeleisen were reported, all to the Republic of Korea, but at a unit value so low as to put the data in question.

The total manganese units imported was about 2% less than that in 1991 and again the least since 1987. Within the content totals for 1992 imports, the ratio of the sum of ore plus dioxide to the sum of ferroalloy plus metal was 3.2, or about midway between values of this ratio for 1990 and 1991. For ore and ferromanganese overall, average manganese contents were nearly the same as in most years of the past decade, at 48.8% for ore and 78.4% for ferromanganese. The apparent increase of about 5% in volume of ore imports was actually about 18% after adjusting the data for transshipments of Gabonese ore to Mexico in 1991. The increase in ore imports in 1992 came about mostly because of ore containing less than 47% manganese received from Brazil.

For most categories of ferroalloy and metal, quantities imported in 1992 were less than in 1991. The overall total for ferromanganese was about 5% lower and the least since 1983. However, imports of medium-carbon ferromanganese rose by about one-fifth to the third largest amount during at least the past two decades. Imports of silicomanganese declined only marginally from the record total set in 1991. Among these, the quantity from Brazil advanced to a new record, and material received from Ukraine was the first significant receipt of mineral-related manganese from countries that had been a part of the now restructured former U.S.S.R. For the two categories of metal exclusive of waste and scrap, although quantities imported decreased overall, the imports

of unwrought metal from China increased for the fourth successive year to rise to about one-fifth of imports of unwrought metal. Imports of spiegeleisen were reported as 214 tons, all from Germany at a high unit value.

Among imports of manganese chemicals, those of manganese dioxide increased about 6% and were the third highest on record. All dioxide imports evidently were synthetic material, disregarding 38 tons that appears to have been misclassified. In rising about 7%, imports of potassium permanganate included for the former Czechoslovakia about seven times the 1991 quantity whereas those from China and Spain declined again. Imports from Mexico under the classification "Other sulfates" that includes manganese sulfate increased by almost one-fourth to 12,439 tons at a value of $6.7 million.

The schedule of tariffs that applied during 1992 to U.S. imports of selected manganese materials is given in table 10.

Most-favored-nation (MFN) trade status was granted in 1992 to a number of the newly independent states that formerly were a part of the U.S.S.R. Of such states having the potential to be a source of U.S. imports of manganese materials, the granting of MFN status was effective June 17 for the Russian Federation (Russia) (57 FR 27840) and June 23 for Ukraine (57 FR 28771).

For most former Yugoslav Republics, duty-free treatment under the Generalized System of Preferences (GSP) program was restored as of September 11, after having been suspended December 24, 1991. The change, effected by Presidential Proclamation 6465 (57 FR 39095), again made ferroalloy producers in Croatia and Macedonia eligible for GSP benefits. The principal manganese item exported to the United States has been silicomanganese.

World Review

Capacity.—The rated capacity data in table 11 are as of December 31, 1992. Generally they differ only in minor respects from those for the previous year except for an increase in the figure for China. The figure for the former U.S.S.R. reflects conditions before the formation of independent Republics. The capabilities of these Republics, largely concentrated in Georgia and Ukraine, may be overstated in view of the political and economic changes that have taken place. 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;[24] no domestic deposits qualify.[25] World reserves of manganese, generally on the same basis as capacity, are given in table 12 with no distinction between ore type or application. The data in table 12 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 13.

Australia.—Manganese ore operations were producing at a substantially diminished rate at the Groote Eylandt Mine (Northern Territory) of the GEMCO subsidiary of BHP. Reflecting this, manganese ore production reported by BHP for the 1992 fiscal year ending May 31 was 970,000 tons, a reduction of about 30% from that in the prior fiscal year and an output less than one-half that of an annual capacity of about 2.3 million tons. Shipments of ore by GEMCO to foreign and domestic destinations during calendar 1992 were reported as only 952,000 tons.[26] This was a decline of about one-fifth from those in 1991.

In Western Australia, 1992 shipments of manganese ore by Portman Mining Ltd. from the Woodie Woodie area of the Pilbara Manganese Province were again in the range of 300,000 tons. In these operations, the Radio Hill and Lox deposits were worked out and mining progressed to the Cracker deposit, for which a heavy-medium separation plant was installed for control of silica and overall product quality. In the Peak Hill Manganese Province to the southwest, ore production was reactivated at the Millidie deposit north of Meekatharra in the latter half of the year. Valiant Consolidated Ltd. and Sabminco NL, principals in this venture, projected an annual output in the vicinity of 100,000 tons within a year, with shipment for export to be via the port at Geraldton.

Brazil.—Shipments of manganese ore by ICOMI from operations at Serra do Navio, Amapá Territory, through Porto de Santana on the Amazon River, increased by more than one-fourth to 490,000 tons. Most of the increase was in domestic shipments, which more than doubled from 76,000 tons to 160,000 tons. Exports of ICOMI, a subsidiary of Cia. Auxiliar de Empresas de Mineração S.A., rose by 21,000 tons to 330,000 tons.[27]

CVRD's production of manganese ore from its Azul Mine in the Carajás region was 372,000 tons, a decrease of almost 40% from the 601,000 tons produced in 1991. In 1992, CVRD's manganese ore sales were 322,000 tons to export, a 27% increase, and 79,000 tons to domestic customers, a 28% decrease. CVRD acquired a 35% interest in Société Européene d'Alliages pour la Sidérurgie (SEAS), a new producer of manganese ferroalloys whose coastal plant at Dunkirk, France, was completed near the end of 1991. CVRD previously had entered into a long-term contract to supply about two-thirds of the manganese ore feed for the SEAS plant, initially to come from the Azul Mine.

Also in the Carajás region, the endeavors of Prometal Produtos Metalúrgicos S.A. to begin manganese mining and/or smelting were scaled back to development of the Buritirama deposit acquired in 1986, subject to the making of financial arrangements within Brazil.

Output of manganese ore by Urucum Mineração in the State of Mato Grosso do Sul, 47% owned each by CVRD and the State, declined by 24%, to 203,000 tons

from 267,000 tons in 1991. In 1992, sales to the domestic market more than doubled, to 205,000 tons from 87,000 tons, whereas those to foreign markets decreased by 44% to 63,000 tons from 114,000 tons. Export destinations in recent years have included Romania. A further potential outlet developed for ore being produced by Urucum Mineração was a silicomanganese plant proposed to be set up in Paraguay, which would use a duplex smelting process to deal with the relatively high alkali and phosphorus contents of Urucum ore.

Canada.—In the latter half of the year, RAM Batteries Canada Inc. (RAM) completed, with governmental aid, the financing for a $10 million dry cell battery plant. Initially, this plant would manufacture a popular consumer type of alkaline battery that would be mercury-free and rechargeable. The Nova Scotia Business Development Corp. provided a major loan for the plant, which was to be built in Amherst, Nova Scotia. The technology to be employed by RAM Batteries was under license from Battery Technologies Inc. of Ontario.

China.—Imports of manganese ore continued a growing trend, with quantities reported in thousand tons as 425, 357, 561, and 640 in 1989, 1990, 1991, and 1992, respectively.[28] Australia and Gabon were the leading sources of these imports.

An important factor in the magnitude of imports of high-grade ore has been the importing of ore into China for conversion into manganese ferroalloys that are subsequently exported for sale, particularly to other countries in the Far East. According to press reports, Hong Kong-based Eastern Century Holdings Ltd. has been a major participant in this activity via a subsidiary, Bogay Investment Ltd. Gabon has been the source of Eastern Century's manganese ore via France's SFPO, in which COMILOG has held a significant interest. In the latter part of 1992, Eastern Century invested in three of China's most important manganese ferroalloy producers: Jiangxi Xinyu Iron and Steel Complex, Jilin Ferro Alloy plant, and Shanghai Ferro Alloy plant.

At the Jiangxi Xinyu Iron and Steel Complex, China's largest ferromanganese producer, a duplex blast furnace process has been developed for obtaining high-carbon ferromanganese from domestic ores whose contents are typically relatively low in manganese and high in phosphorus. Development of the process also reflected the relative abundance of coal but shortage of electric power in China. By this process, manganese ore was first smelted to segregate phosphorus and iron into a pig iron byproduct and a manganese-rich slag that was fed to a second blast furnace for production of ferromanganese. Drawbacks of the process were a high coke consumption and a manganese recovery of only 69%.[29]

Egypt.—Manganese ore and ferromanganese production resumed on the Sinai Peninsula following lapses extending back to the late 1960's at the time of the Arab-Israeli War. At Abu Zenema in southwestern Sinai, a refurbished and modernized electric furnace facility with an annual capacity of about 40,000 tons for high-carbon ferromanganese was obtaining at least a portion of its feed from reactivated mines about 200 kilometers south of Suez in the Um Bogma region. The Um Bogma mines and the Abu Zenema plant were operated by the Sinai Manganese Co., one of the companies belonging to the public sector's Mining and Refractories Corp.

France.—Late in the year, Pechiney took actions that would end its participation in France in production of manganese ferroalloys. The plant of its Dunkerque Electrométallurgie subsidiary on the northernmost coast at Dunkirk was sold to SFPO, the operator of a blast furnace ferromanganese plant at Boulogne, also on the coast southwest from Dunkirk. Pechiney gave as a reason for the sale the need for a close connection with a manganese ore producer such as the relation between SFPO and COMILOG. Pechiney also announced the intention to close by the end of 1993 its Le Giffre plant, a producer of specialty manganese alloys located in the alpine region of southeastern France. Pechiney ascribed this decision to a decline in demand for low-carbon ferroalloys and competition with material from China and the former U.S.S.R. Reported annual capacities were 60,000 tons of silicomanganese at Dunkirk and 20,000 tons of manganese in products at Le Giffre.

As mentioned above under Brazil, Brazil's CVRD acquired a 35% interest in SEAS, a new manganese ferroalloys subsidiary of the French steel producer Usinor-Sacilor S.A.

Gabon.—Production and exports of metallurgical-grade ore from COMILOG's Moanda Mine decreased by 7% and 17%, respectively, whereas those of battery-grade ore rose substantially, by 84% and 65%, respectively. The production total included 101,000 tons of battery-grade ore. The export total of 1,551,000 tons consisted of 1,458,000 tons of metallurgical-grade ore and 93,600 tons of battery-grade ore. In November it was reported that COMILOG had ended export of manganese ore via the traditional route through neighboring Congo. This was the outcome of failure to resolve controversy arising from an accident in September 1991 on the rail portion of the route terminating at the Congolese port of Pointe-Noire. All of COMILOG's shipments henceforth would be via the Trans-Gabon Railroad and the Gabonese port of Owendo.

COMILOG's involvement in manganese ferroalloy production in China is discussed above under China.

Ghana.—Exports of ore from the Nsuta Mine of Ghana National Manganese Corp. through the Port of Takoradi were 284,000 tons, a decline of 11% from the 320,000 tons shipped in 1991. Destinations of the shipments were Japan and Europe (the former Czechoslovakia, Finland, France, Ireland, Norway,

Romania, and Spain).[30]

Japan.—Overall production of manganese ferroalloys decreased by about one-sixth to 458,000 tons. For ferromanganese, production decreases were about one-fifth each for total quantity, to 362,000 tons; for high-carbon, to 294,000 tons; and for low-carbon, to 68,000 tons. In each case, these outputs were the least since 1987. Production of silicomanganese increased by about one-tenth to 96,400 tons.

Imports of manganese ferroalloys declined 20% overall to 219,000 tons. Of this total, silicomanganese was imported in the largest quantity, 194,000 tons, a decrease also of almost 20%. Principal supplying countries for silicomanganese were China, Republics of the former U.S.S.R., and Brazil, with 37%, 22% combined, and 19% of the total, respectively. On June 18, the Japanese Government announced that it would not impose provisional duties on imports of silicomanganese from China, Norway, and the Republic of South Africa before conclusion of its antidumping investigations. Within 1 month, the Japan Ferro Alloys Association formally notified the Government of its dissatisfaction with this interim decision. Among other items of foreign trade in manganese ferroalloys, overall imports of ferromanganese decreased almost 22% to 25,500 tons. Exports of manganese ferroalloys were still relatively small. Those of ferromanganese rose by two-thirds to 8,400 tons overall and of silicomanganese by about one-third to 86 tons.

For EMD, production declined by 7% to 54,300 tons. Exports decreased 3% to 30,300 tons while remaining at roughly the same level as in 1989-91.

Imports of unwrought manganese metal, including scrap, increased 11% to 19,950 tons, of which 51% was from the Republic of South Africa and 46% was from China.

Mexico.—Ore output from the operations of Autlán in the Molango District of Hidalgo State rebounded from the abnormally low levels of 1991. In that year, the rotary kiln used to produce oxide nodules from carbonate ore was shut down for 5 months for repairs and installation of pollution control equipment. Production in 1992 consisted of 525,000 tons of carbonate ore, of which 65,000 tons was sold without nodulizing; 316,000 tons of oxide nodules; and, from the Nonoalco Mine, 26,000 tons of battery ore. Autlán's production of manganese ferroalloys also advanced to total almost 189,000 tons, an increase of about 8%. The product mix consisted of 95,900 tons of high-carbon ferromanganese, 35,300 tons of low- and medium-carbon ferromanganese, and 57,500 tons of silicomanganese, which represented increases of 1%, 12%, and 17%, respectively.

Autlán's increased ferroalloy output helped compensate for the domestic production lost from closure at the end of 1991 of the ferroalloy plant of Ferroaleaciones de México, S.A. (Ferromex). Ferromex, headquartered at Gómez Palacios, Durango State, had been principally a producer of ferromanganese and silicomanganese with a combined annual capacity for these ferroalloys in the range of 40,000 tons.

Norway.—Faced with losses and weak markets for its products, Elkem, the larger of the two Norwegian producers of manganese ferroalloys, strengthened its financial position by carrying out a refinancing plan late in the year. The plan involved a share issue for which there proved to be sufficient interest that a commitment made by the Norwegian state to serve as an underwriter was not needed. The refinancing was preceded at Elkem by economy moves and an internal reorganization. Elkem's plant at Sauda experienced an explosion in late March that put out of service for some weeks a newly installed unit for producing granulated silicomanganese. Because of market conditions, the Sauda plant was shut down the last 6 weeks of 1992.

Panama.—On August 5, Caribbean Mining Co. Inc. received a manganese extraction concession from the Government of Panama. This concession had been preceded in June by an authorization for exchange of an exploration concession for an extraction concession and, before that, by the granting of an exploration concession in the Colón area. Caribbean Mining was reported to have plans to reopen a mine not far from the canal passing through central Panama. The ore output of the mine was expected to be in the range of 100,000 tons annually and targeted mainly at the U.S. market.

South Africa, Republic of.—Overall manganese ore production declined for the third successive year; the decline in 1992 was more than one-fifth. The bulk of production was metallurgical-grade ore, which totaled 2,375,000 tons. Of this quantity, the two largest components of the metallurgical-grade ore were material having a manganese content exceeding 48% and material with a manganese content between 30% and 40%. These two components accounted for 56% and 21%, respectively, of the output of metallurgical-grade ore. The relative magnitudes of these two components in the South African statistics for metallurgical-grade ore have been about one-half or greater, and one-fifth, respectively, since Samancor, following its installation of a heavy-medium ore-beneficiating plant, began producing in late 1989 a high-grade sinter containing a minimum of 48% manganese. In the statistics for the years just before that, the relative proportions by content had been almost 40% for ore containing 30% to 40% manganese and about 30% for ore containing more than 48% manganese.

Besides having added sintering capabilities, Samancor worked toward future production of high-quality mine and smelter products. One project involved extending the supply of high-grade ore from its underground Wessels Mine in the Kalahari Field in the northern Cape Province. Access to the western block of reserves at that mine was provided by excavation work and installation of crushing and ore-handling equipment. Another project involved

installing a casting machine at the North Plant of Samancor's Meyerton manganese ferroalloys operations. The purpose of this machine was to give more uniform sizing to products from the two large high-carbon ferromanganese furnaces at that plant.

Former U.S.S.R.—Manganese ore production continued to suffer from the economic disruption accompanying changeover to a Commonwealth of Independent States from the former Soviet state. Aggregated ore output for 1991 and as estimated for 1992 was at the lowest level since 1970.

Transition to a decentralized economy also required the establishment of new relationships between suppliers and consumers. This involved manganese ore and ferroalloys production that was concentrated in Georgia and Ukraine, particularly the latter, plus a minor amount of ore produced in Kazakhstan. Kazakhstan's production is estimated to have been typically of the order of 100,000 to 200,000 tons annually but was only a fraction of that in 1992. One of the more significant inter-Republic shipments of ore was that from Ukraine to Russia. This was from mines in the Nikopol' Basin to blast furnace ferromanganese operations at the Kosaya Gora Iron Works south of Moscow. Problems encountered in material flow to meet a manganese demand coming mostly from steel production centers in Russia and Ukraine included internal ones related to payments. Shipments for export were hampered somewhat by port realignments.

Ore exports had increased somewhat in 1991 from the total of only 128,000 tons in 1990, although quantities for both years were relatively small in comparison with quantities exported annually during the four previous decades. Destinations of Ukraine's 1991 ore exports were, in tons, Poland, 91; the Republics of the former Czechoslovakia, 72; and the former Yugoslavia, 3, for a total of 166.[31]

Current Research

Information on manganese mineral resources was significantly enlarged by issuance of several publications. The U.S. Bureau of Mines updated information on the principal manganese deposits of MEC's through the 1988-89 period, with emphasis on supply and demand aspects.[14] This information, developed by the Bureau's Denver Minerals Availability Field Office, previously had been reported on in 1984. The August 1992 issue of Economic Geology contained a collection of 16 papers on manganese deposits. Five were relatively general and discussed geological conditions and environments associated with the deposits and their mineralogy. Eleven dealt mainly with specific deposits in Australia, Brazil, China, India, Japan, Mexico, Namibia, Nova Scotia, and Scotland.[32] In one of a series of studies on small U.S. manganese deposits, the U.S. Geological Survey presented evidence for a submarine hydrothermal origin of the Bald Knob deposit in upper northwestern North Carolina. This deposit was found to have geological similarities with three other small metamorphosed manganese deposits in California.[33]

The U.S. Bureau of Mines, in cooperation with the Minnesota Geological Survey, University of Minnesota, and the Minnesota Department of Natural Resources, has been exploring the potential for using in situ leach mining to extract manganese from manganiferous iron formations of the Cuyuna Range in central Minnesota. This work has resulted in publication of several studies addressing geological factors related to two potential sites, one in the Emily district and the other slightly to the south, and the need to make further investigations.[34]

In another project aimed at determining the potential for utilizing domestic resources, the U.S. Bureau of Mines conducted tests on manganese- and cobalt-bearing samples from former mines in a region of west central Arkansas having as yet undefined resource possibilities. Head samples with contents of manganese ranging from 9.2% to 22.6% and of cobalt from 0.02% to 0.11% were subjected to mineralogical examination and tests of grinding, gravity and magnetic concentration, and hydrometallurgical response. Magnetic separation gave the highest recoveries, which were as great as 95% for manganese and 93% for cobalt at grades of 41% Mn and 0.22% Co.[35]

The proceedings of the 6th International Ferroalloys Congress (INFACON 6), which was held in the Republic of South Africa in March, contained several technical papers dealing with the pyrometallurgical processing of manganese materials.[36] On pp. 131-138, P. C. Pienaar and W. F. P. Smith of Samancor reviewed the steps taken that ultimately led to production of sinter containing 48% manganese from ore containing 38% manganese from the company's Mamatwan Mine and stated the improvements in productivity and product manganese content that resulted when this sinter was used in smelting high-carbon ferromanganese. S. Suzuki and M. Masukawa of Japan's Mizushima Ferroalloy Co. described, on pp. 149-154, how oil injection and accompanying oxygen enrichment of the blast was used to increase by about one-tenth the productivity of the company's shaft furnace for smelting ferromanganese. On pp. 145-147, Z. Jinhua (Univ. of Science and Technology, Beijing) and L. Zhizhong (Liaoyang Ferroalloy Plant) discussed development in China of silicothermic technology that entails use of a shaking ladle to produce low- and medium-carbon ferromanganese. Chinese ferroalloy producers have widely adopted this technology because of the high silica content of native manganese ores. Another application of silicothermic technology, in this case for producing silicomanganese from slag from ferromanganese smelting, was set forth on pp. 139-143 by R. Kamata, Y. Kizu, and H. Tsujimura of Japan's Nippon Denko Co. Ltd. Reduction conditions were enhanced by injection, using a gas such as nitrogen for stirring and a flux such as lime for adjusting slag basicity. The process was claimed to result in

phosphorus and carbon contents lower than in silicomanganese conventionally obtained by electric furnace smelting.

Operational features and improvements of the Øye Smelteverk manganese ferroalloy plant of Norway's Tinfos Jernverk A/S were presented at a meeting held in the United States. During the plant's first 17 years of service, 1974-91, 2.3 million tons of high-carbon ferromanganese and silicomanganese was produced. In the past decade, mostly silicomanganese has been produced at near the annual capacity rate of 135,000 tons. Specific energy consumption for producing silicomanganese has been lowered from about 4,800 kW • h per ton to slightly more than 3,000 kW • h per ton, including the effect of electric energy recovery begun in the early 1980's.[37]

The U.S. Bureau of Mines carried out a laboratory investigation of the feasibility of recovering manganese from slag generated during basic oxygen steelmaking. With the use of an ammonium carbamate leach, manganese recoveries of more than 80% were obtained for a silicon steel slag containing 3% manganese. The investigators found that pretreatment of the slag with hydrogen gas at about 700° C was necessary to achieve a reasonable degree of recovery.[38]

The potential effect of steel property requirements on steel manganese content was illustrated in a comparative study of steels for automotive wheels. Wheel design trends tending to increase wheel weight have been leading to a need for stronger but lighter formable steels. Improved properties obtained with a high-strength low-alloy steel or a dual-phase steel were associated with compositions requiring roughly twice as great a manganese content, 1.4% and 1.2%, respectively, as in a conventional mild steel containing 0.7% manganese.[39]

The possibility of attaining superplasticity in Hadfield manganese steels and thereby overcoming difficulties in shaping such steels was investigated in the laboratory. Various thermomechanical processing techniques were applied to samples containing 1.2% to 1.7% carbon and 12.3% to 16.3% manganese to develop the requisite ultrafine grain structures. In initial tests conducted at 750° C to 900° C, strain rate behavior indicative of superplasticity was observed.[40]

Iron-base alloys capable of undergoing reversible martensitic transformations have the possibility of serving as shape memory alloys capable of reassuming a previous geometry upon heat treatment. Alloys containing 14% to 30% manganese and 2% to 7% silicon were among a number of compositions investigated for this possibility. Studies indicated that such ferrous alloys had promise, particularly for a one-time application, as an alternative to the more expensive nickel-titanium shape memory alloys.[41]

Thermodynamic assessments were performed of two binary systems, manganese-oxygen and aluminum-manganese, by researchers at the Royal Institute of Technology in Stockholm, Sweden. For the Mn-O system, a calculated phase diagram was presented for the temperature range of 1,000° K to 2,500° K and an oxygen partial pressure of 0.21 atmospheres that applied to compositions ranging from pure manganese to those with oxygen mole fractions of up to 0.7.[42] For the Al-Mn system, the "CALPHAD" computer technique was used to obtain a complete description of the system for all compositions between pure aluminum and pure manganese, based on which a phase diagram was presented for the temperature range of 400° C to 1,400° C.[43]

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.

For the past decade, U.S. apparent consumption of manganese has not varied from 635,000 tons of contained manganese by much more than plus or minus 10%, as shown in table 14. This has largely been a consequence of similar variability in domestic steel production. Manganese demand as calculated in table 14 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 in 1993, as discussed in the Annual Report for Iron and Steel, includes a further improvement over that for 1992, from which a corresponding increase in manganese demand can be expected. Forecasts of the International Iron and Steel Institute (IISI) continue to suggest only slow growth in U.S. steel output through 1995. This indicates that U.S. apparent consumption of manganese in 1993-95 is unlikely to range far from 635,000 tons of contained manganese, on the 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's late-1992 estimate of world steel consumption in 2000 is only 105% of consumption in 1990. IISI foresees for steel consumption a static condition for industrialized countries and an increase for developing countries and China that offsets the decrease expected for the former U.S.S.R. and Eastern Europe. Developments in the steel and manganese industries of China and the former U.S.S.R. can be expected to have a particularly significant influence on world manganese supply and demand in the coming years. Resurgence of ore production from localities such as Western Australia and potential new developments elsewhere could add to future supply for at least a limited number of years, depending on future ore

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TABLE 1
SALIENT MANGANESE STATISTICS

(Thousand metric tons, gross weight)

	1988	1989	1990	1991	1992
United States:					
Manganese ore (35% or more Mn):					
Exports	62	52	70	66	13
Imports for consumption	464	580	307	234	247
Consumption	e503	559	497	473	438
Stocks, Dec. 31: Consumers	e415	470	379	275	276
Ferromanganese:					
Exports	3	8	7	15	13
Imports for consumption	482	432	380	320	304
Consumption	425	399	413	346	339
Stocks, Dec. 31: Consumers and producers	83	68	56	50	28
World:					
Production of manganese ore	r25,013	r26,389	r25,252	r21,213	e19,929

eEstimated. rRevised.

TABLE 2
U.S. GOVERNMENT DISPOSAL AUTHORITIES AND YEAREND INVENTORIES FOR MANGANESE MATERIALS IN 1992

(Metric tons, gross weight)

Material	Disposal authority	Physical inventory, Dec. 31				
		Uncommitted			Sold, pending shipment	Grand total[1]
		Stockpile grade	Nonstockpile grade	Total		
Natural battery ore	166,107	150,517	15,590	166,107	12,428	178,534
Synthetic manganese dioxide	2,732	2,732	—	2,732	—	2,732
Chemical ore	156,711	156,630	81	156,711	378	157,089
Metallurgical ore	1,572,050	1,155,826	416,223	1,572,050	[2]302,576	1,874,625
High-carbon ferromanganese	851,199	973,331	—	973,331	[2]10,306	983,636
Medium-carbon ferromanganese	—	22,745	—	22,745	[2]2,704	25,448
Silicomanganese	—	12,149	—	12,149	—	12,149
Electrolytic metal	—	12,857	—	12,857	—	12,857

[1]Data may not add to totals shown because of independent rounding.
[2]Includes quantities reserved for payment-in-kind disposal.

TABLE 3
DOMESTIC PRODUCERS OF MANGANESE PRODUCTS IN 1992

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.

[1]FeMn, ferromanganese; SiMn, silicomanganese; Mn, electrolytic manganese metal; MnO_2, synthetic manganese dioxide.

TABLE 4
U.S. CONSUMPTION AND INDUSTRY STOCKS OF MANGANESE ORE,[1] BY USE

(Metric tons, gross weight)

Use	Consumption		Stocks, Dec. 31	
	1991	1992	1991	1992
Manganese alloys and metal	W	W	W	W
Pig iron and steel	47,000	49,000	27,000	20,000
Dry cells, chemicals, miscellaneous[2]	W	W	W	W
Total	473,000	438,000	275,000	276,000

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Containing 35% or more manganese (natural).
[2]Natural ore, including that consumed in making synthetic manganese dioxide.

TABLE 5

U.S. CONSUMPTION, BY END USE, AND INDUSTRY STOCKS OF MANGANESE FERROALLOYS AND METAL IN 1992

(Metric tons, gross weight)

End use	Ferromanganese			Silico-manganese	Manganese metal
	High carbon	Medium and low carbon	Total[1]		
Steel:					
Carbon	190,839	72,657	263,496	76,589	2,450
Stainless and heat-resisting	13,679	(2)	13,679	5,169	1,768
Full alloy	20,942	5,283	26,225	15,728	464
High-strength, low-alloy	18,811	2,563	21,374	4,915	(2)
Unspecified[3]	389	689	1,079	546	260
Total steel[1]	244,661	81,192	325,853	102,947	4,943
Cast irons	10,809	585	11,394	11,355	6
Superalloys	W	—	W	—	103
Alloys (excluding alloy steels and superalloys)	1,102	275	1,377	(4)	[5]19,659
Miscellaneous and unspecified	W	—	W	(4)	W
Total consumption[1]	256,572	82,052	338,624	[6]114,303	24,712
Total manganese content[7]	200,000	66,000	266,000	75,000	25,000
Stocks, Dec. 31:					
Consumers and producers	22,370	6,059	28,429	7,106	(8)

W Withheld to avoid disclosing company proprietary data; included in "Alloys (excluding alloy steels and superalloys)."
[1]Data may not add to totals shown because of independent rounding.
[2]Withheld to avoid disclosing company proprietary data; included in "Steel: Unspecified."
[3]Includes electric and tool steel, and items indicated by (2).
[4]Withheld to avoid disclosing company proprietary data; included in "Cast irons."
[5]Approximately 85% of this combined total was for consumption in aluminum alloys.
[6]Internal evaluation indicates that silicomanganese consumption is considerably understated.
[7]Estimated based on typical percent manganese content (rounded).
[8]Withheld to avoid disclosing company proprietary data.

TABLE 6

U.S. UNIT CONSUMPTION OF MANGANESE IN IRONMAKING AND STEELMAKING

(Kilograms per metric ton of raw steel unless otherwise specified)

Form used		1991	1992
IRONMAKING			
Basis:			
Production of raw steel	million tons[1]	79.74	84.32
Ore[2]		.24	.26
STEELMAKING			
Basis:			
Production of raw steel and steel castings	million tons	80.65	e85.27
Ore[2]		—	(3)
Ferromanganese		3.24	3.00
Silicomanganese		.80	.80
Manganese metal		.06	.06
Total, steelmaking[4]		4.11	3.85

eEstimated.

[1]As ingots, continuous- or pressure-cast blooms, billets, slabs, etc.

[2]Containing 35% or more manganese.

[3]Less than 1/2 unit.

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

TABLE 7

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[1]
1972	0.59	1.52
1973	.64	1.55
1974	.89	1.97
1975	1.36	2.76
1976	1.43	2.73
1977	1.46	2.61
1978	1.38	2.29
1979	1.38	2.10
1980	1.67	2.33
1981	1.69	2.15
1982	1.56	1.86
1983	1.36	1.56
1984	1.40	1.54
1985	1.41	1.49
1986	1.32	1.36
1987	1.27	1.27
1988	1.75	1.69
1989	2.76	2.54
1990	3.78	3.34
1991	3.72	3.16
1992	3.25	2.69

[1]Based on Implicit Price Deflators for GDP (1987 = 100%). Previous years' tables were based on Implicit Price Deflators for GNP. Source: Department of Commerce, Bureau of Economic Analysis.

TABLE 8

U.S. EXPORTS OF MANGANESE ORE, FERROALLOYS, AND METAL, BY COUNTRY

Country	1991		1992	
	Gross weight (metric tons)	Value (thousands)	Gross weight (metric tons)	Value (thousands)
ORE AND CONCENTRATES WITH 20% OR MORE MANGANESE				
Belgium	778	$62	1,024	$82
Canada	26,895	2,152	10,612	1,942
Korea, Republic of	3,128	326	1,308	175
Mexico[1]	30,528	5,496	—	—
Other	[2]4,963	[2]487	142	96
Total	66,292	8,523	13,086	2,295
FERROMANGANESE, ALL GRADES				
Belgium	363	620	200	366
Canada	11,920	11,681	10,469	9,025
Mexico	444	480	995	860
Sweden	371	428	34	63
United Kingdom	908	1,515	1,221	2,181
Other	568	690	484	500
Total[3]	14,573	15,414	13,404	12,996
SILICOMANGANESE				
Canada	1,948	1,932	8,681	6,139
Mexico	874	804	416	277
Other	52	66	74	84
Total[3]	2,873	2,802	9,171	6,500
METAL, INCLUDING ALLOYS AND WASTE AND SCRAP				
Canada	1,611	4,407	1,798	4,777
Japan	161	2,005	1,011	2,028
Netherlands	1,776	4,223	1,545	3,564
Other	1,723	2,023	650	1,576
Total[3]	5,272	12,658	5,005	11,946

[1]Includes quantities believed transshipped from Gabon, about 25,000 tons in 1991.
[2]Unspecified group of countries differs from that in the 1991 Minerals Yearbook.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS, METAL, AND SELECTED CHEMICALS, BY COUNTRY

Country	1991			1992		
	Gross weight (metric tons)	Manganese content (metric tons)	Value (thousands)	Gross weight (metric tons)	Manganese content (metric tons)	Value (thousands)
ORE AND CONCENTRATES WITH 20% OR MORE MANGANESE						
All grades						
Australia	32,962	16,485	$4,620	50,518	25,519	$5,184
Brazil	4,874	2,583	407	38,732	15,541	2,225
Canada[1]	11	5	4	—	—	—
Gabon[2]	158,685	79,997	29,801	148,617	75,354	20,970
Ghana	10,332	4,594	1,209	—	—	—
Mexico[3]	10,586	4,673	1,356	8,566	3,930	1,556
Morocco	87	[4]44	25	105	[4]56	32
Norway[1]	16,322	8,872	2,911	—	—	—
Total[5]	233,860	117,255	40,332	246,538	120,400	29,967
More than 20% but less than 47% manganese						
Brazil	—	—	—	35,426	13,953	1,916
Gabon	—	—	—	2,500	1,138	371
Ghana	10,332	4,594	1,209	—	—	—
Mexico[3]	7,621	3,102	949	7,233	3,264	1,343
Total	17,953	7,696	2,158	45,159	18,355	3,630
47% or more manganese						
Australia	32,962	16,485	4,620	50,518	25,519	5,184
Brazil	4,874	2,583	407	3,307	1,588	308
Canada[1]	11	5	4	—	—	—
Gabon[2]	158,685	79,997	29,801	146,117	74,216	20,599
Mexico	2,965	1,571	407	1,332	666	213
Morocco	87	[4]44	25	105	[4]56	32
Norway[1]	16,322	8,872	2,911	—	—	—
Total[5]	215,907	109,560	38,174	201,379	102,045	26,337
FERROMANGANESE						
All grades						
Australia	9,400	6,902	3,510	24,280	17,707	7,413
Brazil	32,559	25,039	16,817	33,468	25,786	16,189
Canada	11,125	8,595	4,773	244	196	95
China	4,521	3,438	2,366	2,620	2,154	2,014
France	83,104	65,394	52,617	81,793	64,247	41,883
Germany	18,174	14,479	15,183	15,497	12,657	12,784
Italy	945	841	1,393	4,978	4,477	7,256
Mexico	41,299	32,868	27,439	20,551	16,468	16,832
Norway	12,363	9,830	6,725	19,800	16,009	15,200
Philippines	5,652	4,354	2,721	—	—	—
South Africa, Republic of	81,068	63,415	44,850	82,976	64,895	39,244
United Kingdom	15,178	11,734	6,980	16,005	12,369	6,833
Other	[6]4,394	[6]3,585	[6]3,788	1,945	1,505	1,071
Total[5]	319,781	250,473	189,162	304,157	238,470	166,815
1% or less carbon						
China	—	—	—	1,285	1,065	1,036
France	11,375	10,127	16,166	4,263	3,785	6,400

See footnotes at end of table.

TABLE 9—Continued

U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS, METAL, AND SELECTED CHEMICALS, BY COUNTRY

Country	1991			1992		
	Gross weight (metric tons)	Manganese content (metric tons)	Value (thousands)	Gross weight (metric tons)	Manganese content (metric tons)	Value (thousands)
FERROMANGANESE						
1% or less carbon—Continued						
Italy	945	841	$1,393	4,978	4,477	$7,256
Japan	1,221	1,110	1,782	265	240	388
Other	[6]44	[6]38	[6]68	398	333	360
Total[5]	13,584	12,116	19,409	11,190	9,901	15,440
More than 1% to 2% or less carbon						
Brazil	—	—	—	3,905	3,143	3,230
China	—	—	—	1,336	1,088	978
France	1,920	1,524	1,287	—	—	—
Germany	18,174	14,479	15,183	15,497	12,657	12,784
Mexico	18,850	15,211	15,700	20,551	16,468	16,832
Norway	8,811	7,030	5,202	17,470	14,230	14,003
South Africa, Republic of	5,883	4,738	5,114	7,368	5,926	6,150
Other	1,407	1,171	1,116	—	—	—
Total[5]	55,045	44,152	43,602	66,126	53,513	53,977
More than 4% carbon						
Australia	9,400	6,902	3,510	24,280	17,707	7,413
Brazil	32,559	25,039	16,817	29,563	22,642	12,960
Canada	11,091	8,570	4,763	224	177	65
China	4,521	3,438	2,366	—	—	—
France	69,810	53,743	35,164	77,530	60,461	35,483
Mexico	22,448	17,657	11,739	—	—	—
Philippines	5,652	4,354	2,721	—	—	—
South Africa, Republic of	75,185	58,677	39,736	75,608	58,969	33,095
United Kingdom	15,178	11,734	6,980	16,005	12,369	6,833
Other	5,309	4,090	2,355	3,632	2,729	1,550
Total[5]	251,151	194,205	126,151	226,841	175,056	97,399
SILICOMANGANESE						
Argentina	8,176	5,314	3,721	12,348	8,026	4,299
Australia	37,216	24,438	17,159	31,984	20,869	12,213
Brazil	49,365	32,149	23,498	57,056	37,140	24,479
Canada	15,682	10,509	7,616	142	95	74
China	5,305	3,514	2,665	11,423	7,476	5,096
France	9,938	6,642	5,543	11,841	7,939	5,533
Macedonia[7]	—	—	—	8,822	6,011	4,014
Mexico	22,955	15,052	11,770	19,812	12,728	10,228
Norway	15,733	10,214	9,942	10,746	6,940	7,881
South Africa, Republic of	62,129	41,290	32,088	64,013	42,315	31,063
Ukraine	—	—	—	7,992	5,971	3,237
Venezuela	2,500	1,666	1,300	8,900	5,594	3,921
Yugoslavia[8]	22,880	14,845	11,343	8,699	5,792	3,954
Other	[6]6,414	[6]4,151	[6]4,034	3,398	2,152	2,471
Total[5]	258,293	169,784	130,677	257,177	169,047	118,464

See footnotes at end of table.

TABLE 9—Continued

U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS, METAL, AND SELECTED CHEMICALS, BY COUNTRY

Country	1991			1992		
	Gross weight (metric tons)	Manganese content (metric tons)	Value (thousands)	Gross weight (metric tons)	Manganese content (metric tons)	Value (thousands)
METAL						
Unwrought:						
China	997	XX	$1,298	1,480	XX	$2,001
South Africa, Republic of	8,634	XX	13,585	6,709	XX	10,304
Other	2	XX	4	183	XX	288
Total[5]	9,632	XX	14,887	8,372	XX	12,593
South Africa, Republic of	5,908	XX	9,007	5,152	XX	7,789
Other	148	XX	558	355	XX	1,563
Total[5]	6,057	XX	9,565	5,507	XX	9,353
Waste and scrap:						
Canada	62	XX	7	69	XX	41
Mexico	—	XX	—	4	XX	4
Venezuela	40	XX	50	—	XX	—
MANGANESE DIOXIDE						
Australia	8,415	XX	12,255	9,939	XX	14,655
Belgium	1,445	XX	2,238	933	XX	1,502
Brazil	1,641	XX	2,242	1,130	XX	1,554
Ireland	6,288	XX	9,013	7,491	XX	10,758
South Africa, Republic of	1,956	XX	2,700	1,403	XX	1,960
Other	269	XX	727	252	XX	661
Total[5]	20,016	XX	29,174	21,149	XX	31,089
POTASSIUM PERMANGANATE						
China	374	XX	348	116	XX	115
Czechoslovakia	90	XX	138	664	XX	1,114
Germany	273	XX	451	158	XX	288
Spain	181	XX	388	26	XX	65
Other	[6]56	XX	[6]225	80	XX	353
Total	974	XX	1,550	1,044	XX	1,935

XX Not applicable.

[1]Country of transshipment rather than original source.

[2]Includes quantities believed transshipped to Mexico, about 25,000 tons in 1991.

[3]Includes U.S. Bureau of Mines revision of part of reported data.

[4]Includes U.S. Bureau of Mines conversion of part of reported data (from apparent MnO_2 content to Mn content).

[5]Data may not add to totals shown because of independent rounding.

[6]Unspecified group of countries differs from that in the 1991 Minerals Yearbook.

[7]Formerly part of Yugoslavia; shipments before June 1, 1992, included in Yugoslavia.

[8]Dissolved in 1992. Includes shipments from all Republics before June 1, 1992, and after June 1,1992, from Serbia and Montenegro, if any.

Source: Bureau of the Census, adjusted by the U.S. Bureau of Mines.

TABLE 10

U.S. IMPORT DUTIES ON MANGANESE MATERIALS[1]

Item	HTS No.	Rate of duty effective Jan. 1, 1992	
		Most favored nation (MFN)	Non-MFN
Ore and concentrate	2602.00.0040/60	Free	2.2 cents per kg Mn.
Manganese dioxide	2820.10.0000	4.7% ad valorem[2 3 4]	25.0% ad valorem.
Ferromanganese:			
Low-carbon	7202.19.1000	2.3% ad valorem[2 3 5]	22.0% ad valorem.
Medium-carbon, 1% to 2% carbon	7202.19.5000	1.4% ad valorem[2 3 5 6]	6.5% ad valorem.
High-carbon	7202.11.5000	1.5% ad valorem[2 5]	10.5% ad valorem.
Silicomanganese	7202.30.0000	3.9% ad valorem[2 3 5 7]	23.0% ad valorem.
Metal, unwrought	8111.00.4500	14.0% ad valorem[2 8]	20.0% ad valorem.

[1]All subject to (1) 0.17% ad valorem Merchandise Proceessing Fee (MPF) 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. The MPF was increased to 0.19% ad valorem as of Oct. 1, 1992.
[2]Free from beneficiary countries under CBERA, the Andean Trade Preference Act, and for products of Israel.
[3]Free from certain countries under Generalized System of Preferences.
[4]0.9% ad valorem for products of Canada.
[5]Free for products of Canada.
[6]Not duty free for Mexico.
[7]Not duty free for Brazil.
[8]8.4% ad valorem for products of Canada.

Source for rates of duty: Harmonized Tariff Schedule of the United States (1992).

TABLE 11

WORLD ANNUAL MANGANESE MINE PRODUCTION CAPACITY, DECEMBER 31, 1992

(Thousand metric tons of manganese content)

Country	Rated capacity
North America:	
Mexico	220
South America:	
Brazil	1,000
Chile	17
Total	1,017
Europe:	
Bulgaria	15
Hungary	26
U.S.S.R.	[1]2,800
Other	37
Total	2,878
Africa:	
Gabon	1,200
Ghana	130
Morocco	30
South Africa, Republic of	2,300
Total	3,660
Asia:	
China	750
India	540
Other	50
Total	1,340
Oceania:	
Australia	1,250
World total (rounded)	10,400

[1]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual Republics.

TABLE 12
WORLD MANGANESE RESERVES AND RESERVE BASE

(Million metric tons of manganese content)

Country	Reserves	Reserve base
North America:		
Mexico	4	9
South America:		
Brazil	21	58
Europe: U.S.S.R.[1]	300	450
Africa:		
Gabon	52	160
Ghana	1	4
South Africa, Republic of	370	4,000
Total	423	4,164
Asia:		
China	14	29
India	17	25
Total	31	54
Oceania: Australia	26	72
World total (rounded)	800	4,800

[1]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual Republics.

TABLE 13

MANGANESE ORE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	Range percent Mn[e 3]	Gross weight					Metal content				
		1988	1989	1990	1991	1992[e]	1988	1989	1990	1991	1992[e]
Australia[4]	37-53	1,985	2,124	1,920	r1,482	1,200	945	e1,008	e909	e701	570
Bosnia and Herzegovina[5 6]	25-45	—	—	—	—	15	—	—	—	—	5
Brazil[7 8]	30-50	r1,991	r1,904	r2,300	r2,000	1,800	763	r724	r874	r760	684
Bulgaria	29-35	34	32	r39	r e35	35	10	11	r11	r e10	10
Chile	30-40	44	44	40	r44	44	15	14	12	e13	13
China[7 9]	20-30	3,212	3,331	e3,300	e3,400	3,500	642	666	660	680	700
Gabon[7 10]	50-53	2,254	2,592	2,423	r1,620	11,556	1,040	1,197	r1,118	r748	718
Georgia[12]	29-30	—	—	—	—	1,200	—	—	—	—	350
Ghana[7]	30-50	260	279	247	r320	11279	r97	110	96	r120	107
Hungary[7 13]	30-33	81	84	60	r30	18	26	26	19	r9	6
India[7 10 14]	10-54	1,333	1,334	1,393	r1,401	1,400	496	497	r522	r525	525
Iran[7]	25-35	75	81	54	r48	50	23	24	r18	r16	16
Kazakhstan[12]	29-30	—	—	—	—	9	—	—	—	—	3
Mexico[15]	27-50	444	394	365	r254	11407	169	150	139	r93	153
Morocco[7]	50-53	30	32	r49	r59	59	16	17	r26	31	31
Romania[7 13]	30	65	60	55	50	45	20	18	17	15	14
South Africa, Republic of[7 10]	30-48+	4,023	4,884	4,402	r3,146	112,464	1,656	2,044	1,911	r1,369	1,077
Ukraine[12]	29-30	—	—	—	—	5,800	—	—	—	—	1,700
U.S.S.R.[16]	29-30	9,108	9,141	8,500	r7,240	—	2,700	112,740	2,500	r2,150	—
Yugoslavia[6 17]	25-45	40	39	51	e40	—	14	14	18	e14	—
Other[18]	XX	35	33	54	43	48	15	15	24	19	21
Total[19]	XX	r25,013	r26,389	r25,252	r21,213	19,929	r8,646	r9,273	r8,875	r7,273	r6,701

eEstimated. rRevised. XX Not applicable.

[1]Table includes data available through July 12, 1993. Data pertain to concentrates or comparable shipping product, except in a few instances where the best data available appear to be for crude ore, possibly after some upgrading.

[2]In 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 metric tons, gross weight: Argentina (19%-30% Mn), 1988—9 (revised); 1989—6; 1990—4 (estimated, revised); 1991—5 (revised), and 1992—4; and Czechoslovakia (about 17% Mn), an estimated 1 in each year.

[3]May be for average content of each year's production rather than for content of typical products.

[4]Metallurgical ore.

[5]Formerly part of Yugoslavia.

[6]All production in Yugoslavia from 1988-91 came from Bosnia and Herzegovina.

[7]Gross weight reported; metal content estimated. Estimated metal content figures have been revised as necessary.

[8]For 1989-92, production of beneficiated ore as reported in Sumário Mineral (Brasilia); for 1988, the same plus direct-shipping manganese ore as reported in Anuário Mineral Brasileiro, the latest year for which such data were available.

[9]Includes manganiferous ore.

[10]Calculated metal content includes allowance for assumed moisture content.

[11]Reported figure.

[12]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[13]Concentrate.

[14]Much of India's production grades below 35% Mn; average content was reported as 38% Mn in 1985.

[15]Mostly oxide nodules; may include smaller quantities of direct-shipping carbonate and oxide ores for metallurgical and battery applications. Gross weight is calculated from reported metal content data.

[16]Dissolved in Dec. 1991.

[17]Dissolved in Apr. 1992.

[18]Category represents the combined totals of Burma, Egypt, Greece, Indonesia, Italy (from wastes), Japan, the Philippines, Thailand, Turkey, and Zambia.

[19]Data may not add to totals shown because of independent rounding.

TABLE 14

MANGANESE SUPPLY-DEMAND RELATIONSHIPS[1]

(Thousand metric tons, manganese content)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mines[2]	22	4	4	10	2	1	2	1	1	1	—
Shipments of Government stockpile excesses	116	25	32	9	83	7	95	(2)	(5)	20	29
Imports, ore and dioxide	273	101	161	163	185	215	164	238	275	153	129
Imports, ferroalloy and metal	558	390	330	386	367	410	383	527	502	458	436
Industry stocks, Jan. 1	644	637	523	420	381	345	286	253	287	294	241
Total U.S. supply[3]	1,613	1,157	1,050	989	1,018	978	930	1,017	1,059	926	836
Distribution of U.S. supply:											
Industry stocks, Dec. 31	637	523	419	381	345	286	253	287	294	241	186
Exports, ore	29	13	9	27	28	21	34	32	26	42	33
Exports, ferroalloy and metal	15	12	15	12	12	9	8	16	15	13	19
Industrial demand	932	610	606	569	633	662	634	682	723	630	598
U.S. DEMAND PATTERN[4]											
Appliances and equipment	46	27	30	33	29	24	28	17	11	9	8
Batteries	15	19	23	31	35	39	39	44	41	42	52
Cans and containers	42	28	25	34	32	28	32	28	21	22	20
Chemicals[5]	45	26	20	31	20	21	40	42	39	36	33
Construction	229	138	137	154	149	134	150	221	138	138	122
Machinery	155	83	82	88	71	59	70	100	75	74	45
Oil and gas industries	81	36	25	33	31	23	27	19	9	14	10
Transportation	194	104	117	126	112	86	95	93	49	45	47
Other[6]	125	147	147	39	154	248	153	119	340	250	260
Total U.S. primary demand[3]	932	610	606	569	633	662	634	682	723	630	598

[1]Where available, data for manganese dioxide included beginning in 1984.

[2]Including manganiferous ore.

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

[4]New series for steel-related end uses beginning in 1989.

[5]Includes miscellaneous nonmetallurgical uses of ore beginning in 1987.

[6]Not specifically based on reported data; includes processing losses. Through 1988, the distribution within this category is approximately the same as for end uses above exclusive of batteries and chemicals. Beginning in 1989, includes nonidentified uses of steel corresponding to about one-third of total steel shipments.

MATERIALS RECYCLING

By Arnold O. Tanner

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INTRODUCTION

Modern society faces significant changes in the ways it makes use of and interacts with the physical world. With continued growth in population and increasing material consumption come related effects on the availability of material resources and on the natural environment from which they are extracted. Use of our raw and manufactured materials with increasing efficiency can partly offset these effects. The recycling of scrap and waste materials provide an alternative material source to that of virgin supplies. Fairly rapid growth has occurred in recent years in the recycling of a wide variety of physical structure materials and products that are used in our everyday lives. If a substance can be reused or recycled for part or all of its inherent value, it is a candidate for diversion from the solid waste stream. The longer a material's useful lifetime can be extended, the less Earth's virgin resources of that material must be consumed.

The greater the economic viability of a material's overall recycling process, the greater is its potential for continued recycling. Successful recycling provides opportunities for new businesses in the economy, thereby providing materials, services, and jobs. The recycling of the aluminum used beverage can (UBC) is a prime example of a profitable secondary/used material recovery operation. The reuse of UBC's requires significantly less energy resources than the equivalent processing of virgin aluminum and reduces the quantity of waste that is overcrowding our landfills.

The shrinking availability of landfill space is a very visible and politically active issue. Along with associated water and air pollution at some existing landfills, the growing question of how best to manage our waste and other used materials is coming under increasing scrutiny. Increased interest in more efficient materials use and reduction of the impacts of waste on the environment are part of the sustainable development approach to economic activity and environmental protection. Sustainable development was defined in the Bruntland report as development that meets the needs of the present without compromising the ability of future generations to meet their own needs.[1] Materials recycling, although far from a total solution for all our waste ills, is one avenue for managing our used, or otherwise rendered-useless, materials.

A large variety of materials are recycled by different sectors of our society. The materials recycling that is mainly addressed in this writing is from waste that is generated after manufacturing and use. Included is recycling that is generally more obvious to the public: the collection, reprocessing, and remanufacture of materials into new products from post-consumer UBC's, scrap metal, glass containers, paper goods, increasingly plastics, as well as rubber tires and other used goods. On the other hand, a variety of materials are recycled within the individual operations by mineral and material processors, the chemical industry, product manufacturers, utility companies, etc. This latter solid and liquid reprocessing and recycling is done internally in many industries and is generally less visible to the general public than the recycling of materials from municipal solid waste. Recycled materials in the various industries are commonly liquid or chemical in form, but also include the clean excess scrap from metal, paper, glass, and plastic manufacturers (often called "home," run-around, or flash scrap). A significant portion of pre-consumer scrap, sometimes called new scrap, is traded to industrial consumers of scrap materials to produce new products and is included in much of the data that follow. Most of the physical structure materials that are recycled back to the consumer as new products are solid materials. Other materials such as lubricating oils, solvents, and increasingly, household hazardous substances such as paints, home solvents, and cleaners, are currently categorized as "solid" waste, but are not addressed in this writing.

The U.S. Bureau of Mines (USBM) publishes several annual reports that address many of these recycled materials and products. For the most part these publications address metals that society has traditionally recycled. This chapter is the initial attempt to cover several of the basic materials and products that are not covered in other USBM writings. These materials are diverse in their makeup;

hence, the general title "Materials Recycling" was used. However, one "characteristic" ties them together: if, following their initial intended use they are not: (1) reused relatively "as-is"; (2) recycled following material reprocessing; (3) incinerated in a waste-to-energy (WTE) facility; or (4) otherwise processed into usable material, such as through composting, then they become waste and are landfilled. Society may always produce some quantity of waste products that cannot be used again and must be disposed of. The important consideration here is how much must be discarded at what rate. Solid waste management, or resource management as some professionals more positively characterize it, is the overall theme surrounding the growing efforts to reuse and recycle our used materials. Of equal importance for future generations is the conservation of our natural resources, especially nonrenewable resources. This also has been a motivational force behind recent efforts to increase the recycling of materials.

DOMESTIC DATA COVERAGE

Data in this report are derived from a variety of published and unpublished sources that are mostly external to the USBM. Much of the solid waste data and some of the recycling data come from U.S. Environmental Protection Agency (EPA) studies. The other main data sources were various industry, trade association, and independent contractor studies and journal and media reports. At this writing limited Federal Government surveys existed concerning the quantities of post-consumer materials in the municipal solid waste stream or of those being recycled. Several Agencies, in particular the USBM, the Bureau of Census in the Department of Commerce (DOC), and the EPA, have been involved in early talks concerning the gathering of such data.

BACKGROUND

Definitions, Grades, and Specifications

Overall Solid Waste Material Flow.—Post-consumer materials become part of the solid waste stream unless otherwise diverted into secondary material use. Although commonly used by various industries to refer to pre-consumer scrap, the term secondary also can be applied to used or post-consumer waste materials that are recovered for recycling. The most publicized waste is municipal solid waste (MSW), and much of the materials recycling that has become an important public issue in the past decade comes from MSW. Municipal solid waste, however, is an extremely small portion of the total solid waste stream. Estimates of solid waste from all sources vary greatly, and most are based on incomplete, mid-1980's data. But from estimates of between 11 and 13 billion tons[2] of legally designated "solid" waste, only about 180 million tons is MSW, a little more than 1.5% of total solid waste, as shown in figure 1. Also note that these "solid" waste streams are perhaps 80% or more liquid, a common constituent being wastewaters as well as other liquid wastes. Much of these liquid-form "solid" wastes are contained in surface impoundments for treatment, storage, or disposal. True solid wastes that are not recycled, composted, or incinerated are generally managed by way of landfills, waste piles, or in other land disposal areas.

Municipal Solid Waste Material Flow.—Municipal solid waste, while being a small portion of our total solid waste stream, is mostly (about 95%) solid in nature when introduced into the wastestream. Two of the included categories of waste, yard waste and food waste, are mostly solid in form but have low to moderate liquid (commonly water-based) contents. These liquid-containing wastes contribute liquid to landfill effluent as landfill wastes degrade. Together yard and food waste comprise about 25% of MSW.

Solid Waste Management Options.—**The Hierarchy.**—A hierarchy of solid waste management methods has been established by the EPA. Although a strong emphasis is often placed upon its first two levels, the solid waste hierarchy is a list of method preference rather than a rigid set of hard and fast rules. The hierarchy includes: (1) source reduction, (2) reuse, compost, or recycle, (3) waste-to-energy incineration, and (4) landfilling. A balanced approach in choosing the best methods for managing wastes in each particular situation is called integrated waste management (IWM). In IWM, the different methods are intended to be utilized, as appropriate, for the varied locales or States. Recycling is not always the answer because of such reasons as geography and sparse population, local economics, lack of accessible technology, etc. Likewise, the next preference, incineration, also may be impractical. For example, an adequate future supply of solid waste "fuel" must be confidently anticipated to justify the high capital cost of building an incinerator. Landfilling in conjunction with minimal recycling activities may be the most workable and beneficial waste management choice for the solid wastes in a certain county. Local or regional economics can restrict the use of the other options, especially in sparsely populated areas.

Source Reduction.—The first preferred option is actually a "pre-option" called source reduction, sometimes referred to as waste reduction. Solid waste source reduction is the design, manufacture, purchase, or use of materials or products (including packages) to reduce their amount or toxicity before they enter the solid waste stream. Not creating the waste in the first place is better than having to deal with it later. Because it is intended to reduce pollution and conserve resources, source reduction should not increase the net amount or toxicity of wastes generated throughout the life of the product.[3] Reduction of the quantity of materials in a particular packaging application is one example of source reduction. Another example is the design of a product, such as the

automobile or a home appliance, with recycling in mind. A more easily disassembled vehicle, refrigerator, or stove, made of readily recyclable materials, will reduce the amount of discarded material. One related design factor, the energy that will be needed to reprocess the materials, may either encourage or discourage a source reduction effort. The total energy expended, commonly derived from nonrenewable hydrocarbons, is considered as well as the metals, plastics, and glass materials that may be kept out of the wastestream by recycling into new, qualitative hard goods and materials.

Recycling and Composting.—Direct reuse or the recycling, physical or chemical, of a product or other waste material is given second preference. The goal here is to recover materials from the wastestream and thereby minimize the use of virgin resources. Recycling is not 100% effective because there is always some waste that results during the recycling process. Some portion of the material either degrades too much to be reused or is lost in the process. But, recycling, while not being a perfect solution, does extend the lifespan of a material by keeping it in use. Recycling decreases the throughput of materials into the wastestream and thereby slows the filling up of valuable landfill space.

Composting is also included in this level of preference. It involves the chemical breakdown of materials into different, usually more basic, materials or chemical compounds. This contrasts with the physical breakdown of a material into smaller pieces that are chemically the same. The recycling of paper is a physical process in which the individual paper fibers may be reduced in size but remain chemically unchanged. The composting of food and yard waste is increasingly becoming an integral part of the solid waste management efforts of many communities, especially where laws have been passed banning the landfilling of yard wastes. Composting provides an alternative to chemical fertilizers in a variety of applications. Municipal solid waste is also compostable after the removal of metals, plastics, rubber, and glass. Three factors that tend to limit its popularity are: (1) the concentration levels of some contaminates, especially metals such as lead and cadmium, (2) small pieces of glass, metals, and plastics that remain, and (3) competition from the other waste management methods, especially the recycling of paper.

Waste-to-Energy Incineration.—The next choice in the hierarchy is MSW incineration, especially when it is used to produce energy. WTE incineration, producing energy either in the form of steam or electricity, is often a viable waste handling option that makes use of the energy values contained in MSW rather than simply burying it. Incineration of MSW also reduces the volume of the waste that remains to be disposed of to as little as 15% of the combusted materials' original volume. Some components of MSW, such as plastics, are virtually reduced to zero, only a very minute portion of char remaining. This volume reduction is especially important in regard to plastics because, when compared to other MSW materials of like weight, plastics take up about twice as much space. Although volume reduction is a significant reason for incinerating MSW, incinerators without energy recovery have of late been on the decline and those with such recovery are becoming the norm. Plastic material (as well as rubber) is an important portion of MSW "fuel" in a WTE incinerator because it can provide higher energy values than the other components of MSW.

Sanitary Landfilling.—Although it is still the most common form of used/waste material management, landfilling is becoming the least preferred. Minimizing the quantity of discarded materials that are landfilled has been stressed during the past several years because of the shrinking availability, sometimes physical and sometimes political, of landfill space. The diversion of materials from landfills and the solid waste stream as a whole is the dominant force driving current material reuse and recycling efforts.

Material Resources and Related Economic Issues.—**Collection and Material Processing.**—Supplies of materials collected for recycling are relatively large in the United States. Old newspaper, mixed paper, green glass, and some plastics are examples of materials that have been collected in quantities beyond the markets' capacity to absorb them. Causes for the oversupply of some recovered materials include: (1) lack of a recycling industry infrastructure; (2) inadequately developed markets; (3) often, an uneven playing field of competition with competing virgin materials; (4) low prices for recovered materials; and (5) the recent weak state of the U.S. economy. Sometimes lacking are supplies of clean or uncontaminated materials. A load of an otherwise usable material can be rendered useless if it includes too high a level of other unlike materials. The processing of such loads can be limited for technological or economic reasons. Further development of collection practices and sorting procedures and technologies, such as those for sorting plastic containers of different types, may serve to increase supplies of more competitive, marketable materials.

A foreign example of collection that exceeds secondary markets is to be found in Germany. During 1992, the nationwide recycling collection organization, Duales System Deutschland, collected more than 4.5 times as much tonnage of scrap plastic as it had initially anticipated, and this 205 million kilograms of plastic was more than 3 times the amount that the country had the capacity to handle. One-third of the plastic was exported, and the rest was stockpiled awaiting future increases in capacity and better markets for the materials. This oversupply was felt beyond the German border. In at least one district in England, secondary raw materials from Germany could be purchased for less than it cost the district to collect its own. For 1993 Germany is predicting a doubling of plastics collection to about 410 million kilograms to be used

in about the same proportions as in 1992. Almost one-third, 135 million kilograms, will likely be added to the current stockpiles.

Economic Factors Within the Recycling Industry.—The basic economic structures for each commodity within the recycling industry are similar. Metal recycling, particularly of steel and aluminum, is the most established. The paper and glass recycled material markets also have been in place for a long time.

The market for recycled plastics is still in development and in most cases secondary plastic resin is more expensive than virgin material. Makers of plastic bottles buy the recycled material in spite of the price disadvantage because they have faced regulation against their products to keep them out of landfills and recycling of the material is economically more favorable to the industry than a ban or costly restrictions.

Plastics recycling businesses are not as integrated as those for other materials. A significant number of small firms perform only one or a few of the various steps involved in recycling and reproducing plastic materials and manufacturing new products that go to market. Companies in the other more established marketplaces commonly undertake many or even all of the steps. This allows for greater efficiency and leaves the companies less vulnerable to changes in markets and prices. For example, when several companies are involved in various steps of the recycling of a material, the transportation costs alone between sites can significantly add to overall processing costs compared to a more "integrated" company handling the entire process at a single site.

Another difficulty for materials recycling is that of classic supply and demand. Most recycled materials, with the exception of scrap metals, face similar basic economic problems: high supply, low demand, high cost, low quality (compared to virgin), and low, unsteady prices. The high supplies have been caused by somewhat enthusiastic collecting by the public, and in part by mandatory recycling without sufficient building of the product marketplace. Low quality, commonly due to contamination by unlike materials, such as paper mixed in with a load of post-consumer plastics, limits the use and value of the materials. Contamination results in higher processing costs, or even rejection of the otherwise good material load. Virgin material is usually less expensive and quality is far more consistent and easier to control. Oversupply and unreliability of the material quality only adds to the standard costs of recycling, which are collection, transportation, sorting, further processing, and the specific technologies involved in reproducing a useful new material and final product. The recycled material marketplace can be made more stable through: (1) continued improvements in material quality, (2) the continuous reliability of that supply, and (3) emphasis on the demand for the final product to better match increasing quantities of collected materials.

The primary sources of pricing information for most recycled goods are weekly and monthly trade publications, which calculate the prices by polling traders. In recognition of the often low, changeable prices, the Chicago Board of Trade (CBT) began an experimental project to help develop the recycled material market. The CBT is creating the country's first recyclables cash exchange market as an electronic forum for buyers and sellers of recyclables. This is hoped to provide potential buyers with more accurate pricing information and standardized quality specifications. CBT believes that the unregulated and volatile nature of dealing recyclables has in part been responsible for the slow development of recycled material and product markets.[4]

The "Not-In-My-Back-Yard" Factor.—"NIMBYism," as it is often called, refers to resistance by citizens to the siting of certain nonresidential facilities near to where they live. Whether the resistance is based on legitimate concerns or is more an emotional reaction, it represents a real problem for both the solid waste and recycling industries. The siting of a needed recycling facility, incinerator, or landfill can be a very difficult process. Most people do not want one "in their back yard," but reality dictates that they must be constructed somewhere. The public must be protected from unreasonable or harmful facility sitings and at the same time be served in their needs for solid waste management and materials recycling. Various facilities are needed to recycle the various used and waste materials. Some examples of these are materials recovery facilities (MRF's) where collected materials are sorted and made ready for shipment to recycled material processors and materials transfer stations that handle and process the materials that the public puts out at the curbside for collection. Location is not the only issue; general economic issues involved can prohibit the siting of a facility in a location even when most of the people concerned accept the site.

Legislation and Government Actions[5]

Issues surrounding the transportation of solid waste and hazardous waste across State lines received significant attention during 1992 at both the State and Federal levels. Representatives from garbage importing States attempted to write legislation that would provide State Governors with the authority to restrict the disposal of out-of-State wastes. Several State legislatures had attempted to restrict the importation of unwanted wastes through the enactment of bans or other restrictive measures.

On June 1, 1992, the U.S. Supreme Court ruled on two jurisdictional waste transportation cases: Chemical Waste Management, Inc. v. Hunt and Fort Gratiot Sanitary Landfill, Inc. v. Michigan Department of Natural Resources. The Court reaffirmed its original holding in the 1978 case of Philadelphia v. New Jersey that interstate waste transactions are subject to the Commerce Clause and that undue discrimination against out-of-State waste resulted in economic protectionism and was therefore unconstitutional. In Chemical Waste Management, Inc. (a

case in which the EPA participated as amicus, arguing against the State law), the State of Alabama had imposed a differential fee on all hazardous waste generated out of State that was disposed of at in-State facilities. This was deemed by the Court to be an undue burden on interstate commerce. In Fort Gratiot, a Michigan statute had prohibited out-of-county solid waste unless authorized by a State-approved county plan. Likewise, the Court ruled against the State, holding that the Michigan law violated the Commerce Clause.

In the context of these and other related factors, the 102d Congress set out to reauthorize the Resource Conservation and Recovery Act (RCRA), which had last been accomplished in 1984. In furtherance of the reauthorization the Senate Environment committee produced a series of bills, the most noteworthy of which had three primary themes: that of (1) providing States greater latitude in restricting out-of-State municipal waste; (2) allowing ash from municipal incinerators to be treated as regular solid waste, thereby allowing easier disposal (environmental groups advocated treating this ash as hazardous waste, thereby necessitating potentially more onerous disposal procedures); and (3) the prohibition against discarding lead-acid batteries in municipal landfills or incinerators and a requirement that retailers, wholesalers, and manufacturers take back old batteries for safe disposal or recycling. The Energy and Commerce Committee proved unable to resolve the interstate waste shipment issue and the Senate bill was not passed.

In the House, under the combined work of the Energy and Commerce Committee and the Hazardous Materials Subcommittee, a narrowed down version of an initially broader-scoped and controversial solid waste bill was attempted. Primarily, passage of the House Rule would have amended Subtitle D of RCRA and provided the EPA with the authority to regulate nonhazardous solid wastes. In its narrowed down version the bill contained provisions relating to requirements for recycled paper and packaging, environmental marketing claims, and the recycling and disposal of scrap tires and batteries. But because of the large number and complexity of issues involved in this bill, it also was put on hold.

Efforts to again fully reauthorize RCRA are not expected in the 103d Congress because of a shift in focus to Superfund and related hazardous waste issues. Currently, Federal Circuit Courts of Appeal are applying the two 1992 U.S. Supreme Court holdings aforementioned to a variety of State and municipal law challenges. One 1993 holding of importance was rendered by the Eighth Circuit in the case of Waste Systems Corp. v. County of Martin, Minn. In Waste Systems, the county ordinance required all compostable solid waste to be delivered only to local facilities. The rationale for the county "exportation" restriction was that it required a long-term reliable waste supply for its economic security. Relying on the Supreme Court's Philadelphia decision, the Circuit Court held that unreasonable exportation restrictions, like importation restrictions, violated the Commerce Clause.

ANNUAL REVIEW

Paper Recycling

Paper and paperboard materials are initially produced almost exclusively from wood pulp, which is wood or "cellulose" fiber that is mainly processed from softwood timber and to a lesser degree from hardwood timber. Softwood fibers impart strength and tear resistance while hardwood fibers provide density and printability. The major categories of paper products include: paperboard; kraft paper, including that used for corrugated container board; cardboard; newsprint; printing and writing paper; and various utility papers, such as for bags, plates, tissues, and towel products. These products, as well as fiberboard used in construction and paper-based insulation materials, are potential markets for both pre-consumer and post-consumer recycled paper fibers to supplement virgin fiber content and reduce the quantity of paper in the solid waste stream.

Issues.—Two issues with potential to affect increases in paper recycling are the growing quantities of paper in municipal solid waste and environmental issues related to virgin material supply. Our society has become a heavy consumer of paper and paperboard products. The "paperless society" speculated by many in the past does not appear to be close at hand. We are using more and throwing away more with each passing year.

According to the EPA, the total generation of paper and paperboard products in MSW has grown steadily from 27 million tons in 1960 to almost 67 million tons in 1990. As a percentage of the total MSW generated, paper (by weight) represented about 34% in 1960. Although the percentage has varied over time, it has generally increased, to 37.5% of total MSW generated in 1990. Much of the paper that we use comes in the form of nondurable goods with relatively short lifespans. Waste from paper packaging materials and newspapers, having lifespans of less than 1 year (often only several days) have followed this same trend. When added together, they account for about 60% of total paper waste. However, the actual quantities going to landfills has shown small decreases of late. Based upon EPA data, the quantity of paper being landfilled dropped by about 5% between 1985 and 1990. During this time paper recovery for recycling and incineration (usually with energy recovery) has significantly increased.

Paper recycling, a common practice during the newspaper drives since the 1950's and 1960's, has greatly increased in the past two decades. The recycling of paper reduces the need for virgin wood fiber. The diversion of paper alone could significantly reduce the quantities of waste filling up our landfills.

Quantities of solid waste managed by incineration substantially declined from the mid-1970's through the mid-1980's, but rebounded to above 1970 levels by 1990. Since 1985, numerous new facilities—cleaner, more efficient, and almost exclusively with energy recovery

systems—have come into operation. This includes both mass burn and refuse-derived-fuel (RDF) plants. RDF is MSW that has had certain materials, especially metals, separated out, after which the remaining materials are processed into a fairly consistent, uniform-sized feed of combustible material.

Secondly, because paper materials are produced from wood fibers, the production of paper and paperboard products promotes significant use of timber resources. About 25% of U.S. timber production goes into the making of woodpulp, of which about 95% is used in the production of paper. Increasing attention is being paid to a variety of environmental issues. Growing controversies over various endangered species, the loss of virgin forests with relatively untouched biological diversity, and the erosional effects of the clear-cutting of forests are several issues related to the harvesting of timberland. These factors have a potential to influence the increased use of recycled paper fibers in new paper products.

Currently at issue is establishing a generally acceptable standard or legal definition of "recycled paper." The use of pre-consumer scrap paper in paper production is a common practice of many manufacturers because it is a good alternate source of raw material. It generally yields a high-quality product more easily, and most often at a lower cost than when post-consumer paper is used. Post-consumer paper tends to be "dirtier" with more contaminants than the more consistent and controlled quality of pre-consumer scrap that often has not left the factory. The need to divert more post-consumer paper from the Nation's landfills is becoming increasingly emphasized. Settling on ways to accomplish this while continuing to encourage the recycling of pre-consumer scrap has been difficult. Proper definitions are needed for government procurement procedures to be effective. The Federal Government is a significant potential market for recycled paper. It is not only the largest single consumer of paper, but additionally, it may serve to set an example for the voluntary efforts of other organizations. State agencies and private industry tend to follow its lead.

Annual Supply and Recycling Rates.—All recycling rates are not based on the same type of data. EPA and the American Forest and Paper Association (AFPA) report paper recycling from two different perspectives. EPA compares the total post-consumer paper recovered for recycling to the estimated total paper waste generated each year. AFPA compares the combined total of pre-consumer and post-consumer paper recovered to the total "new supply" (apparent consumption) consumed by the paper industry during that year. Fabrication scrap is included in its pre-consumer recycled scrap numbers as part of the recycling rate.

EPA estimated that 28.6% (19 million tons) of the paper waste generated (66.5 million tons) during 1990 was recovered. This was up from the 22% and 21% rates of the early and mid-1980's, respectively. By AFPA measures the paper recovery rate was 33.6% in 1990, up from 26.75% for both 1980 and 1985. During 1992, AFPA reported that 30.5 million tons (33.6 million short tons) of paper and paperboard were recovered out of a total supply of 79.4 million tons (87.5 million short tons). This translates into a recovery rate of 38.4%, as shown in figure 2. Also shown are the recovery rates for the two leading types of paper products. According to AFPA, old newspaper (ONP) recovery grew from almost 45% in 1990 to almost 56% in 1992. Old corrugated containers (OCC's) are the highest tonnage source of recovered paper, as shown in figure 3. The recovery of OCC's grew from almost 55% to 59% of the total supply of new OCC paper between 1990 and 1992.

The pattern of growth in the consumption of fiber used at U.S. paper and paperboard mills between 1980 and 1992 is shown in figure 4 and table 1. The quantities of primary (virgin) wood fibers have consistently grown during this time period, but its percentage of total consumption has remained fairly constant, and the use of other (virgin) plant fibers, a relatively small quantity, has dropped by 1%. The greatest growth by percent, from 22.5% to 29.5%, has come from the increasing use of fiber from recovered paper. Quantities of wood residues and waste, also a recovered/recycled material, have fluctuated in small amounts since 1980, but have only minimally increased since 1980.

Consumption and Uses.—Although more than 70 different types, or grades, of paper exist, the paper industry uses 5 basic classifications: corrugated containers, newsprint, mixed, pulp substitutes (clean converting scrap), and high-grade deinking. A summary of the quantities of recovered paper and paperboard between 1982 and 1992, as reported by AFPA, is provided by category in table 2. These data include pre-consumer paper scrap. Consumption of growing supplies of collected waste paper is complicated by contamination by other waste materials, reduced secondary fiber quality (shorter fibers), and economically viable markets for the secondary paper fibers. Though not without its own difficulties, a collection program can be set up in a rather short period of time. But creating cost-competitive, marketable products is the greater challenge.

Kraft paper can serve as an example of a paper material with a secondary market. Kraft paper is the brown paper used to make corrugated containers and paper bags. According to EPA, it makes up about 36% of the total generation of paper waste. The previously mentioned 38.4% paper recycling rate is possible because of a specific market for recycled kraft paper fiber. The outside sheets of corrugated board, called liner paper, often need to meet rigorous specifications for resistance to bursting, puncturing, and crushing. This is especially true for paper that is to be made into boxes for shipping fragile products such as electronics, appliances, and glassware.

Recycled paper has shorter fibers than does virgin paper and it is consequently, not as strong. As the recycled content of the liner paper increases, the paper's strength decreases. This limits the

potential use of recycled fibers in the liner paper of corrugated boxes. The specifications for the paper from which the inner fluting of the corrugated box is made are much less rigorous. The inner fluting is the curved middle paper material between the two paper liners that gives a box the structure and look that we think of as "corrugated." It provides the transported product protection from potential damage.

Another example where significant opportunity exists for using recycled paper in lower grade applications is that of used newsprint recycled to manufacture cellulose insulation and garden mulch. In such less demanding types of applications lie a significant potential for the use of large volumes of waste paper.

Technology.—Contamination can make the recycling of post-consumer paper very expensive if not economically impractical. OCC's sometimes include wax coatings, plastics, food, mill wrappings, etc. The recycling of office paper is complicated by a large diversity of paper grades, as well as quantities of contained groundwood fiber, nonwater-soluble glues, paper clips, and rubberbands. Although improved cleaning equipment and technological advances are minimizing these impacts, continual improvements in collection methods and an evolving education of the public concerning the problems caused by contamination are an important part of the solutions. Probably the most significant technological progress is occurring in the deinking industry, in which new methods and technologies are being developed and many new plants have been coming on-line or are in the planning stages.

Steam explosion deinking technology is a current state-of-the-art and increasingly utilized method to deink office paper, especially the lower and mixed grades of paper. The process can be used as well to process OCC's at roughly two-thirds the cost of a similarly sized plant using conventional technology. A number of new plant projects were begun in 1992, both in the United States and in Canada. Steam explosion, a process used in the past to break apart wood chips and other biomass, deinks by "exploding" waste paper. This is accomplished by feeding the paper into a high-pressure chamber and then releasing it to atmospheric pressure. This process enables the recycling of even contaminated and low grades of waste paper. The steam explosion system results in more uniform pulp than other processing alternatives, requires no hazardous chemical deinking, and can process problem feedstocks, such as coated and waterproof stocks. Also it requires substantially less water and energy than the more commonly used technologies. When used for newsprint and writing paper-grade sheets, some further deinking by the more common methods of flotation and washing is needed to remove small quantities of ink that remain.[6] In flotation methods ink and other contaminants are chemically induced to be hydrophobic (water-repelling). Air is injected in the lower half of the flotation tank. Ink and contaminants attach to rising air bubbles because they are repelled by the water and the bubbles are the only way to get away from the water. Washing, the oldest deinking technology, involves chemically inducing ink particles to be hydrophilic (water-attracting) so that the ink is washed away with the water. A company in Virginia and another in Maryland were developing cogeneration plants to turn coal (VA) and natural gas (MD) into electricity and steam. New waste paper facilities were to be added, using the electricity generated to run the plants and provide the steam for the deinking processes.[7]

International Paper Co. announced a new recycling initiative for recovering milk and juice cartons into recycled-content copier and printing papers, and a variety of other recycled paper products. The company had completed a pilot project on the west coast and was planning to install a new carton processing plant in one of its existing mills in the Northeast. Recovered cartons there will be used to produce copier and printing papers. The initial concern has been to establish an adequate flow of suitable materials. For this reason the company was holding ongoing discussions with several major metropolitan areas about adding cartons to their curbside collection programs.[8]

Markets and Prices.—Markets for recovered paper and reprocessed paper pulp vary with the type and grade of paper that is collected or processed. A large variety of paper products with recycled content is produced in the United States. But significant quantities of scrap and discarded paper, notably newsprint, OCC's, and office paper are exported as well. The third largest market for old newspapers in the United States is the export market. These ONP exports primarily go to Pacific Rim mills that use waste paper as a primary raw material. Almost 3 of the 14.5 million tons of OCC's that industry reported as recycled in 1991 were exported. And more than one-half of the office paper collected for recycling is generally exported, again primarily to Pacific Rim countries.[9] Quantities of recovered paper being recycled have been continually increasing, but except for minor upswings in 1992, the prices paid for recycled pulp fiber remained relatively flat. The prices have been relatively low in part because of oversupplies of recovered paper in addition to the sluggish overall economy. At the same time, efforts continue to collect increasing quantities of post-consumer paper. Without significant improvements in the general economy, prices for secondary fiber were not expected to greatly improve.

Plastics Recycling

Plastics are long-chain polymer and resin materials that are synthetically produced almost entirely from nonrenewable hydrocarbon resources, most notably natural gas and petroleum. During the past three decades rapid growth has occurred in the use of plastics for a seemingly countless variety of purposes. Production in the United States has shown an average annual growth rate of 10% with continued growth expected

into the future. This growing flow of plastic materials has resulted in gradually accelerating increases in the quantity of plastic waste annually generated in the United States as shown in figure 5. The increasing use of plastics in packaging accounts for much of the waste. According to the EPA's municipal solid waste characterization study, containers and packaging accounted for almost 43% of all the plastic waste generated in the United States in 1990. Plastic packaging is a target for recycling because most packaging material has a relatively short period of use (less than 1 year) before discard. Packaging is usually a temporary "transportation" medium for another product and is not intended to have a long useful life. The typically more durable products it contains are generally not intended for such immediate discard, and the packaging material is quickly available for use in another product.

Other sources of waste plastic in MSW are appliances, furniture, carpets, and lead-acid batteries, in addition to a variety of nondurable goods such as plates and cups, trash bags, footwear, disposable diapers, and synthetic textiles. Textiles are in an industry separate from the plastics industry and are sometimes forgotten to be a source of waste resin. In 1990, approximately 62% of the fibers consumed in the U.S. textile industry were synthetic resin fibers. Textile resin fibers also become part of the municipal solid waste stream. However, only small quantities were actually recycled in 1990. Although not included in MSW data, significant quantities of waste plastic result from the discard of automobiles and from the construction and even more from demolition (C&D) of houses, buildings, and other human-made structures.

Issues.—Plastic products, especially as used in packaging and containers, are a low weight but high volume waste material that contributes to filling up our landfills. Although being about 9% by weight of our municipal solid waste that is landfilled each year, they account for possibly 20% or more of the volume, as reported by the EPA. A recent estimate of the volume of plastics in landfills was reported by William Rathje of the University of Arizona. In archeological digs of landfills across North America, as part of his "The Garbage Project," he determined that plastics compact better in landfills than has generally been believed. In these excavations plastics took up about 16% of the space in the landfill. Although they may take up less space than previously believed, plastics by weight still take up more than their share of landfill space. Because they are a significant nonbiodegradable material, they are often a target for recycling or incineration. Some of the very qualities, such as durability and corrosion resistance, for which plastic materials are used are the same "qualities" for which they are criticized upon discard. The management of plastic products when they have outlived their usefulness is an ongoing issue. Some States and counties have chosen to manage certain plastics by banning their use.

Under the EPA's waste management hierarchy, recycling used or waste plastic products into new products is preferred to the incineration or landfilling of them. Plastics recycling is further encouraged by some advocates because plastic is derived from nonrenewable energy resources and cannot be grown as a tree can from a seed. But to be successful recycling must result in a product with (1) high enough quality, (2) low enough cost, and (3) be done with an efficient expenditure of energy and other natural resources. If not, incineration of waste plastic is a potentially valuable alternative. When its hydrocarbon origins are considered, plastic is, not surprisingly, a highly energy-intensive material. In the WTE incinerator it is a very valuable component of the mixed municipal solid waste. As well as having high energy values, the heat it gives off promotes better burning of the surrounding mixed wastes. Incineration is a final one time use of the material promoted by its advocates as more productive than simply burying it.

Although some degradable plastics have been produced and others are under design, they are only a small part of the solution to related landfill and litter problems. These materials may be useful in specific applications; for example, for 6-pack beverage container rings, packing peanuts, compost bags, and possibly disposable diapers. But they are not practical for many uses of plastic. Also, the production of truly degradable plastics in the large scales necessary would currently be technologically and economically prohibitive. The large majority of "degradable" plastics at present are more accurately labeled as "bio-disintegratable" or "photo-disintegratable" as the plastic itself does not truly degrade. Disintegratable plastics, such as our everyday plastic grocery bags, break down into a plastic sand or dust when the starch molecules that join them together truly degrade due either to biological agents or solar energy reactions. The polymer in these materials does not degrade—it is the same durable plastic in miniature. The environmental consequences of this plastic dust is unknown. For some applications the desired characteristics of plastics, such as durability and corrosion resistance, would be adversely affected by formulating the plastic to be degradable. Another issue is that of the recyclability of other plastic materials, for technological or economic reasons, can be limited when contaminated with quantities of biodegradable plastics.

An ongoing, controversial issue for many recycled plastic material and product producers is that they conduct business on an uneven, unfairly competitive playing field with virgin plastic producers, resulting in unfairly stiff competition. Recyclers contend that virgin producers have the advantage of buying their raw materials from the oil and gas industry, which receives either subsidies or tax breaks, thereby reducing the expense of their raw materials. In efforts to encourage more recycling, a number of alternative approaches to this controversial problem was under discussion in the EPA and the U.S. Congress, as well as other government agencies and independent task forces.

The Recycling Advisory Council

(RAC), formed in 1989 in part under a grant from EPA, consists of representatives from business, industry, environmental organizations, and public interest groups. In a major effort to find ways to increase recycling in the United States, RAC's mission was to investigate the crucial issues concerning and surrounding materials recycling, not the least of which were barriers to the development of the various scrap commodity markets. During 1992 and to be completed in 1993, its market development committee conducted a study of the barriers to recycling and possible approaches to solve these problems. To encourage greater use of recycled materials, several of the alternatives proposed for consideration were: (1) establish a variety of minimum content standards for recycled materials in products, (2) require that the manufacturer of a product be responsible for its recycling, (3) apply a tax on the production of virgin materials, and (4) establish a subsidylike "trust fund" for rebates to companies using recycled materials.

Annual Supply and Recycling Rates.—Most survey-based plastics recycling data came from trade groups and consulting groups who conducted studies of the relatively young plastics recycling industry. The American Plastics Council (APC), a major plastics recycling trade group, reported the results of its fourth annual post-consumer plastics recycling rate study, conducted by R. W. Beck and Associates. The study examined six resins commonly used in consumer packaging that also were recycled: polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-/linear low-density polyethylene (LDPE/LLDPE), polypropylene (PP), and polystyrene (PS). Various other plastics, such as polycarbonate and nylon, were included in the survey totals as they also were reported as recycled by some of the companies. For a detailed breakdown of the recycled plastics from the APC study for the years 1991 and 1992 see table 3.

The APC surveys, as well as the other more limited surveys, have consistently reported increases in plastics recycling each year. APC reported that total plastics recycling during 1992, including both packaging and nonpackaging, grew 41% over that of 1991, while the recycling of packaging plastic was strongest with a 47% rise. More than 582,410 tons of post-consumer plastics was recycled in 1992, up from almost 413,680 tons in the previous year. Almost 75% of the recycled plastic was from packaging materials. The packaging component grew from 291,660 tons to 429,950 tons. As this survey has been refined each year, not only have newly formed companies been added, but also some companies missed in a previous year were picked up and added that following year. Thus, some of the recycled increase could reflect the absence of these companies from earlier reporting years. This does, however, also suggest that recycled quantities may have been better in earlier years than those surveys suggest. Nonetheless, it appears to be the most complete and accurate survey that has been conducted for the public record to date.

PET has become the most recycled of all post-consumer plastic in the United States. Recycling of PET has grown from 3,600 tons in 1979 to nearly 210,000 tons in 1992. Almost 83% of the 1992 total, 173,000 tons, resulted from the recycling of soda bottles alone. This quantity was almost 41% as much as the virgin PET sales for soda bottle production for the year. Almost 26,500 tons of nonpackaging PET, 13% of total recycled PET, was recycled in 1992. Total HDPE recycled in 1992 was 201,000 tons, principally from the recovery of natural milk and water bottles, and less so from pigmented bottles and soft drink base cups.

PS is used in packaging applications in the form of PS foam. Both its very high volume-to-weight ratio and its common use with food products makes collection and some associated processing more difficult than other plastics. Nevertheless in 1992, more than 17,000 tons of PS, 53% more than the previous year, was recycled in the United States.

A nonpackaging application where significant plastic recycling growth occurred during 1992 was in the recycling of lead-acid vehicle battery casings made of PP plastic. Recycled quantities of PP from this source alone increased almost 41%, from 65,500 tons in 1991 to 92,200 tons in 1992. One major reason for this recycling growth is the regulations by State and local governments that (1) require lead-acid vehicle battery retailers to return spent batteries directly back to the manufacturer for recycling purposes, and/or (2) prohibit the flow of the same batteries into solid waste landfills. As of mid-1993, 35 States had enacted battery recycling legislation and 7 other States had banned the municipal solid waste disposal of lead-acid batteries.

Whereas the reported increases are an indication of positive movements in the industry, there is still a long way to go. Based on conservative estimates of plastic waste contained in the municipal solid waste that was generated in 1992, the total plastic recycled was, possibly at best, about 3.5% of the total. Although small, this does show progress from the roughly 2% achieved in previous years.

Consumption and Uses.—The two major types of plastic, thermosets and thermoplastics, have significantly different limitations and challenges in recycling. Thermosets are long-chain polymers that have been "set" chemically or "cured" in a crosslinked pattern. When heated to the proper temperature these molecules do not melt in the manner that thermoplastics do. The crosslinked bonds remain intact and the degraded or charred material cannot be formed into a new and usable shape. To date, thermosets have very limited use in recycled products. They are limited to being crushed or cut up into small pieces and used as a filler or aggregate material in certain product applications. Thermoplastics also are composed of long-chain polymers, but they have not been chemically linked together, allowing them to slide by each other when properly heated. They melt into a liquid

or moldable form. When the temperature drops they resolidify or harden into the new product form.

Recovered and reprocessed plastic is consumed by a large number of industries, consequently resulting in a wide variety of new products. Consumption by individual industry is difficult to quantify. Recycled PET plastic is used in the manufacture of carpets, industrial strapping and pallets, fiberfill for sleeping bags and ski jackets, automobiles parts, nonfood containers, plastic lumber, and a continuing variety of other products. An important market for recycled PET is the synthetic fiber (textile) industry that uses the PET for carpet backing and other fiber products. HDPE is commonly formed into bottles, industrial and consumer containers, drums and oil storage containers, fuel and other tanks, tank liners, toys, housewares, corrugated pipe, pipe for irrigation and oil, gas and mineral production, consumer bags, some food packaging, sheeting, wire, and cable. Some of the products manufactured from recycled polystyrene are: park benches, office equipment, videotape cartridges, pallets, the new compact disc "jewel" cases, and a variety of household products.

Most recycling of plastics is based on physical alteration or breakdown (crushing and shredding) and melting of the material to produce another product. Tertiary plastics recycling is a very small portion of plastics recycling and is fundamentally different. The old material is chemically broken down into fundamental components or chemical substances. Recycling occurs when a new, "virginlike" polymer is then produced from the resin components into a new, marketable product. The technology needed to chemically break down plastics into fuels and into the basic feedstock hydrocarbons has been known for decades. But, until recently, it was used principally within manufacturing plants where it was economically beneficial to do so. In part because of the limited one-time reuse, the chemical recycling of plastics into a fuel is generally not considered recycling in EPA's solid waste hierarchy; it is in effect comparable to WTE incineration.

Since late 1990, tertiary recycling by methanolysis, glycolysis, and pyrolysis has been used by three soft drink companies to recycle PET plastic. In these processes used PET bottles are chemically recycled back into new PET soda bottles that are usually composed of a mix of 25% of the recycled material and 75% virgin material. Bottles made of 100% chemically recycled PET are technologically possible but currently cost-prohibitive. The quantities recycled by this method are a very small portion of the PET bottle recycling data. Because of the associated economics, thus far apparently marginal at best, this practice is not flourishing. However, most, though not all, of the original projects are still ongoing. Although virgin PET supplies were sufficient, virgin PET material output was at times near capacity. This measure of uncertainty created a demand for raw materials from the tertiary recycling operations to more securely guarantee supplies of needed new bottle material.

A significantly higher portion of plastic was recovered for WTE incineration to produce energy via steam or more directly to produce electricity than was recycled. In 1990, an estimated 16% of the plastic waste portion of the generated MSW generated was combusted in WTE incineration plants. When the resin fibers in the textile portion of MSW is included, the total percent of plastic incinerated rises to about 19%.

Technology.—Possibly the greatest difficulty in processing post-consumer plastics, both technologically and more so economically, is that of sorting or separating the different types of plastics. A high-quality recycled plastic material of a particular type may be feasible, but many products demand that recovered materials be uncontaminated with glass, dirt, and other types of plastic. In some cases minute quantities of contamination greatly or even critically reduce the quality and usability of the recycled material. A good example of this is PVC-contaminated PET (polyethylene terephthalate-soda bottle plastic). Their similar densities complicate the process of segregating the two before melting, and during melting PVC, which has a sufficiently lower melting point, contaminates the PET with a detrimental char product. Some materials and products demand very pure "recyclate" material, others such as some plastic lumber and park bench materials are more forgiving and can accommodate a combination of plastics.

Highly reliable separation technologies that demand little to no labor and also are cost-effective are needed for the continued and accelerated growth of recycling in the plastics industry. The human sorter cannot recognize all the different variables of plastic categories and subtypes, as well as different colors, particularly at the speeds necessary to make the process economical. Numerous plastics sorting technologies have been invented and range from those achieving limited results to some very effective and sophisticated systems. Most of these are based on various spectroscopic and X-ray analyses, infrared recognition, and laser technologies. Other systems under development include a water surface tension technique, a selective "dissolution system," and a near infrared light system that incorporates specialized "neural networks" instead of conventional computers. Because of the problem of similar densities, in particular that of PET and PVC, one company is developing a flotation-type system to separate the two by means of their differing surface tensions.

The Rensselaer Polytechnic Institute (RPI) is currently testing and developing a selective dissolution system to separate individual resins. In the process, all plastic resins are commingled, shredded, and subjected to several solvent baths. Each bath is heated to the precise dissolving point of a certain resin and the resulting liquid is siphoned off into a holding tank. The temperature increases with each bath until all resins are removed. According to an associated consulting company, after further processing by "flash devolitization," the remaining resin is nearly as pure as

virgin plastic and may be sold at a discount of at least 2.25 cents per kilogram. RPI is currently awaiting approval from the U.S. Food and Drug Administration to use food packaging in a future pilot devolitization process.

The Sandia National Laboratories of the U.S. Department of Energy is developing a system that uses the near infrared light/neural network system. Modeled after the assimilatory abilities of human nerve cells, these networks will be capable of "learning" the characteristics of the resins—a process less arduous and time-consuming than preprogramming. In some test runs, once the networks have been trained through trial-and-error for all types of resins, accuracy levels of 100% have been reported in the lab. A prototype was under testing by a recycling equipment manufacturer.[10]

With the increasing effectiveness and sophistication of sensing systems often comes a higher cost that limits their use by many companies because of the relatively low prices for scrap plastic. But, cost factors aside, some very accurate sensing systems are still hindered by mechanical difficulties encountered in separating the material. Two problems that researchers are working on are how to provide the automated systems with single plastic bottles or pieces and how most perfectly to mechanically segregate the different plastics.

Because of the bailing of plastics that is necessary for economical transport, used plastics become clumped together and a foolproof breaking of these clumps into the individual pieces is expensive and difficult. Several new technologies have been claimed to be virtually 100% effective in sensing the different plastics, but if the plastics are still stuck together then the sensor reads the clump as one object. If there is more than one resin or color in that clump, rather than jeopardize the rest of the stream the system rejects the clump. The more this happens, the larger the amount of material that has to be sent through the system a second time, proportionately reducing the efficiency and increasing the costs of the sorting and processing operation. If bottles are not completely separated into individual pieces, even perfect sensing and physical sorting technologies cannot finish the job as needed. Most, if not all, "singulation" systems are having these problems. The other mechanical difficulty is that of doing the physical sorting. This is generally done by air jet nozzle systems that are becoming increasingly accurate, although not foolproof. These systems balance the sensors recognition time with the speed of the conveyor belt to eject the different bottles via streams of air into the proper collection bins. Some systems use a negative sort in which a plastic is sorted by not being jettisoned, but merely dropping off the belt into another bin. The greater the variety of plastics being separated the more difficult the process is. Some of the most sophisticated systems can separate plastics into four main streams or types. One operation has combined two systems and is able to separate a mixed stream of baled or loose plastics into five categories: colored HDPE, natural HDPE, PVC, green PET, and clear PET.[11]

A major source of waste plastic is that of scrapped automobiles. Following shredding, the auto shredder residue (ASR) that remains, composed of plastics, fluids, glass, rubber, and various other mixed materials, including dirt, is most often landfilled. Plastics compose about one-third or more of the total. About 10 million automobiles are shredded each year. At an approximate average of 100 kilograms of plastic per car, this amounts to 1 million tons (1.1 million short tons) of plastic that could potentially be diverted from our landfills annually. The Argonne National Laboratory (ANL) is one of a number of labs and companies working on technologies to process ASR. Argonne's technique uses solvents in an effort to dissolve the residue into products that could be economically substituted for, or mixed with, virgin material without reduction in final product quality. According to ANL, this process reduces the residue to 50% reusable materials and 50% residue remaining for disposal. Argonne claims to have achieved a 92% recovery of the processing solvents in its laboratory work with even higher anticipated percentages of recovery possible in commercial applications. These recycled plastics could potentially be used in products such as park benches, lamp posts, traffic cones, and construction materials. Under present economic conditions, these recycled materials have limited marketability because most impurities are not removed, and the cost of making the products can be as much as if virgin materials were used.[12]

The Japan Recycle and Research Center, formed in association with the Japan Iron and Steel Scrap Association, is taking a different approach in attempting to deal with the 5 million automobiles that are annually scrapped in Japan. They have begun a new research program to design and construct a new type of WTE incineration plant for elimination of ASR. Remnant ashes are to be processed into concrete materials.[13]

Markets and Prices.—The marketing of recycled plastic products generally suffers because of high costs and insufficient demand for recycled materials. Materials for many products are very specialized and either need a quality that cannot be produced from recycled plastic, or when proper quality can be achieved, the cost would be noncompetitive with virgin resins. Other plastic products can be produced more easily with recycled plastic but are still simply too expensive as compared to the same product made from virgin plastic. An additional reason is true acceptance by the public. The general public is becoming increasingly enthusiastic about the idea of recycling and materials conservation. Municipalities want plastic materials and goods to be diverted from the solid waste stream. But both individuals and institutions have been slow to translate these notions into expressed demand for recycled material content used in lieu of virgin materials in the products that they buy off the shelves every day. The general public often is not readily confident that recycled products may be as good as the virgin

products sitting next to them on the same shelf. In addition, when the recycled products are more expensive, the incentive to purchase the recycled product is further reduced.

Thus far, PET and HDPE are the only plastics that have commanded high enough prices with sufficient demand to achieve a measure of consistency in the recycling industry. PET plastic has been the most cost-effective and consistently recycled of the two with many marketable products that can be made from clean, processed PET scrap. Its main challenge has been to be cost competitive with virgin PET, the price of which has been relatively low during the same period. Recyclers of HDPE, while experiencing a higher percentage increase in output in 1992 than recycled PET processors, had to endure greater competition in the marketplace. One major processor of recycled HDPE canceled its HDPE operations altogether to concentrate its efforts in the better market opportunities of recycled PET, although it planned to restart its HDPE operations when the market showed sufficient improvement and stability.

Rubber Recycling

Rubber recycling includes both synthetic rubber and, to a lesser degree, natural rubber. Synthetic rubber (SR) is a major member of the family of materials called the elastomers. Like plastic, it is made up of long-chain polymers that are produced from hydrocarbon feedstocks. In addition, the SR polymers have been synthesized to consistently reproduce, at ambient temperatures, natural rubber's best properties, most notably its "rubberlike" elasticity. Sources of rubber waste products are discarded clothing, footwear, rubber tires, and a variety of miscellaneous durable and nondurable goods, such as gaskets on appliances, various automobile parts, furniture, floor coverings, and hot water bottles. But rubber tires are the predominant source of rubber in municipal solid waste. As many as 250 million waste tires (about 2.3 million tons) are generated annually in the United States. Of equal concern is the backlog of tires that have accumulated across the country, especially since the end of World War II. Both by illegal dumping and by legal stockpiling, an EPA-estimated 2 billion to possibly as many as 3 billion "units" (tires) have been thus "disposed" of in preference to being landfilled, incinerated, or recycled.

Issues.—Tires, about 85% of which come from automobiles, are a significant and problematic portion of our municipal solid waste. For decades they have been a growing problem because, landfilled or stockpiled, discarded tires can be a threat to human health and the environment. Landfills have traditionally been the method of disposal for scrap tires in the absence of a market. Today landfill bans are restricting this practice, especially the burial of whole tires. Their composition and shape do not allow easy compaction in the landfill, and they do not decompose, thus occupying significant amounts of valuable landfill space. Additionally, whole tires trap gases due to their round and hollow shape and over time "float" to the surface, breaking the landfill cover and allowing landfill gas to escape.[14] Being exposed on the landfill's surface, they then become a breeding ground for insects, rodents, and birds.

Stockpiled tires have similar associated problems, which can be amplified because greater quantities are crowded into one place. Because of their shape tires hold water at any angle, which makes them a very attractive breeding site for mosquitoes and other insects, some of which can carry disease. North American varieties of mosquitoes can be of concern by themselves, but in recent years other strains of insects have been "imported" from other countries. For example, in 1985 the Asian Tiger Mosquito, which is known to carry some relatively dangerous sicknesses, arrived in Houston, TX, aboard a shipload of used tires from Japan. This same mosquito has since been located in other parts of the country.

Another danger is that of fire. A tire fire is extremely difficult to extinguish and can burn for a long time. Uncontrolled tire combustion at the characteristically low temperatures at which these fires usually burn tends to release significant amounts of thick, black smoke. Both the air is fouled and the rubber melts into a toxic substance or "goo" that can adversely affect ground water. A few tire piles that have caught fire have been designated Superfund cleanup sites by the EPA.[15]

Currently, the overriding issue is of how to use or safely dispose of scrap tires and other rubber products: whether to incinerate them for their contained energy values or to stress the reuse and development of recycling uses for waste rubber and tires. Incineration of tires for their energy values is currently the leading method of use/disposal after that of landfilling or stockpiling. While markets for materials and products that include recycled rubber are increasing, the greatest potential to date is the use of ground rubber tires in the production of rubber-modified asphalt for our Nation's roads.

Annual Supply and Recycling Rates.—EPA estimated that in 1990 about 181,400 tons (200,000 short tons) of rubber from tires was recovered for recycling. At an average of 9 kilograms (20 pounds) per tire, the average weight of a passenger car tire, this amounts to more than 20 million tires. More recent estimates have been projected by the Scrap Tire Management Council (STMC). For 1992, the council estimated the annual recovery at more than 68 million tires, 58 million of which was estimated to be used as fuel by several major industries. Of the remaining 10 million tires, nearly one-half was used in rubberized asphalt. Other uses included civil engineering applications and the manufacture of recycled rubber products. A small portion was chemically broken down to more basic chemicals and materials by the process of pyrolysis. The apparent discrepancy between the two recovery estimates is not as great as it may appear because the EPA's estimate does not include tires that were combusted either as a fuel or for the production of energy.

According to an EPA study, an estimated 12 million used/waste tires were exported in 1990. If included with STMC's estimated 1992 recovered quantity of 68 million tires, an approximate 80 million tires were potentially recovered for the production of energy, recycled products, reuse, and export for similar purposes. Thus, about one-third of all waste tires in 1992 (presuming a similar exported quantity as reported for 1990) were potentially diverted from the Nation's landfills, stockpiles, and "illegal dumps." If exports are not included, then the recovery rate was about 28% of total discards.

Retreaded tires usually are not included in recycling data as they are considered a reuse. But they are a valuable "recycling" of the tire body as a whole and their reuse also slows their introduction into the solid waste stream.

Consumption and Uses.—Pulp and paper mills are a major user of tires as a fuel. Tires, like coal, are used as a fuel supplemental to their traditional fuel of wood chips. Consumption in this industry has remained fairly constant in the past several years. The pulp and paper industry consumed between 12 and 13 million tires as a supplemental fuel in 1992. The industry has burned tire-derived fuel (TDF) since the early 1980's. TDF is tire rubber that has been chipped into pieces 2 inches or less in size, called crumb rubber, and is processed to be clean of contaminants, including the steel belts. The steel belts are sold as scrap metal. The pulp and paper industry needs this clean, uncontaminated TDF if it is to use tires as a fuel. In conjunction with this need, the industry's major constraint is the cost of competing fuels, such as wood chips, petroleum coke, and coal. Lower prices for competing fuels can limit the use of TDF. Two other limiting factors are the remote location of many mills, which results in higher transportation costs and the reliability of TDF supply.

Tire recovery has substantially increased during the past 2 to 3 years as a fuel in electric utility boilers, cement kilns, and in new, dedicated tire-to-energy plants. In 1992, almost 17 million tires were combusted in utility company boilers or in other boiler facilities, such as agricultural product processors and chemical companies. TDF is the common rubber fuel that is used in electric power companies' utility boilers, although requirements for clean TDF sometimes are less stringent than those of the pulp and paper industry. Some systems allow for the burning of whole tires. In parts of the Midwest and the East high-sulfur coal is burned in utility plants. At times when coal costs less than TDF, using TDF as a fuel can still be competitive because of its low sulfur content. Both TDF and whole tire combustion is reported to produce less ash than burning coal, emit less carbon dioxide, and produce lower sulfur-dioxide emissions when replacing a high-sulfur coal.[16] Very significant growth has occurred in this sector in the past few years alone, and according to STMC, some of the major utilities are currently considering using scrap tires.

The cement industry has increased its use of waste tires from 3 million tires in 1990 to about 14 million in 1992. Cement kilns are rather heavy users of coal, making the use of the cleaner burning rubber an attractive option. As with some utility users, a growing number of cement kilns are able to burn whole tires, avoiding the associated costs of buying processed TDF. Tires offer these kilns other advantages. Tires have a higher energy value than coal, and a tire's steel belts and beads can replace the iron ore needed in the cement making process, thus reducing the manufacturer's raw material costs.

Only two major tire-to-energy facilities, both built by one company, were operational in 1992, but between them they consumed about 15 million tires. The same company was in the planning stages of building two more plants. The completion of one of these units by 1997 would more than double the current 15-million-unit capacity. Even though these operations have been successful, the use of this technology is usually only practical in regions with high electric rates and high solid waste tipping fees. The capital costs per megawatt of generating capacity for these facilities runs between two and seven times more than coal-fired plants.

In 1992, about 5 million scrap tires were recycled either through incorporation into asphalt binder material or as aggregate in rubber-modified asphalt. Rubberized asphalt costs about twice the price of conventional asphalt, but experience indicates that it can be applied in thinner layers and lasts much longer. A more widespread use of the basic technology as well as the end of a patent on one of the most frequently used processes should help to reduce costs of this rubber-modified product. Some questions as to the safety and durability of this product, as well as its recyclability in the construction of future roadways, has been raised, mostly due to a lack of long-term experience with it. But to date, roads made of this material appear to be more durable and longlasting as well as safe to travel on. According to a recent report to Congress jointly submitted by the EPA and the Department of Transportation, the use of asphalt containing recycled rubber is not substantially different from conventional asphalt in terms of health and environmental effects, recyclability, or adequacy as a paving material.

Another 5 million tires were used mostly in civil engineering applications and to a lesser degree in recycled rubber products. Civil engineering applications include embankments, clean fill, leachate collection in lieu of sand or gravel, artificial reefs, breakwaters, sideslope stabilizers, crash barriers, sound barriers, and playground structures and protection. Other applications include use in products such as railroad crossing ties, dock bumpers, a variety of flooring materials and mats, carpet underlay, sound insulation in automobiles, truck and trailer liners, and drip irrigation pipes.

Possibly as many as 1 million tires were consumed by tire pyrolysis, the process of chemical and physical breakdown of the whole tire into oil, gas, and char (low-grade carbon black) byproducts, and steel from the steel

belting. This use has not flourished because of inconsistent markets for the oil and char byproducts.

Although making new tires out of old tires may seem like the most obvious choice, this is not possible. Tire rubber is a thermoset or "vulcanized" material. To date, no technology has been able to reverse or "devulcanize" this process. Because of this the new, strong chemical bonds necessary for new tire production cannot be achieved. Only a very minimal and inconsequential amount of rubbings, very fine crumb rubber, can be used as noncritical filler in the manufacture of some tires.

The only way that old tires are used in tire manufacture is as retreads. The retreading of tires is a direct reuse of the basic tire and thus is not included in reported recycling amounts and rates. The American Retreaders Association (ARA) contends that it should be considered recycling because of fine lines of difference between retreading and some other recycling uses of used tires. The life of the tire is extended and consequently the annual quantity of tire waste that must be managed is reduced. Additionally, natural resources are conserved because annual demand is reduced for new, virgin tire material. The ARA reported that the retreading process gave new life to about 31 million tires in 1991. Of these, approximately 8 million were passenger car tires, another 8 million were light-truck tires, and 15 million were truck tires, whose high replacement cost makes retreading cost-effective.

Technology.—A significant, source reduction-related technology has been the longer wearing vehicle tire. The development of the radial tire more than a decade ago increased the tread life expectancy from the range of 20,000 to 25,000 miles, for the standard bias-ply tire, to 40,000 miles and more for the then new radial-ply tire. An added advantage of the radial tire was that it delivered better fuel mileage. A trend to smaller cars began somewhat earlier, during the 1970's. Smaller cars usually use smaller tires. These factors caused a reduction in the amount of rubber used in the manufacture of tires and, consequently, in the quantities of tire waste generated. According to a World Rubber & Tire Report issued in 1992 by the Freedonia Group of Cleveland, OH, the amount of natural and synthetic rubber used in tires dropped from 45% of all rubber consumed in 1980 to 42% in 1990. The International Institute of Synthetic Rubber Producers in Houston, TX, recently estimated that almost 52% of all synthetic rubber currently consumed goes into tire production. Both of these percentages could change further during the next decade if the most recent advanced tire technology is successfully integrated into the tire marketplace. In 1991, the original producer of the radial tire introduced a new radial tire in the United States that it warranted for 80,000 miles. Although the new technology has not been fully revealed by the manufacturer, these tires include the use of a newly developed family of elastomers.[17]

Also significantly important is the mix of raw materials used in the radial tire. Radial tire design produces higher operating temperatures than that of other types of tires, and this affects the composition of the tire material. The higher temperatures perpetuated an increase in the percent of natural rubber needed. Synthetic rubber helps tire tread last longer, but natural rubber is less heat sensitive. Radial-ply tires are composed of about 16% natural rubber as compared to their bias-ply predecessors that used 11% natural rubber. Thus a small yet significant portion of synthetic rubber, which is manufactured from nonrenewable hydrocarbon resources, is being replaced with natural rubber, a renewable resource.

Two companies have developed tire pyrolysis technologies that they claim are economically feasible. Up to now pyrolysis overall has not been viable. Too small a portion of the byproducts—pyrolytic oil, gas, char, and metal from the char—have been profitably marketable on a consistent basis. The gas is usually used to fuel the process, and the metal, approximately 1.1 kilograms (2.5 pounds) of the typical 9-kilogram (20-pound) tire, is clean enough to market. But the grade of pyrolytic oil and char is often below market standards. Both companies claim that their more sophisticated pyrolysis technologies produce higher quality materials. One of the proposed processes operates at a relatively low temperature, 177° to 205° C (350° to 400° F) as opposed to the traditional operations at 925° to 980° C (1,700° to 1,800° F). The char or "carbon black" is sold to manufacturers of low-grade carbon products such as hoses and tires for lawn mowers and forklifts. Thus far, pyrolysis technologies have not been able to produce a carbon black of high enough grade to reuse in tire production.[18] But even if low-temperature methods prove to be successful, widespread commercialization of them appears likely to be several years away.

Since 1990, the Scrap Tire Management Council reports that one significant technological change has occurred in the tire-to-energy industry. In the second of the two commercial facilities in the United States, certain innovations have allowed for whole tires, as well as processed TDF, to be combusted, thereby lowering everyday operational expenses.

Markets and Prices.—Continued growth is projected for most scrap rubber markets. But the two market areas that offer the most potential are incineration as a fuel and for the generation of energy and the use of crumb rubber in the maintenance and rebuilding of highways. Most of the current uses are expanding and some, such as cement kilns and utility plants, are limited principally by reliable tire supply. However, the expansion of these uses would require significant capital outlay for plant modifications needed to use TDF or whole tire fuel.

The use for scrap tires is likely to grow significantly through 1997 because of the Intermodal Surface Transportation Efficiency Act (ISTEA) in December 1991. The law mandates a recycled content of rubber material on federally

funded State roads. Beginning in 1994, 5% of all federally funded roads paved with asphalt must contain recycled scrap tire rubber at the approximate minimum rate of 9 kilograms of rubber per ton applied. The 5% is to increase another 5% each year through 1997 when 20% of federally funded roads will be so affected thereafter. Although rubber is likely to be the main component of the recycled materials that are mandated under the law, the use of other materials such as glass, asphalt pavement, or plastic may reduce the anticipated quantities of crumb tire rubber that is included in the mix. The final interpretation and the degree of implementation of the law will determine how much is actually used each year. Under the ISTEA legislation STMC estimates that up to 68 million tires could be used for this application by 1996.

OUTLOOK

Alternative Material/Waste Management Methods

The degree to which an integrated waste management system is instituted will greatly affect the future and the effectiveness of recycling, composting, incineration, and landfilling. Since 1988, the number of recycling collection programs and yard waste composting facilities have increased considerably. Curbside collection programs have risen from little more than 1,000 in 1988 to more than 5,400 by the end of 1992. Yard waste collection and disposal facilities during the same period have increased from 700 in 1988 to almost 3,000 in 1992. The number of incinerators during the same period also rose at a slower rate from more than 135 to more than 171 in 1991, and dropping slightly by two units to 169 units in 1992. Even with increasing quantities of municipal solid waste being landfilled, the number of landfills have dropped from nearly 10,000 in the early 1980's to about 8,000 in 1988 to nearly 5,400 in 1992. Closures of many smaller, less profitable sites and others no longer environmentally permissible account for the large drop.[19] Fewer in number, but much larger and better environmentally designed, new state-of-the-art sanitary landfill facilities, or expansions of existing operations, have replaced some of the reduced landfill capacity. Appropriate local ordinance, and State and Federal laws and regulations have mandated these changes, as concern over clean, freshwater supplies and a clean natural environment have risen. Recycling, composting, and probably WTE incineration is likely to increase, but landfilling will probably continue to decrease in comparison to the other alternatives in the foreseeable future.

Source reduction will continue to be stressed as we reduce the weight and size of the materials and products that we produce to levels that are still adequate for the task at hand. Efficiency and practicality will guide these efforts. A new material may make some forms of packaging lighter and thinner than its predecessor, but if it is not cost-effective or if it uses an excessive amount of energy to produce it, then it is neither efficient nor practical. The development of longer lasting materials is likely to be the target of many future research efforts.

"Design For Recycling" Programs[20]

If designed with recycling in mind, some products could have significant impacts on reducing the generation of solid wastes and on increasing the quantities, as well as the quality, of recycled materials in the future. Automobiles, major appliances, and some packaging applications are just a few examples. This concept is becoming an integral part of the design and research efforts of some companies in the manufacturing and service industries. "Design For Recycling" is an official program and policy of the Institute of Scrap Recycling Industries (ISRI). Through its program, ISRI is seeking a national policy to promote the design and manufacture of goods that, at the end of their useful lives, can be recycled safely and efficiently. Major thrusts of their program are to motivate and assist the manufacturing industry to: (1) make consumer products and durable goods recyclable; (2) reduce environmental risks from consumer products; and (3) control any related special environmental problems.

The concept of design for recycling is relatively simple, but implementation will be a little more difficult to achieve, especially in a culture which, during the past two or more decades, has shifted its habits toward "disposability." U.S. manufacturers presently have no legal responsibilities or obligations to plan ahead for the obsolescence of their products. New products are designed to meet the increasingly complex needs of modern society. The needed materials sometimes become more complex and difficult to recycle and may even contain toxic materials unless attention is paid to recyclability in the product design stage. Toxic materials can be harmful to the environment and to the recycling worker if released during the recycling process. A current example is the sodium azide capsule in the automobile air bag inflation mechanisms. Being both explosive and toxic they have complicated automobile recycling processes. An example of a product that is not dangerous but is complicated to recycle is multilayered food packaging. Although this product is highly effective in protecting food from the environment, the many layers of different materials make it rather difficult to recycle. The scrap recycling industry is aware of these problems, and an objective of ISRI's program is to alert manufacturers.

The Automobile.—Such goals as weight reduction and lower emissions remain important, but increasingly, U.S. automobile manufacturers are instructing designers to give recyclability high-priority consideration. Currently, about 75% of each U.S. auto is recycled in the United States, and the domestic auto industry is striving to do better. Additionally, a number of foreign manufacturers have been in the forefront of recycling-conscious automobile design. One problem that is encountered in automobile design is that as weight reduction is achieved the use of nonmetallic components increases. This

is most of the 25% of the car that is difficult, or currently not possible, to recycle. Plastics are particularly difficult because of the numerous different types that are used and, generally speaking, the lack of compatibility between them.

General Motors (GM) has been using recyclable plastic for body panels on its Saturn[21] automobile. Defective panels at the plants can be ground for immediate recycling into other molding parts. Used body panels can be recovered and recycled when Saturns are scrapped. Chrysler Corp. has developed an award-winning prototype car, the Neon, which contains recyclable interior and exterior panels, wheels made from previously recycled aluminum, and is painted with water-based paint. In an attempt to maximize recycling potential, two Chrysler vehicle lines were introduced in 1992 that were designed for 90% recyclability. E.I. du Pont de Nemours & Co. (DuPont) supplies the glass reinforced, PET-based plastic for the fenders on these cars. This material can be reground, remolded, and reformed. A methanolysis process, also developed by DuPont, can be used to return the material to its original feedstock components, which can be used again on applications, including new fenders.

While the phrases "design for recycling" and "design for disassembly" go hand in hand, they are different. Design for recycling aims not only at ease of disassembly but also minimum disassembly so that subassemblies may be removed and recycled without further separation. Several European carmakers have taken an early lead in establishing programs in these areas. In 1991, Bayerische Motoren Werke AG (Bavarian Motor Works, BMW) and Volkswagenwerk AG (Volkswagen, VW) started pilot disassembly plants to recover metals, plastics, glass, and other materials from old cars, and BMW announced plans to build a commercial plant. The German Automobile Club (ADAC) has a research dismantling facility at which its goal is the design of a 100% recyclable automobile. The French automaker Peugeot SA (Peugeot) has entered a joint venture with a leading French scrap metals processor and a cement manufacturer to maximize recycling and to convert nonrecyclable components into fuel for the cement plants. They plan to recycle more than 7,000 Peugeot and Citroen cars by 1994. In the United Kingdom, the Rover Group has joined with the Bird Group, a leading scrap processor in Europe. They plan to develop rapid dismantling techniques and set up standards and procedures. In Japan, similar efforts began with Toyota's collection of used plastic bumpers. The bumpers were sold to recyclers and manufactured into products such as pallets. This program was started with 26 dealers in Tokyo and was expanded to all dealers in the Tokyo area.

The U.S. big three automakers recently formed a consortium to research and promote the maximum recovery and reuse of materials from junked cars. The Vehicle Recycling Partnership also is expected to develop industry guidelines for new vehicle manufacturing in such areas as materials selection and compatibility and needed materials and techniques for joining, coating, etc.

The Automotive Group of the Durables Committee of the Society of the Plastics Industry has established a pilot study to develop economical and environmentally sound methods of recovering and recycling post-consumer automotive plastics and an industry infrastructure to support such processes. The use of as many as 40 different types of hard-to-identify plastics in automotive applications such as fan shrouds, fender liners, radiator end caps, windshield washer bottles, interior trim pieces, and grill panels has made auto plastic recycling difficult. GM and Ford Motor Company now require labels that identify the type of resin in each plastic part. Auto dismantlers, an auto shredder, a nonferrous metals separator, plastics recovery and reclamation facilities, and industry laboratories will participate in the project. The difficulties encountered and information learned during this project will be used to advise manufacturers in their design for recycling efforts in future cars.

BMW will be cooperating in a pilot automobile recycling program with three U.S. recycling companies in California, Florida, and New York who are members of the Automotive Dismantlers and Recyclers Association (ADRA). They were chosen by meeting criteria that included outstanding adherence to the ADRA Code of Ethics and use of the ADRA Hazardous Waste Management Booklet as the basis for environmentally sound practices. Fluids will be drained and recycled and batteries will be removed and properly disposed of. If the car has air bags, they will be deployed per BMW specifications to eliminate the risk of sodium azide contamination. All economically salvagable components will be removed before the metal shell is shipped to an auto shredder. BMW will use a monetary incentive to encourage the return of old BMW cars for the project.

White Goods.—U.S. steelmakers have begun talks with scrap processors and home appliance designers to develop washing machines, refrigerators, freezers, and stoves that will result in more efficient disassembly and recycling. These discussions thus far have been bilateral rather than industrywide. Steelmakers are enthusiastic because they feel that their material has the advantages of significant recyclability and the potential for easy disassembly. Plastic materials hold the advantages of lower weight and component integration.

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[21]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

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TABLE 1
FIBER USE AT U.S. PAPER AND PAPERBOARD MILLS, BY WEIGHT AND PERCENT

Year	Weight (thousand metric tons)						Percent				
	Recovered paper	Wood residues	Total secondary	Primary fibers	Other fibers	Total fibers	Recovered paper	Wood residues	Total secondary	Primary fibers	Other fibers
1980	13,534	18,428	31,962	27,186	668	59,817	22.6	30.8	53.4	45.4	1.1
1985	14,848	19,485	34,334	28,865	268	63,466	23.4	30.7	54.1	45.5	.4
1987	16,956	21,045	38,001	31,700	290	69,990	24.2	30.1	54.3	45.3	.4
1989	18,340	20,420	38,760	33,995	288	73,043	25.1	28.0	53.1	46.5	.4
1991	21,461	18,891	40,352	35,983	170	76,505	28.1	24.7	52.7	47.0	.2
1992	23,762	19,678	44,257	37,012	187	80,640	29.5	24.4	53.9	45.9	.2

Source: American Forest and Paper Association.

TABLE 2
U.S. PAPER RECOVERY,[1] BY GRADE

(Thousand metric tons)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Corrugated	7,048	7,741	8,493	8,509	9,401	10,166	11,228	11,687	12,160	12,685	13,946
Old newspaper	3,094	3,153	3,423	3,506	3,889	4,075	4,313	4,890	7,277	6,037	6,477
Mixed paper	1,908	2,248	2,478	2,459	2,433	2,518	2,638	2,847	3,257	3,487	3,606
Pulp substitutes	2,208	2,426	2,693	2,463	2,856	3,052	3,250	2,697	2,830	3,218	3,433
High-grade deinking	1,232	1,433	1,534	1,556	1,848	1,915	2,316	2,438	2,680	2,885	3,009

[1]Recovery includes pre-consumer and post-consumer scrap recycled or exported.

Source: American Forest and Paper Association.

TABLE 3

POST-CONSUMER PLASTICS RECYCLED BY CALENDAR YEAR

(Thousand metric tons)

Plastic type/product type	Calendar year 1991			Calendar year 1992		
	Plastic recycled[1]	Virgin plastic sales[2]	Percent of sales recycled[3]	Plastic recycled[4]	Virgin plastic sales[2]	Percent of sales recycled[3]
PET:						
Soft drink bottles	128.6	366.0	35.1	173.0	425.9	40.6
Custom bottles	4.2	174.6	2.4	9.3	203.7	4.6
Other packaging	—	30.8	—	.1	35.8	.3
Total PET packaging	132.8	571.5	23.2	182.4	665.4	27.4
Nonpackaging[5]	27.4	197.8	13.9	26.5	210.5	12.6
Total PET	160.3	769.3	20.8	208.9	875.9	23.8
Soft drink bottles and base cups[6]	148.2	413.7	35.8	194.5	469.0	41.5
HDPE:						
Natural bottles	[7]60.2	430.9	14.0	105.1	448.1	23.5
Pigmented bottles	[8]41.9	618.2	6.8	57.3	662.2	8.7
Base cups	19.6	47.6	41.1	21.5	43.1	49.9
Other packaging[9]	4.0	627.8	.6	5.0	657.7	.8
Total HDPE packaging	125.7	1,724.6	7.3	189.0	1,811.2	10.4
Nonpackaging	10.1	2,038.9	.5	12.3	2,198.6	.6
Total HDPE	135.8	3,763.5	3.6	201.3	4,009.8	5.0
PVC:						
Bottles	.7	92.1	.8	1.6	86.6	1.8
Other packaging[10]	—	218.6	—	3.0	241.8	1.3
Total PVC packaging	.7	310.7	.2	4.6	328.4	1.4
Nonpackaging	2.7	3,114.8	.1	4.7	3,586.1	.1
Total PVC	3.4	3,425.5	.2	9.3	3,914.5	.2
LDPE/LLDPE:						
Bottles	([11])	27.7	.2	([11])	34.9	.1
Other packaging([12])	18.9	1,935.9	1.0	28.8	2,115.6	1.4
Total LDPE/LLDPE packaging	19.0	1,963.6	1.0	28.8	2,150.5	1.3
Nonpackaging	6.5	2,815.4	.2	5.5	2,969.7	.2
Total LDPE/LLDPE	25.5	4,779.0	.5	34.3	5,120.1	.7
PP:						
Bottles	.6	60.8	14.0	1.5	61.7	2.4
Other packaging[13]	1.8	530.7	.3	5.4	612.3	.9
Total PP packaging	2.4	591.5	.4	6.9	674.0	1.0
Vehicle battery casings	65.5	39.9	([14])	92.2	33.6	([14])
Other nonpackaging	.2	2,451.7	([11])	1.8	2,703.0	.1
Total PP	68.0	3,083.1	2.2	100.9	3,410.6	3.0
PS:						
Total PS packaging[15]	10.8	921.2	1.2	14.3	982.0	1.5
Nonpackaging	.2	1,160.7	([11])	2.6	1,238.8	.2
Total PS	11.0	2,082.0	.5	16.9	2,220.8	.8

See footnotes at end of table.

TABLE 3—Continued

POST-CONSUMER PLASTICS RECYCLED BY CALENDAR YEAR

(Thousand metric tons)

Plastic type/product type	Calendar year 1991			Calendar year 1992		
	Plastic recycled[1]	Virgin plastic sales[2]	Percent of sales recycled[3]	Plastic recycled[4]	Virgin plastic sales[2]	Percent of sales recycled[3]
Comingled:						
Rigids	([16])	([16])	([16])	3.1	([17])	([17])
Flexibles	([16])	([16])	([16])	.1	([17])	([17])
Total commingled	([16])	([16])	([16])	3.2	([17])	([17])
Other miscellaneous:						
Packaging	([16])	([16])	([16])	.3	([18])	([18])
Nonpackaging	[19]9.6	([17])	([17])	[20]7.5	([17])	([17])
Total bottles[21]	255.9	1,818.0	14.1	369.4	1,966.3	18.8
Total bottles and rigid containers	258.2	2,336.5	11.1	375.2	2,431.3	15.4
Total packaging	291.5	6,083.1	4.8	[22]429.5	6,611.6	6.5

[1]Based on results of a telephone survey of post-consumer plastic producers conducted from Feb. 1992 through Mar. 1992.

[2]Based on data provided by SPI's Committee on Resin Statistics Subcommittee on Recycling.

[3]Percentages shown are based on virgin sales and do not account for recycled resin used in the manufacturing of product types listed.

[4]Based on results of a telephone survey of post-consumer plastics processors and exporters conducted Feb. 1993 through Mar. 1993.

[5]Recycling consists primarily of X-ray film.

[6]Includes polyester bottles and polyethylene base cups.

[7]60% of HDPE reported in 1991 as mixed natural and pigmented bottles is included as natural bottles to reflect the ratio of material reported in segregated streams.

[8]40% of HDPE reported in 1991 as mixed natural and pigmented bottles is included as pigmented bottles to reflect the ratio of material reported in segregated streams.

[9]Includes tubs/containers, film packaging, and other miscellaneous packaging.

[10]Includes film and sheet packaging and other miscellaneous packaging.

[11]Less than 1/10 of a unit or percent.

[12]Includes shrink/stretch wrap, film packaging and other miscellaneous packaging.

[13]Includes tubs/containers, flexible packaging, and other miscellaneous packaging.

[14]Percent of sales recycled could not be calculated due to large quantities of recycled polypropylene used in the manufacturing of new batteries and imports of batteries that could not be estimated by SPI's Committee on Resin Statistics Special Subcommittee on Recycling.

[15]Includes rigid (nonfoam) packaging, rigid (foam) packaging, protective packaging, food service, and other miscellaneous packaging.

[16]New 1992 category not used in 1991.

[17]Sales data are reflected in segregated categories above.

[18]Sales data are reflected in segregated packaging categories above.

[19]Unclassified nonpackaging material consist of a mix of all above resin categories.

[20]1992 category consists of polycarbonate, ABS, nylon, plastics coded #7, and other miscellaneous nonpackaging.

[21]Total of bottles in all six resins categories and HDPE base cups.

[22]For the six resins above, the rigid commingled category, and the other miscellaneous packaging category only.

Source: R. W. Beck; American Plastics Council.

FIGURE 1
ANNUAL SOLID WASTE GENERATION IN THE UNITED STATES

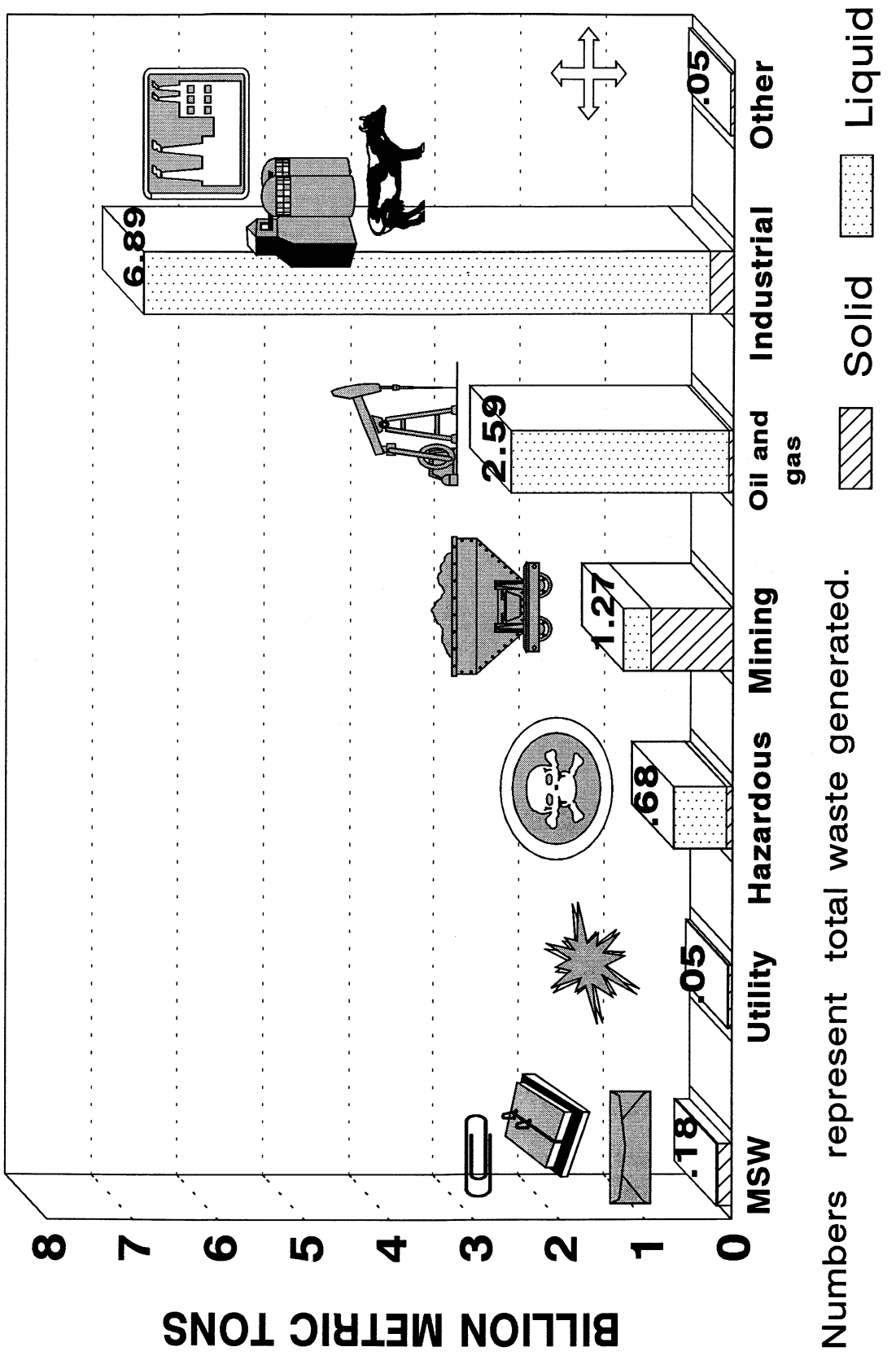
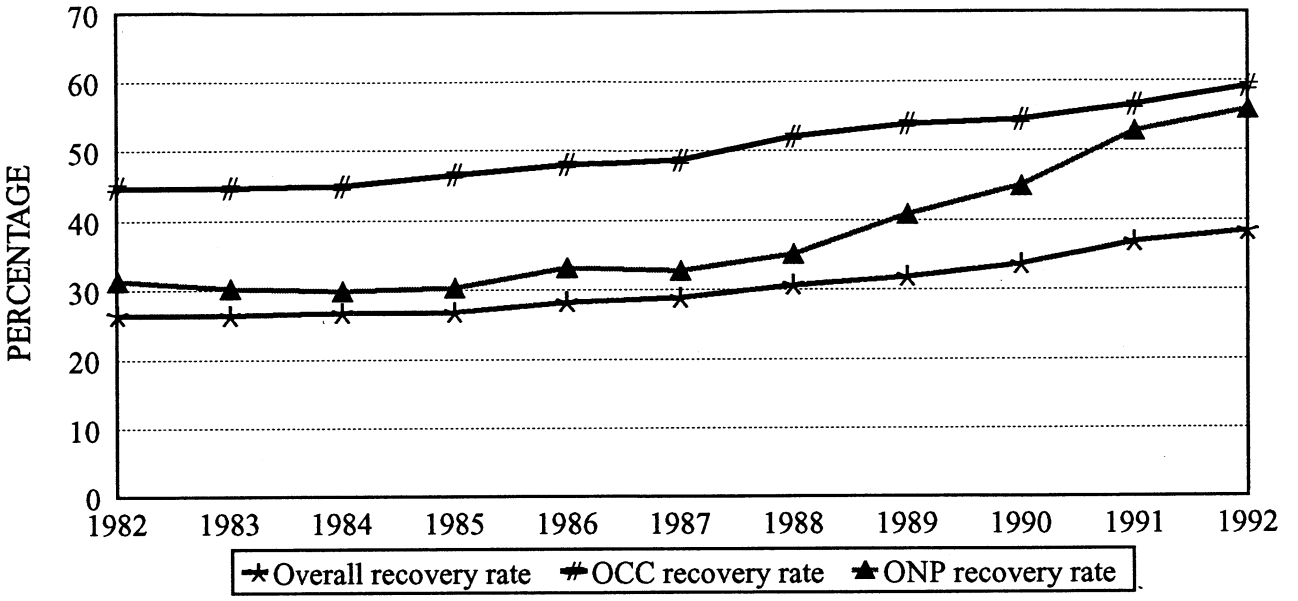


FIGURE 2

PAPER AND PAPERBOARD RECOVERY[1] [2]

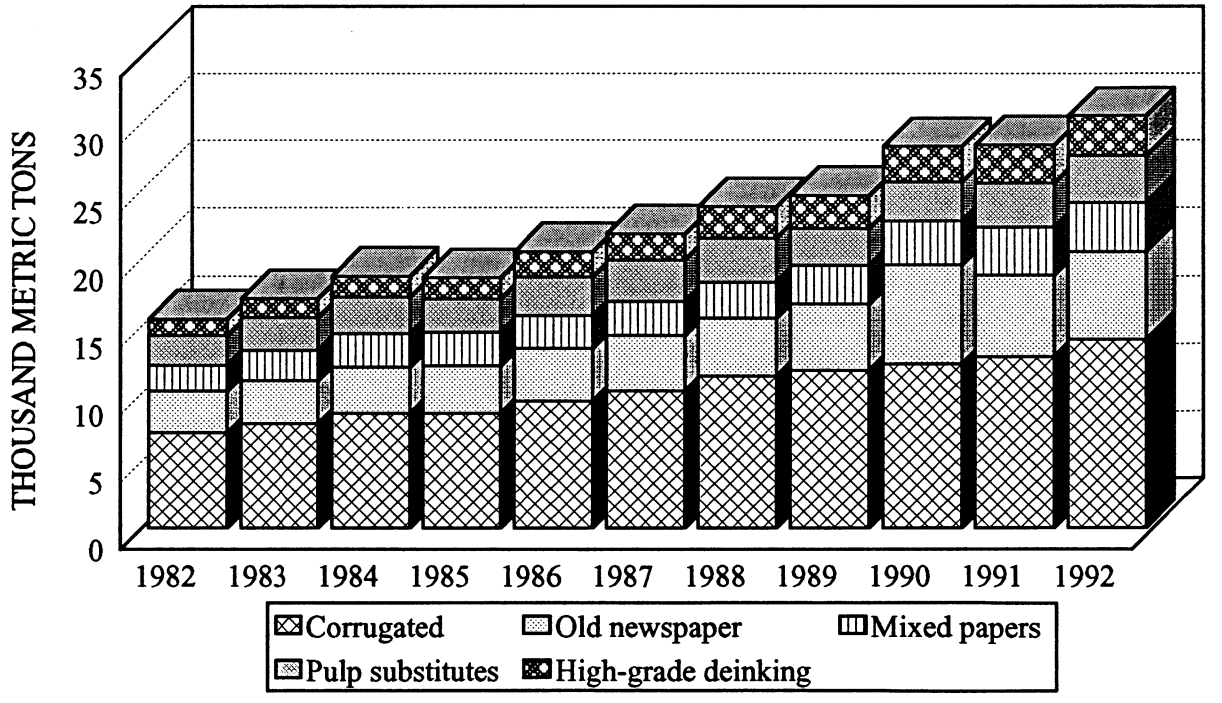


[1]Recovery rate is the ratio of recovered paper to new supply (apparent consumption) of paper.
[2]Recovery includes pre-consumer and post-conumer scrap recycled or exported.

Source: American Forest and Paper Association.

FIGURE 3

U.S. PAPER RECOVERY, BY GRADE[1]

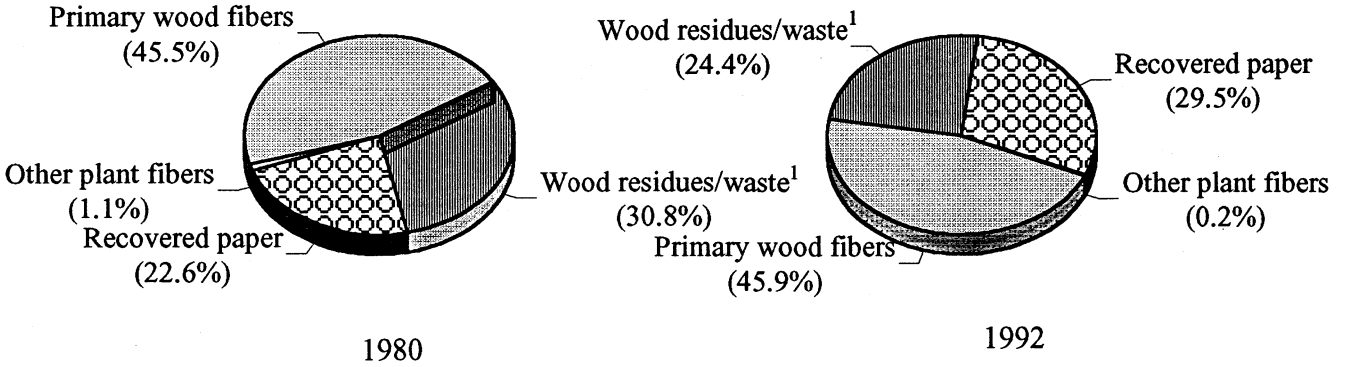


[1]Recovery includes pre-consumer and post-consumer scrap recycled or exported.

Source: American Forest and Paper Association.

FIGURE 4

FIBER USED AT U.S. PAPER AND BOARD MILLS, 1980 VS. 1992

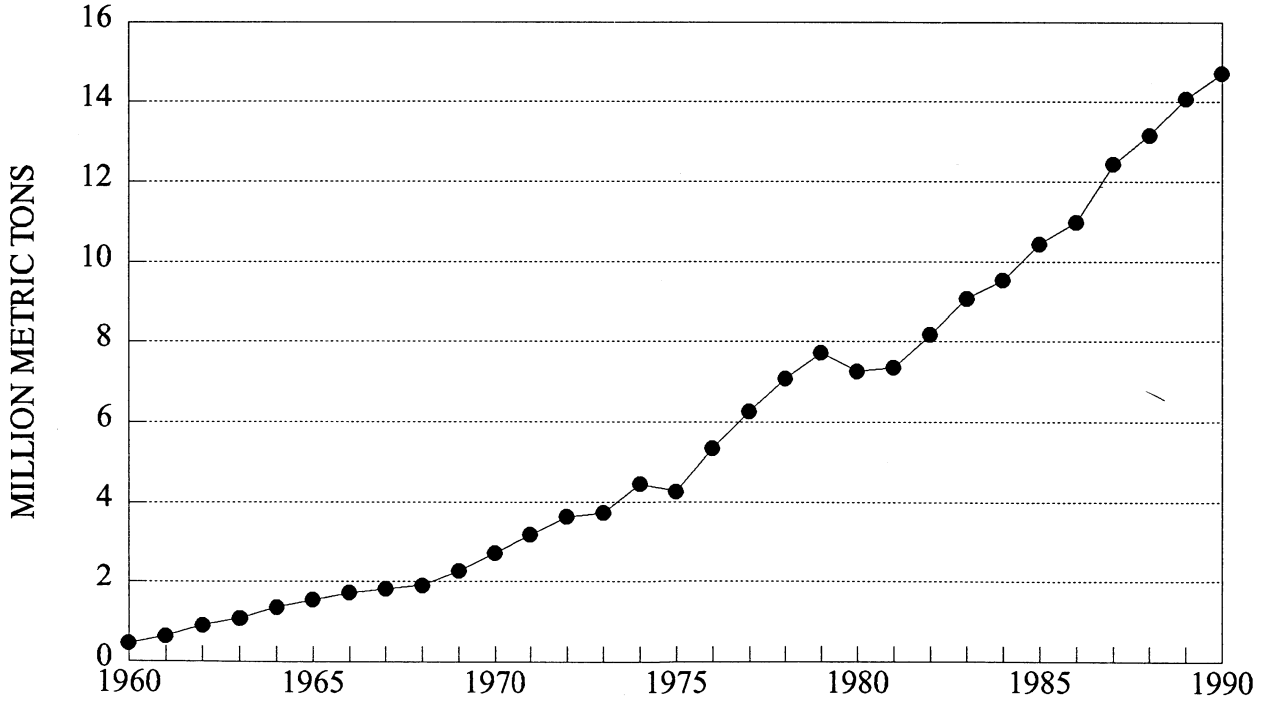


[1]Wood residues/waste denote mill residue such as slabs, edgings, trimmings, cores, planar shavings, sawdust or other similar residues and wastes.

Source: American Forest and Paper Association.

FIGURE 5

GENERATION OF PLASTIC IN MUNICIPAL SOLID WASTE



Source: EPA.

MICA

By Lawrence L. Davis

Mr. Davis, a physical scientist with 37 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.

In 1992, about 85,000 metric tons of scrap and flake mica was produced in the United States, a decrease of 17% from 1991 production. Ground mica sales were 84,000 tons valued at $22 million, an increase in tonnage of about 13%.

Almost all sheet mica supply continued to be imported. Consumption of muscovite block mica decreased 6% to 5.6 tons. Consumption of mica splittings decreased slightly to 836 tons. The value of sheet mica exports decreased 4% to $7.5 million. The value of imports for consumption of sheet mica increased 31% to $11.0 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, 17 operations, or 94%, responded, representing 95% of the production shown in table 1. Of the 17 operations to which the ground mica form was sent, 16 responded, representing 97% of the production in table 1. Of the five canvassed operations to which the mica block and film consumption form was sent, four, or 80%, responded, representing 96% 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 about 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 6.45 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 4.84 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 6.45 usable square centimeters) to grade OOEE special (with 645 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 former 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 Russia, 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 Russia.

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, although not of sheet quality, are suitable for grinding.

ANNUAL REVIEW

Legislation and Government Programs

The Government inventory of stockpile-grade mica decreased slightly to 9,700 tons. The U.S. Department of Defense sold 157 tons of muscovite block, stained and better; 11 tons of muscovite film; 71 tons of muscovite splittings; and 25 tons of phlogopite splittings. *(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 United States competes with the rest of the world for Indian 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.—Mica was mined by 9 companies with 12 mines in 5 States. Four mines that reported production in 1991 were idle during 1992. North Carolina remained the major producing State, with 60% of the total production. The remainder was produced in Georgia, New Mexico, 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; Franklin Mineral Products Co., Hartwell, GA; KMG Minerals Inc., Kings Mountain, NC; Lithium Corp. of America, Gastonia, NC; and MICA, Fairview, NM. These five companies produced 69% of the national total.

Low-quality sericite, used primarily in brick manufacturing, is excluded from tabulated data contained in this report. In 1992, three companies, one in North Carolina and two in South Carolina, mined low-quality sericite and reported an average value of $5.52 per ton.

Ground Mica.—Ten companies operated 13 grinding plants in 6 States. Nine plants produced dry-ground and four produced wet-ground mica. The five largest producers accounted for 73% of the total. They were, in alphabetical order, KMG Minerals, Kings Mountain, NC; MICA, Fairview, NM; Spartan Minerals Corp., Pacolet, SC; Unimin Corp., Spruce Pine, NC; and USG Corp., Spruce Pine, NC. *(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 also is 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 5.6 tons, a 6% decrease from that of 1991. Stained and lower-than-stained quality remained in greatest demand accounting for 90% 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 decreased slightly to 836 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 also is 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 slightly from that of 1991. Segment plates and molding plates were the major end products, accounting, respectively, for 31% and 25% 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 1992 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 1992, the major end uses were joint cement, 51%; paints, 19%; plastics, 4%; and well-drilling muds, 3%. *(See table 4.)*

Stocks

Reported yearend consumer stocks of sheet mica decreased 27% to 469 tons; of this, mica splittings represented 91%, and mica block and film represented 9%.

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 1992 compared with 1991 were as follows: Block decreased 8% to $80 per kilogram, and splittings decreased slightly to $1.53 per kilogram. The average value of phlogopite block remained at $26 per kilogram, while the value of phlogopite splittings remained about the same at $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 $58.

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 2,100 tons, 50% more than in 1991. Worked mica imports were about 1,400 tons, 56% more than in 1991. About 11,600 tons of ground mica was imported mostly from Canada, while about 4,000 tons was exported to 27 countries. The combined value of all mica imports increased 33% to $19.5 million, while the combined value of all mica exports decreased 1% to $9.7 million. *(See tables 8, 9, 10, 11, 12, and 13.)*

World Review

World production of mica decreased 12% to 186,000 tons. The United States continued to lead in the production of flake mica. India continued to lead in the production of sheet mica. *(See table 14.)*

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 increased construction activity in 1992, ground mica consumption increased about 12%. In the near future, modest increases in construction activity are expected to continue, 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 about one-half of the market. Consumption for other uses—in paints, well-drilling muds, and plastics—is expected to increase slightly by 1995.

[1]American 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: V. 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.

[2]Skow, M. L. Mica—A Materials Survey. BuMines IC 8125, 1962, 240 pp.

[3]Production of high-quality sericite is included in the totals; however, figures for low-quality sericite, used principally for brick manufacturing, are not included.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

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Industrial Minerals (London).
Industrial Minerals and Rocks, 5th ed., AIME, 1983.
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The Economics of Mica 1989, Roskill Information Services Ltd.
The Mica Industry Association.

TABLE 1
SALIENT MICA STATISTICS

		1988	1989	1990	1991	1992
United States:						
Production (sold or used by producers):						
Scrap and flake mica	thousand metric tons	130	119	109	103	85
Value	thousands	$6,793	$6,273	$5,811	$5,542	$4,638
Ground mica	thousand metric tons	109	101	97	75	84
Value	thousands	$23,687	$22,443	$21,610	$17,286	$21,755
Consumption:						
Block, muscovite	metric tons	14	7	6	6	6
Value	thousands	$628	$599	$554	$502	$447
Splittings	metric tons	1,104	1,108	842	854	836
Value	thousands	$1,544	$1,703	$1,414	$1,427	$1,388
Exports	metric tons	7,168	5,327	5,659	4,901	5,035
Imports	do.	14,478	15,834	1,587	15,695	18,815
World: Production	do.	r251,269	r229,459	r215,242	r210,488	e186,046

eEstimated. rRevised.

TABLE 2
STOCKPILE GOALS AND GOVERNMENT INVENTORIES FOR MICA, DECEMBER 31, 1992

(Metric tons)

Material	Inventory		Available for disposal	1992 sales
	Stockpile grade	Non-stockpile grade		
Block:				
Muscovite, stained and better	2,114	89	1,220	157
Phlogopite	8	52	—	—
Film: Muscovite, 1st and 2d qualities	523	(1)	442	11
Splittings:				
Muscovite	6,431	—	743	71
Phlogopite	649	—	649	25

[1]Less than 1/2 unit.

TABLE 3

SCRAP AND FLAKE MICA[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	Quantity	Value
1988	130	6,793
1989	r119	6,273
1990	109	5,841
1991	103	5,542
1992:		
North Carolina	51	2,967
Other States[2]	34	1,671
Total	85	4,638

rRevised.

[1]Includes finely divided mica recovered from mica schist and high-quality sericite schist, and mica that is a byproduct of feldspar, kaolin, and lithium beneficiation.

[2]Includes Georgia, New Mexico, South Carolina, and South Dakota.

TABLE 4

GROUND MICA SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY END USE AND METHOD OF GRINDING[1]

(Thousand metric tons and thousand dollars)

	1991			1992		
	Quantity	Value	Unit value[2]	Quantity	Value	Unit value[2]
End use:						
Joint cement	39	6,173	$157	43	6,819	$157
Paint	15	4,428	294	16	5,227	323
Plastics	1	560	423	4	1,347	357
Well-drilling mud	4	484	123	2	281	123
Other[3]	15	5,642	371	19	8,082	432
Total[4]	75	17,286	231	84	21,755	258
Method of grinding:						
Dry	W	W	150	W	W	168
Wet	W	W	640	W	W	745

W Withheld to avoid disclosing company proprietary data.

[1]Domestic and some imported scrap. Low-quality sericite is not included.

[2]Based on unrounded dollars and metric tons.

[3]Includes mica used for molded electrical insulation, roofing, rubber, textile and decorative coatings, welding rods, and miscellaneous.

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

TABLE 5

FABRICATION OF MUSCOVITE BLOCK MICA IN THE UNITED STATES, BY QUALITY

(Kilograms)

Quality	1991	1992
Good stained or better	835	563
Stained or lower[1]	5,088	5,013
Total	[2]5,922	5,576

[1]Includes punch mica.

[2]Data do not add to total shown because of independent rounding.

TABLE 6
CONSUMPTION AND STOCKS OF MICA SPLITTINGS IN THE UNITED STATES

Year	Consumption		Stocks on Dec. 31 (metric tons)
	Quantity (metric tons)	Value (thousands)	
1988	1,104	$1,544	444
1989	1,108	1,703	505
1990	842	1,414	632
1991	854	1,427	612
1992	836	1,388	427

TABLE 7
BUILT-UP MICA[1] SOLD OR USED IN THE UNITED STATES, BY PRODUCT

Product	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Flexible (cold)	105	$685	163	$794
Heater plate	W	W	W	W
Molding plate	305	1,708	211	1,516
Segment plate	281	1,893	262	1,729
Tape	W	W	W	W
Other	148	r1,737	216	2,036
Total	839	[2]6,022	852	6,075

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Other."
[1]Consists of alternating layers of binder and irregularly arranged and partly overlapped splittings.
[2]Data do not add to total shown because of independent rounding.

TABLE 8

U.S. EXPORTS OF CRUDE AND RIFTED MICA, MICA POWDER, AND MICA WASTE IN 1992, 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)
Argentina	20	$7	—	—	—	—	—	—
Australia	—	—	—	—	20	$17	—	—
Barbados	—	—	—	—	23	47	—	—
Bermuda	17	6	—	—	—	—	—	—
Brazil	—	—	—	—	68	57	—	—
Canada	10	5	—	—	1,411	528	79	$15
Chile	—	—	—	—	13	10	—	—
Colombia	—	—	7	$15	89	48	36	8
Dominican Republic	—	—	—	—	19	11	—	—
France	—	—	—	—	286	256	—	—
Germany	21	7	—	—	296	100	—	—
Hong Kong	—	—	—	—	2	7	2	4
India	—	—	10	47	—	—	—	—
Indonesia	—	—	—	—	8	5	—	—
Ireland	—	—	—	—	16	3	—	—
Israel	—	—	—	—	14	9	—	—
Italy	—	—	—	—	131	31	—	—
Jamaica	—	—	—	—	9	9	—	—
Japan	178	58	104	147	362	181	20	62
Korea, Republic of	35	12	27	57	298	215	—	—
Malaysia	—	—	—	—	14	11	—	—
Mexico	20	3	1	21	354	164	5	9
Netherlands	—	—	—	—	316	177	—	—
New Zealand	32	8	—	—	—	—	—	—
Pakistan	—	—	—	—	5	4	—	—
Peru	—	—	(1)	3	—	—	—	—
Philippines	—	—	—	—	20	15	—	—
Saudi Arabia	—	—	—	—	34	17	—	—
Sweden	—	—	19	15	—	—	—	—
Switzerland	—	—	—	—	4	3	—	—
Taiwan	—	—	—	—	40	29	—	—
United Kingdom	—	—	—	—	61	70	—	—
Uruguay	—	—	2	3	—	—	—	—
Venezuela	—	—	—	—	44	31	—	—
Total[2]	332	107	170	307	3,954	2,054	142	97

[1]Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 9

U.S. EXPORTS OF WORKED MICA IN 1992, BY COUNTRY

Country	Plates, sheets		Other	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	(1)	$4	—	—
Australia	3	69	—	—
Austria	1	21	—	—
Bahamas, The	12	16	9	$44
Belgium	18	505	—	—
Brazil	50	668	3	97
Canada	103	2,162	30	779
Chile	1	5	—	—
China	—	—	(1)	7
Colombia	—	—	9	96
Egypt	5	141	—	—
France	4	47	1	30
Germany	2	42	9	48
Guatemala	1	8	—	—
Honduras	—	—	1	3
Hong Kong	—	—	(1)	4
Hungary	1	13	—	—
India	(1)	8	(1)	4
Indonesia	—	—	3	8
Ireland	4	5	—	—
Israel	—	—	1	13
Italy	18	373	—	—
Japan	19	487	2	21
Korea, Republic of	1	24	1	72
Kuwait	—	—	1	14
Martinique	3	26	—	—
Mexico	21	365	7	98
Netherlands	2	9	1	29
Netherlands Antilles	(1)	7	4	7
New Zealand	34	112	—	—
Panama	3	69	—	—
Saudi Arabia	(1)	4	(1)	6
Singapore	3	101	—	—
South Africa, Republic of	(1)	8	1	3
Suriname	12	33	3	28
Sweden	(1)	4	—	—
Taiwan	2	26	22	296
Thailand	—	—	(1)	3
Trinidad and Tobago	2	14	—	—
Turks and Caicos Islands	—	—	1	3
United Arab Emirates	—	—	(1)	5
United Kingdom	1	35	1	37
Venezuela	(1)	8	—	—
Total[2]	326	5,422	110	1,758

[1]Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND RIFTED MICA IN 1992, BY COUNTRY

Country	Split block		Splittings		Other			
					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)
Brazil	—	—	—	—	120	$42	—	—
Canada	—	—	—	—	65	4	—	—
China	—	—	14	$39	—	—	115	$270
France	1	$26	—	—	—	—	—	—
Germany	—	—	—	—	—	—	12	32
India	272	265	1,572	994	2,622	550	4	43
Japan	—	—	—	—	—	—	48	271
Madagascar	—	—	15	64	—	—	—	—
Russia[1]	—	—	—	—	53	29	—	—
United Kingdom	—	—	(2)	7	—	—	—	—
Total[3]	273	291	1,601	1,104	2,860	626	180	616

[1]Formerly part of the U.S.S.R.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF MICA POWDER AND WASTE IN 1992, BY COUNTRY

Country	Powder		Waste	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	8	$4	—	—
Austria	10	6	—	—
Canada	11,029	5,086	277	$20
France	34	57	—	—
Germany	61	264	—	—
India	64	9	648	324
Japan	168	1,899	—	—
Mexico	—	—	2	4
Norway	189	150	—	—
United Kingdom	5	3	—	—
Total[1]	11,568	7,479	926	348

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

Source: Bureau of the Census.

TABLE 12
U.S. IMPORTS FOR CONSUMPTION OF WORKED MICA IN 1992, BY COUNTRY

Country	Plates, sheets		Other	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	—	—	173	$462
Austria	(1)	$5	4	77
Belgium	655	4,870	—	—
Brazil	55	227	38	185
Canada	1	23	(1)	3
China	57	140	(1)	2
Denmark	—	—	(1)	5
France	16	112	9	63
Germany	—	—	13	204
India	32	338	208	806
Indonesia	(1)	2	—	—
Japan	7	76	39	399
Korea, Republic of	15	87	16	29
Portugal	10	27	—	—
Switzerland	44	792	—	—
Taiwan	—	—	(1)	8
United Kingdom	12	29	3	42
Total[2]	903	6,728	504	2,283

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13
SUMMATION OF U.S. MICA TRADE DATA

	Scrap and flake mica				Sheet mica			
	Powder		Waste		Unworked		Worked	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Exports:								
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
1992	3,954	2,054	475	204	170	307	436	7,180
Imports for consumption:								
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
1992	11,568	7,479	3,786	974	2,054	2,011	1,407	9,011

NA Not available.

Source: Bureau of the Census.

TABLE 14
MICA: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992e
Argentina:					
Sheet	330	327	e400	350	340
Waste, scrap, etc.	630	e500	e500	r450	450
Brazil	2,520	3,700	r5,000	r5,080	5,000
Canada e	12,000	12,000	r16,000	r17,000	17,500
France e	9,000	8,000	7,000	6,000	5,000
India:					
Crude	3,839	4,186	3,860	r3,607	3,500
Scrap and waste	3,694	3,121	2,822	r1,922	2,000
Total	7,533	7,307	6,682	r5,529	5,500
Iran[3]	r1,167	2,294	1,352	r4,135	4,000
Korea, Republic of (all grades)	18,848	7,888	4,765	r5,127	5,000
Madagascar (phlogopite)	618	1,068	721	r680	680
Mexico (all grades)	6,228	4,510	5,863	7,222	7,200
Morocco e	1,500	1,500	1,500	1,500	1,500
Mozambique e	(4)	—	—	—	—
Peru e	5 93	100	100	100	100
Russia[6 7]	—	—	—	—	35,000
Serbia and Montenegro[8 9]	—	—	—	—	600
South Africa, Republic of (scrap)	1,669	1,708	1,765	1,883	5 2,088
Spain e	300	350	300	300	250
Sri Lanka	1,981	2,510	e2,400	e2,400	2,000
Taiwan	4,387	4,290	r4,946	r8,596	8,000
Tanzania (sheet)	(4)	(4)	(4)	(4)	(4)
U.S.S.R. (all grades) e [7 10]	50,000	50,000	45,000	40,000	—
United States (scrap and flake)[11]	129,900	119,142	108,845	102,830	5 85,338
Yugoslavia[9 12]	768	794	802	e800	—
Zimbabwe	1,797	1,471	r1,301	r506	500
Total	r251,269	229,459	r215,242	r210,488	186,046

eEstimated. rRevised.

[1]Table includes data available through June 14, 1993.

[2]In 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.

[3]Data are for year beginning March 21 of that stated.

[4]Less than 1/2 unit.

[5]Reported figure.

[6]Formerly part of the U.S.S.R.

[7]All production in the U.S.S.R. from 1988-91 came from Russia.

[8]Formerly part of Yugoslavia.

[9]All production in Yugoslavia from 1988-91 came from Serbia and Montenegro.

[10]Dissolved in Dec. 1991.

[11]Excludes U.S. production of low-quality sericite and sheet mica, if any.

[12]Dissolved in Apr. 1992.

MOLYBDENUM

By John W. Blossom

Mr. Blossom, a physical scientist/engineer with 45 years of industry and Government experience, has been the commodity specialist for molybdenum since 1982. Survey and trade data were prepared by Sherwood C. Jordan, statistical 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 112,000 metric tons (molybdenum contained in concentrate) in 1992, of which Canada, Chile, China, and the United States provided 80%. An estimated 13% of world output came from the former 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 12 operations to which surveys were sent, all responded, representing 100% of the total United States 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 Mossiam, a French chemist, succeeded in producing a 99.98%-pure metal by reduction of molybdenum in an electric furnace. Mossiam 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, primary 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 also has 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 former 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 former 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. Two types of deposits, primary and byproduct porphyry copper provided the U.S. and world output of molybdenite. 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 former 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 reflotation. 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). A small amount of 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 the 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 a manner as 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 did not change in 1992. Domestic stock levels increased 26%. U.S. mine output of molybdenum was about 45% of world production. Reported end-use consumption of molybdenum in raw materials remained about the same as that of the previous year. Exports of all forms of molybdenum from the United States decreased, while imports of molybdenum increased. Domestic producer stocks of molybdenum products decreased about 21% from that of the previous year. Domestic mine production of molybdenum concentrate decreased to a total of 50,000 tons of contained molybdenum compared with 53,000 tons in 1991. World mine production of molybdenum concentrate also decreased from a total of 118,000 tons in 1991 to 112,000 tons in 1992. Canada, Chile, China, the former U.S.S.R., and the United States accounted for more than 93% of the molybdenum produced worldwide. *(See tables 1, 2, and 3.)*

Consumption and Uses

Consumption of molybdenum concentrate decreased 5,500 tons in 1992. Domestic mine production of molybdenum concentrate was either roasted,

exported for conversion, or purified to lubrication-grade molybdenum disulfide. The consumption in 1992 of technical-grade molybdic oxide remained about the same as 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 21,000 tons of molybdenum. *(See table 4.)*

Stocks

Total industry stocks, which include those of producers and consumers, increased about 4,600 tons of contained molybdenum. Inventories of molybdenum in concentrate at producer locations increased about 6,600 tons. Producer stocks of molybdenum in consumer products, such as oxide, ferromolybdenum, molybdate, metal powders, and other types, decreased about 2,000 tons. Compared with apparent consumption, year-end producer stocks of these materials represented about a 12-month supply. Domestic consumer inventories of about 2,500 tons, the same amount as at year-end 1991, represented approximately a 2-month supply as measured by average monthly reported consumption. *(See table 5.)*

Prices

The average 1992 "Metals Week Dealer" (MWD) price of concentrate (per kilogram of contained molybdenum) was $4.851. The average MWD price of oxide was $4.851 and the average MWD price of ferromolybdenum was $6.937.

Foreign Trade

Exports of molybdenum in concentrate and of oxide remained about the same when compared with those of 1991. Molybdenum concentrate exports were about 67% of domestic mine production. Approximately 95% of reported shipments of concentrate and oxides were made to Belgium, Chile, France, Germany, Japan, the Netherlands, Sweden, and the United Kingdom. The calculated molybdenum content of all exports was about 35,000 tons in 1992. Total value of exports increased from $154 million in 1991 to $165 million in 1992.

Approximately 3,000 tons of molybdenum in various forms was imported into the United States, about 400 tons more than in 1991. Total value of all forms of molybdenum imported increased from $26 million in 1991 to $27 million in 1992. In terms of both value and quantity, the major form imported was ferromolybdenum. *(See tables 6, 7, 8, and 9.)*

World Review

Capacity.—The rated capacity for mines and mills as of December 31, 1992, was 150,000 tons per year of contained metal. 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.

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 10. 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 former 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.

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 1993. Short-term molybdenum demand is expected to remain a little below that of 1992. Molybdenum production must be adjusted to

reduce inventories that have been built up during 1992. The long-term demand depends on 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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The Northern Miner (Canada).

TABLE 1
SALIENT MOLYBDENUM STATISTICS

(Metric tons of contained molybdenum unless otherwise specified)

		1988	1989	1990	1991	1992
United States:						
Concentrate:						
Production		43,051	63,105	61,611	53,364	49,725
Shipments		45,240	61,733	61,580	53,607	45,098
Value	thousands	$266,899	$421,427	$346,262	$249,909	$189,895
Reported consumption		35,690	41,877	35,455	32,998	e27,500
Imports for consumption		514	238	478	161	831
Stocks, Dec. 31: Mine and plant		r4,777	6,969	7,672	r5,291	11,905
Primary products:						
Production		25,646	27,985	28,764	33,714	26,009
Shipments		20,535	18,277	17,983	19,105	17,305
Stocks, Dec. 31		7,116	6,675	r5,918	r9,421	7,479
Reported consumption, by end use		17,422	17,204	18,060	r16,901	17,068
World: Mine production		r112,860	r135,799	r128,402	r117,732	e111,667

eEstimated. rRevised.

TABLE 2

PRODUCTION, SHIPMENTS, AND STOCKS OF MOLYBDENUM PRODUCTS IN THE UNITED STATES

(Metric tons of contained molybdenum)

	1991	1992	1991	1992	1991	1992
	Metal powder		Other[1]		Total[2]	
Received from other producers	216	233	r3,521	2,953	r3,737	3,186
Gross production during year	2,305	2,355	31,409	23,653	33,714	26,009
Used to make other products listed here	262	391	r12,670	11,738	r12,932	12,129
Net production	2,043	1,964	r18,739	11,916	r20,782	13,882
Shipments	493	572	18,612	16,734	19,105	17,305
Producer stocks, Dec. 31	r138	143	r9,283	7,336	r9,421	7,479

rRevised.

[1]Includes ferromolybdenum, molybdic oxides, phosphomolybdic acid, molybdenum disulfide, molybdic acid, ammonium molybdate, calcium molybdate, sodium molybdate, molybdenum metal, pellets, molybdenum pentachloride, molybdenum hexacarbonyl.

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

TABLE 3

MOLYBDENUM: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons of contained molybdenum)

Country[2]	1988	1989	1990	1991	1992e
Bulgaria e	200	190	180	160	160
Canada	13,535	13,543	12,188	r11,329	9,540
Chile	15,515	16,550	13,830	r14,434	14,500
China e	14,400	15,700	15,700	16,000	16,000
Iran e	700	750	500	r400	600
Korea, Republic of	144	132	103	r144	140
Mexico	4,456	4,189	e3,200	r1,716	31,582
Mongolia e	1,400	1,450	r1,670	r1,130	1,410
Niger e	15	13	10	10	10
Peru	2,444	3,177	2,410	r3,045	3,000
U.S.S.R. e 4	r17,000	r17,000	r17,000	r16,000	15,000
United States	43,051	63,105	61,611	53,364	349,725
Total	r112,860	r135,799	r128,402	r117,732	111,667

eEstimated. rRevised.

[1]Table includes data available through June 18, 1993.

[2]In 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.

[3]Reported figure.

[4]Dissolved in Dec. 1991. This commodity is believed to be produced in Armenia, Georgia, Kazakhstan, Russia, Tajikistan, and Uzbekistan; however, information is inadequate to formulate reliable estimates of individual country production.

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]
1991					
Steel:					
Carbon	5,098	1,208	—	344	6,649
Stainless and heat resisting	30,746	2,230	—	657	33,632
Full alloy	r28,675	r8,984	—	198	r37,857
High-strength low-alloy	3,877	3,371	—	—	7,248
Tool	3,402	1,681	—	179	5,262
Cast irons	726	r5,594	—	132	r6,452
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	r3,811	r3,811
Miscellaneous and unspecified	1,965	r602	1,552	248	r4,367
Total[3]	r91,278	r24,949	10,576	r42,208	r169,011
1992					
Steel:					
Carbon	6,930	1,196	—	357	8,483
Stainless and heat resisting	31,029	2,091	—	684	33,804
Full alloy	23,361	9,633	—	58	33,052
High-strength low-alloy	4,040	3,675	—	—	7,715
Tool	6,979	2,801	—	184	9,964
Cast irons	866	6,347	—	132	7,345
Superalloys	W	523	—	8,211	8,734
Alloys:					
Welding materials (structural and hard-facing)	—	836	—	38	874
Other alloys[4]	W	W	—	507	507
Mill products made from metal powder	—	—	—	24,578	24,578
Chemical and ceramic uses:					
Pigments	18	—	W	—	18
Catalysts	9,459	—	W	1,793	11,252
Other	W	W	W	2,715	2,715
Miscellaneous and unspecified	8,769	871	10,812	1,183	21,635
Total[3]	91,450	27,972	10,812	40,441	170,675

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Miscellaneous and unspecified."

[1]Includes calcium molybdate.

[2]Includes purified molybdenum disulfide, molydenite concentrate added directly to steel, molybdenum metal powder, molybdenum metal, pellets and other molybdenum materials.

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

[4]Includes magnetic and nonferrous alloys.

TABLE 5

INDUSTRY STOCKS OF MOLYBDENUM MATERIALS, DECEMBER 31

(Metric tons of contained molybdenum)

	1988	1989	1990	1991	1992
Concentrate: Mine and plant	r4,777	6,969	7,672	r5,291	11,905
Producers:					
Molybdic oxides[1]	4,816	W	W	W	W
Metal powder	136	124	254	r138	143
Other[2]	2,164	6,551	r5,664	r9,283	7,336
Total	7,116	6,675	r5,918	r9,421	7,479
Consumers:					
Molybdic oxides[1]	r1,577	r1,624	r1,559	r1,570	1,487
Ferromolybdenum[3]	260	235	219	r220	195
Ammonium and sodium molybdate	r24	19	24	28	24
Other[5]	752	703	786	771	791
Total	r2,613	r2,581	r2,588	r2,589	2,497
Grand total[5]	r14,506	r16,225	r16,179	r17,302	21,881

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

[1]Includes technical and purified molybdic oxide and briquets.

[2]Includes ferromolybdenum, phosphomolybdic acid, molybdenum disulfide, molybdic acid, ammonium molybdate, sodium molybdate, calcium molybdate, molybdenum metal, pellets, molybdenum pentachloride, and molybdenum hexacarbonyl.

[3]Includes calcium molybdate.

[4]Includes purified molybdenum disulfide, molybdenite concentrate added directly to steel, molybdenum metal powder, molybdenum metal, pellets, and other molybdenum materials.

[5]Data may not add to totals shown because of independent rounding.

TABLE 6

U.S. EXPORTS OF MOLYBDENUM ORE AND CONCENTRATES (INCLUDING ROASTED AND OTHER CONCENTRATES), BY COUNTRY

(Metric tons)

Country	1991		1992	
	Quantity (contained molybdenum)	Value (thousands)	Quantity (contained molybdenum)	Value (thousands)
Australia	206	$893	197	$43
Belgium	6,467	23,513	6,188	23,563
Brazil	255	713	242	892
Canada	210	1,385	430	948
Chile	1,235	2,774	2,457	6,840
China	323	1,010	1	33
France	1,757	5,346	1,188	5,110
Germany	2,372	8,014	722	1,956
India	80	298	49	204
Japan	5,479	21,349	4,438	13,299
Korea, Republic of	256	749	—	—
Mexico	37	203	61	126
Netherlands	7,694	31,497	13,722	48,895
Sweden	202	876	2,252	9,285
United Kingdom	6,734	13,707	1,435	5,937
Other	117	r1,386	57	8,274
Total[1]	33,424	r113,714	33,438	125,405

rRevised.

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

Source: Bureau of the Census.

TABLE 7

U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

(Metric tons)

Product and country	HTS No.	1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
Oxides and hydroxides, gross weight:	2825.70.0000				
Australia		9	$55	—	—
Austria		451	3,285	—	—
Belgium		83	334	6	$34
Canada		212	1,286	249	1,378
Japan		358	2,181	186	1,102
Korea, Republic of		23	127	10	34
Mexico		1	35	—	—
Netherlands		171	1,138	33	129
United Kingdom		172	841	—	—
Other		r89	r395	71	212
Total[1]		1,571	9,678	556	2,889
Molybdates—all, contained weight:	2841.70.0000				
Canada		342	1,901	531	2,497
Japan		r274	1,446	279	1,321
Korea, Republic of		r19	r106	60	342
Mexico		r29	85	75	346
Taiwan		35	175	23	95
Other		r41	252	62	376
Total[1]		740	3,965	1,030	4,976
Ferromolybdenum, contained weight:[2]	7202.70.0000				
Canada		r49	579	85	954
Japan		r143	r2,096	101	1,937
Malaysia		r7	r97	65	951
Mexico		r5	50	20	156
Singapore		r3	r31	3	30
Venezuela		r12	r117	19	176
Other		r6	r88	27	200
Total[1]		r225	3,058	319	4,403
Powder, gross weight:	8102.10.0000				
Belgium		1	69	1	39
Brazil		4	107	4	162
Canada		5	147	4	110
France		13	359	14	203
Germany		3	142	18	331
India		10	158	23	364
Italy		2	65	2	48
Japan		54	1,687	28	1,068
Mexico		7	110	6	133
Netherlands		12	161	137	1,041
Sweden		32	374	10	150
Taiwan		49	947	88	1,663

See footnotes at end of table.

TABLE 7—Continued

U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

(Metric tons)

Product and country	HTS No.	1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
Powder, gross weight—Continued:	8102.10.0000				
United Kingdom		14	$364	10	246
Other		r25	r217	8	253
Total[1]		230	4,907	350	5,811
Molybdenum unwrought, gross weight:	8102.91.0000				
Canada		30	r496	3	67
France		(2)	9	3	67
India		1	4	4	55
Japan		r32	r357	21	224
Mexico		1	r27	—	—
Netherlands		18	259	41	188
United Kingdom		—	—	(2)	4
Other		r7	52	2	36
Total[1]		88	1,204	74	640
Molybdenum wrought, gross weight:	8102.92.0000				
Australia		4	22	(2)	22
Austria		—	—	(2)	3
Brazil		1	r53	(2)	6
Canada		4	r210	7	293
France		11	r588	24	1,170
Germany		r21	r1,080	10	677
Japan		r32	r1,828	39	1,379
Korea, Republic of		r2	r70	2	58
Mexico		2	78	1	36
Netherlands		r6	453	4	295
Singapore		(2)	r37	(2)	3
South Africa, Republic of		(2)	9	—	—
Sweden		1	60	1	30
United Kingdom		18	r763	44	1,414
Other		r10	r320	12	388
Total[1]		110	5,570	144	5,772
Wire, gross weight:	8102.93.0000				
Argentina		r2	r68	1	37
Belgium		47	1,637	62	1,865
Brazil		19	r760	30	1,004
Canada		6	r259	10	335
France		21	748	23	1,025
Germany		r92	r2,271	90	2,408
India		r15	593	22	956
Italy		r20	693	13	489
Japan		r49	r1,799	40	1,576
Korea, Republic of		17	r851	18	846
Mexico		r12	r473	12	432

See footnotes at end of table.

TABLE 7—Continued

U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

(Metric tons)

Product and country	HTS No.	1991		1992	
		Quantity	Value (thousands)	Quantity	Value (thousands)
Wire, gross weight—Continued:	8102.93.0000				
Singapore		r2	$79	(3)	$3
South Africa, Republic of		r12	164	2	74
Spain		10	296	5	163
Sweden		14	423	5	217
Taiwan		r9	392	5	214
United Kingdom		4	240	2	132
Other		r10	r310	16	3,197
Total[1]		360	r12,057	355	14,972

rRevised.
[1]Data may not add to totals shown because of independent rounding.
[2]Ferromolybdenum contains about 60% to 65% molybdenum.
[3]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF MOLYBDENUM

Item	HTS No.	1991			1992		
		Gross weight (metric tons)	Contained molybdenum	Value (thousand)	Gross weight (metric tons)	Contained molybdenum	Value (thousand)
Molybdenum ore and concentrates, roasted	2613.10.0000	167	100	$554	1,022	585	$2,884
Molybdenum ore and concentrates, other	2613.90.0000	106	61	328	403	246	1,197
Molybdenum oxides and hydroxides	2825.70.0000	948	NA	5,013	1,032	NA	3,928
Molydates of ammonium	2841.70.0000	139	77	772	154	86	757
Molybdates—all others	2841.70.5000	(1)	(1)	(1)	(2)	(2)	6
Molybdenum orange	3206.20.0000	812	NA	2,399	894	NA	2,566
Mixtures of inorganic compounds	3823.90.3400	1	(2)	105	5	2	104
Ferromolybdenum	7202.70.0000	1,521	953	7,304	1,722	1,096	6,974
Molybdenum powders	8102.10.0000	32	r27	r788	68	52	1,784
Molybdenum unwrought	8102.91.1000	64	45	r1,703	71	46	1,437
Molybdenum waste and scrap	8102.91.5000	371	363	3,238	128	125	1,000
Molybdenum wrought (includes bars, rods, profiles, plate, sheets, strips, foil)	8102.92.0000	53	NA	3,275	46	NA	3,004
Molybdenum wire	8102.93.0000	2	NA	211	1	NA	177
Molybdenum, other	8102.99.0000	2	NA	495	2	NA	8007
Total[3]		4,217	1,627	r26,186	5,548	2,238	26,618

rRevised. NA Not available.
[1]No data recorded.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9

HARMONIZED TARIFF SYSTEM ON U.S. MOLYBDENUM IN THE UNITED STATES

Type trade	HTS No.	Commodity description	Quantity (kilograms)	General most favored nation	Rates of duty during 1992 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, J) 7.9 cents/kg on molybdenum content + 1.1% 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.	19.8 cents/kg on molybdenum content	Free (E, IL, J) 3.9 cents/kg on molybdenum content (CA)	77.2 cents/kg on molybdenum content.
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, J) 0.6% (CA)	20.5% ad valorem.
Export	2825.70.0000	do.	do.	—	—	—
Export	2841.70.0000	Molybdates—all	Contained	—	—	—
Import	2841.70.1000	Molybdates of ammonium	do.	4.3% ad valorem	Free (A, E, IL, J) 0.8% (CA)	29% ad valorem.
Import	2841.70.5000	Molybdates—all others	do.	3.7% ad valorem	Free (A, E, IL, J) 0.7% (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, J) 0.7% (CA)	25% ad valorem.
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, J) 0.5% (CA)	18% ad valorem.
Ferroalloys:						
Export	7202.70.0000	Ferromolybdenum	do.	—	—	—
Import	7202.70.0000	do.	do.	4.5% ad valorem	Free (E, IL, J) 0.9% (CA)	31.5% ad valorem.
Import	8102.10.0000	Powders	do.	13.9 cents/kg on molybdenum content + 1.9% ad valorem	Free (E, IL, J) 2.7 cents/kg on molybdenum content 0.3% (CA)	$1.10/kg on molybdenum content + 15% ad valorem.
Export	8102.10.0000	do.	Gross	—	—	—
Export	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, J) 2.7 cents/kg on molybdenum content 0.3% (CA)	$1.10/kg on molybdenum content + 15% ad valorem

See footnotes at end of table.

TABLE 9—Continued

HARMONIZED TARIFF SYSTEM ON U.S. MOLYBDENUM IN THE UNITED STATES

Type trade	HTS No.	Commodity description	Quantity (kilograms)	General most favored nation	Rates of duty during 1992 special[1]	Non-most favored nation
Ferroalloys—Continued:						
Import	8102.91.5000	Waste and scrap	Contained	Free	—	Free.
Import	8102.92.0000	Wrought	Gross	6.6% ad valorem	Free (A, E, IL, J) 1.3% (CA)	60% ad valorem.
Export	8102.92.0000	do.	do.	—	—	—
Import	8102.93.0000	Wire	do.	6.6% ad valorem	Free (A, E, IL, J) 1.3% (CA)	60% ad valorem.
Export	8102.93.0000	do.	do.	—	—	—
Import	8102.99.0000	Other	do.	5.5% ad valorem	Free (A, E, IL, J) 1.1% (CA)	45% ad valorem.
Export	8102.99.0000	do.	do.	—	—	—

[1]Symbols 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, J Andean Trade Preference Act.

Source: USITC Pub 2449.

TABLE 10

MOLYBDENUM RESERVES AND RESERVE BASE[p]

(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.[2]	450	680
Other	—	270
Asia:		
China	500	1,220
Iran	50	140
Other	—	140
Total	5,530	11,810

[p]Preliminary.
[1]Less than 1/2 unit.
[2]Dissolved in Dec. 1991.

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, Metals Data Section. International data tables were prepared by Ivette E. Torres, Chief, Jeremy Tidwell, and Ronald Hatch, 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 1992, as a result of the global recession. Demand for nickel in the Western World was about 635,000 metric tons, down 35,000 tons from the record high of 1990.[1] Nickel prices continued to weaken because of oversupply and the stagnating economic situation in Japan and the United States. At the end of 1992, recessionary forces also began to take hold in Western Europe. The assimilation of eastern Germany into the European Community (EC) began running into roadblocks at a time when the entire economic structure of Western Europe was being overhauled and upgraded.

The splintering of Yugoslavia and economic turmoil in the rest of Eastern Europe complicated midterm planning for French, German, and Scandinavian stainless steel producers. With the dissolution of the former U.S.S.R. and the creation of a market economy in the Russian Federation, large tonnages of primary nickel that would have been used by the Soviet military-industrial complex were made available to markets in Western Europe, Japan, and the United States. This influx of Russian material accelerated in early 1992, exerting downward pressure on nickel prices in the second half of 1992. On December 31, 1992, the London Metal Exchange (LME) cash price was only $7,001 per ton ($3.176 per pound).

Prices recovered briefly during the first quarter of 1993, only to drop back below the $2.50 per pound mark at midyear. In June 1993, North American producers began idling less profitable operations because of the poor price situation. Outokumpu Oy of Finland and Western Mining Corp., however, were more sanguine about the future of the nickel industry and proceeded to bring two new mines in Western Australia on-stream.

The United States produced 1.27 million metric tons (Mmt) of nickel-bearing stainless steel in 1992, an increase of 6% from that of the previous year.[2] In Japan, though, production of nickel-bearing stainless steel dropped, falling 8%.[3] Japan has been the largest stainless steel producer in the Western World for more than a decade and produced 1.85 Mmt of hot-rolled, nickel-bearing stainless in 1992.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines (USBM) tries to identify and canvass every nickel consumer who uses 2 tons or more per year. Most of the larger companies report on a monthly basis. Reports were received from 77 of the 84 facilities on the 1992 monthly canvass. An additional 176 facilities were canvassed at the end of the year. Of the 176 facilities, 123 responded, or about 70% of the second canvass. 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 80% 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.)*

BACKGROUND[4]

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 has traditionally been 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. Several customers prefer the shot over the ingot because the shot is more amenable to computerized,

bulk loading systems than the ingot. 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 nitrate, oxide, hydroxide, and peroxide are preferred for fuel cell and battery manufacturing.

Industry Structure

At least 22 countries mined some type of nickel ore in 1992. In almost every case, the nickel came from either a laterite deposit or a sulfide deposit. Seven 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 1988 through 1992, laterite operations accounted for about 37% 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 1988 through 1992, the six largest producing countries and their share of world mine production were as follows: the former U.S.S.R. (27%), Canada (21%), New Caledonia (10%), Indonesia (7%), Australia (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. Most of the nickel at Sudbury is tied up in iron sulfides, which are intergrown, in turn, with copper sulfides. 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. Like Sudbury, all three have numerous deposits of sulfide ores averaging more than 2% Ni and 1% copper (Cu).

Cuba and New Caledonia have the largest reserves of laterite. Laterites are also currently mined in Australia, Brazil, Colombia, the Dominican Republic, Greece, Macedonia, Indonesia, the Philippines, Russia, and the Ukraine. The only U.S. producer is Glenbrook Nickel, which operates a laterite mine and ferronickel smelter at Riddle, OR. Some nickel is also produced in the United States as a byproduct of copper refining and recycling. The Glogovac mining and smelting complex in Serbia reportedly closed in late 1992.

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 also can 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.

Recycling

The International Metals Reclamation Co., Inc. (INMETCO), a subsidiary of Inco United States Inc., has been operating a recycling plant for chromium and nickel at Ellwood City, PA, since 1978. Baghouse dust, mill scale, grinding swarf, and other particulate waste from stainless steel plants are blended, pelletized, mixed with a reductant, reduced in a rotary hearth furnace, and then smelted in an electric furnace. The nickel and chromium are recovered as a remelt alloy and sold back to the stainless producers.

The Pennsylvania plant was modified several years ago so that a wider variety of waste materials could be treated. INMETCO now accepts spent pickling solutions, pickling and wastewater treatment filter cakes, and chromium-bearing refractories. Spent nickel-cadmium (Ni-Cd) batteries are also processed on-site. The cadmium is recovered as a dust and sent across the State to a zinc recycling plant for further treatment.

A completely different type of plant is operated by the U.S. Filter Recovery Services, Inc. at Roseville, MN. The Minnesota plant uses a variety of hydrometallurgical and electrowinning processes to recover nickel, cadmium, and copper from scrap and ion exchange resins.

Substitutes

With few exceptions, substitutes for nickel would result in increased cost or some sacrifice in the performance of the product. For example, manufacturers can cut costs by substituting aluminum, coated steels, or even plastics for austenitic stainless steel in certain situations. However, substitution may not be desirable because of significant downstream tradeoffs. Most plastics are more susceptible to fatigue than stainless and can crack over long periods of time, raising the end user's maintenance costs and encouraging the end user to turn to another manufacturer. Other present and potential nickel substitutes include nickel-free specialty steels for the power generating, petrochemical, and petroleum industries; titanium and plastics for highly corrosive environments; and cobalt, copper, and platinum for catalysts.

Economic Factors

Prices.—Nickel prices traditionally have been quite volatile. The time-price relationship for the metal over a 150-year span is given in the metal prices handbook recently published by the USBM.[5] 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 1.)*

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 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 cobalt, copper, and precious metals. The Sudbury nickel deposits are an important source of both platinum and palladium. The principal platinum mineral is sperrylite, $PtAs_2$, 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 USBM published an information circular entitled "Availability of Primary Nickel in Market-Economy Countries."[6] 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 Issues.—The principal environmental problem associated with nickel production is the emission of sulfur dioxide (SO_2) from smelters that process sulfide ores. The SO_2 emitted from smelter smokestacks combines with water in the atmosphere to form droplets of sulfuric acid (H_2SO_4), a major component of acid rain. The Provincial government of Ontario has ordered Inco to reduce SO_2 emissions at its Sudbury complex by two-thirds and has imposed a ceiling of 265,000 metric tons per year (mt/yr), starting in 1994. The company is spending $530 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 ton of sulfur is generated for each ton of copper produced. In contrast, 8 tons of sulfur is generated for each ton 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 an initial list of pollution source categories that warranted regulation. It took EPA more than 1 year to develop the list because of the magnitude and complexity of the problem. EPA received more than 140 comments from public and private interests between June 1991 and July 16, 1992, when the list was finally published in the Federal Register.[7] A number of nickel consumers appeared on the July list, including integrated steel mills, electric arc furnace operations, iron and steel foundries, and ferroalloy production facilities. Primary producers of aluminum, copper, and lead were also listed, together with their secondary counterparts. Additional categories were to be added at a later date. A draft schedule for promulgating emission standards for each of the initial 174 source categories was published in the Federal Register on September 24, 1992, as part of the 10-year phase-in of CAA regulations.

Because many facilities will need new pollution control equipment to comply with these standards, the enactment of the Clean Air Act Amendments is expected to increase demand for stainless steel and other alloys of nickel. Under the new law, 111 fossil fuel-fired powerplants must reduce their SO_2 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 pound of SO_2 per million British thermal units. Not all of the plants exceeding the 2.5-pound 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 SO_2 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 soon may 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. 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 tons of corrosion-resistant alloy will be required for each scrubber. Although it is not clear which alloy will be used, many of the most promising candidates contain significant amounts of nickel. Nickel is ideal in this situation because of the element's ability to improve the resistance of different metals to both corrosion and heat.

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.

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/m^3) 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/m^3 for insoluble forms of nickel (e.g., NiO) and 0.1 mg/m^3 for soluble forms of nickel (e.g., $NiSO_4$). 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.[8] 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/m^3 in the case of soluble nickel compounds and more than 10 mg/m^3 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/m^3) was minute and, possibly, nonexistent. The study was sponsored by, among others, the EPA, NiPERA, and Energy, Mines, and Resources—Canada.

In 1991, the United Nations published indepth environmental health criteria for nickel, together with a companion health and safety guide on nickel metal, nickel carbonyl, and selected nickel compounds.[9] The 383-page report was prepared as part of the International Program on Chemical Safety (IPCS), a joint venture of the UN Environmental Program, the International Labor Organization, and the World Health Organization. The principal conclusions are summarized below:

> "Although some, and perhaps all, forms of nickel may be carcinogenic, there is little or no detectable risk in most sectors of the nickel industry at current exposure levels; this includes some processes that were associated, in the past, with very high lung and nasal cancer risks. Long-term exposure to soluble nickel at concentrations of the order of 1 mg/m^3 may cause a marked increase in the relative risk of lung cancer, but the relative risk among workers exposed to average metallic nickel levels of about 0.5 mg/m^3 is approximately 1. The cancer risk at a given exposure level may be slightly higher for soluble nickel compounds than for metallic nickel and, possibly, than for other forms as well. The absence of any marked lung cancer risk among nickel platers is not surprising, as the average exposures to soluble nickel are very much lower than those in electrolytic refining or nickel salt processing."

Energy Requirements.—As mentioned earlier, energy costs are much more critical for laterite operations than for

sulfide operations. Laterite ores are typically smelted in direct-arc furnaces having power ratings on the order of 20 to 40 megawatts (MW). Glenbrook Nickel, for example, has four 24-MW furnaces. Power is provided by the Bonneville Power Administration, a hydroelectric-based utility.

Glenbrook smelts the laterite by the Ugine Process. The process is not only power intensive, but also requires the addition of ferrosilicon—a source of chemical energy. This chemical energy is transferred to the molten ferronickel when the ferrosilicon is converted to slag.

The ferrosilicon can be produced on-site in a similar submerged arc furnace by reacting lumps of quartzite with shredded steel scrap and a carbon-rich reductant, such as coke. Electrical power consumption is the principal cost in producing ferrosilicon. Ferrosilicon and silicon metal are the most power intensive of the bulk ferroalloys, requiring 8,500 to 14,000 kilowatt hours of electrical energy per ton of contained silicon.

ANNUAL REVIEW

Legislation and Government Programs

On March 24, 1993, the Defense Logistics Agency (DLA) began selling nickel metal from the National Defense Stockpile (NDS). At least 29,212 tons of the 33,760 tons of nickel in inventory is in the process of being sold at auction twice per month. The auctions are to run for the next 5 years.

The Federal Government no longer has a stockpile goal for nickel. Until the end of 1992, the goal had been 181,437 tons. This goal was deemed unnecessary when the entire NDS program was reevaluated during the drafting of the fiscal year 1993 Annual Materials Plan. Nickel was only one of several strategic metals, including copper, lead, and zinc, whose goals disappeared. Goals were kept, but drastically reduced, for aluminum metal, titanium sponge, and cobalt.

Legislation supporting the disposal was passed by 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). The revised fiscal year 1993 plan, which took effect on March 18, 1993, allows the Defense National Stockpile Center (DNSC) to sell a maximum of 9,072 tons (10,000 short tons) of nickel in the fiscal year ending September 30, 1993. Several nickel producers were concerned that the long-term selloff would unduly disrupt an already weakened North American market. A twice monthly auction schedule was adopted to ease their concerns, with only about 270 tons (300 short tons) being offered at each auction.

The new law established an advisory committee to oversee stockpile operations and a market impact committee to minimize market disruptions. The advisory committee is currently composed of officials from seven different Federal agencies as well as representatives from a mix of industries. The legislation requires the impact committee to consult with industry on a regular basis.

The bulk of the nickel in the NDS was purchased during the Korean War or the 5-year period immediately following the war. The first material offered for sale consisted of 21,013 tons of cathode of Canadian and Norwegian origin and 520 tons of oxide of Cuban origin. The cathode sheets ranged in size from 12 by 25 inches to 25 by 36 inches.

DLA found immediate buyers for the cathode, but was disappointed by the bids received for the fine-grained oxide powder. The Agency rejected all of the bids on the oxide and, in April 1993, temporarily withdrew the Cuban material from future bidding until an indepth market assessment could be conducted. The Cuban oxide was acquired between 1950 and 1959 and is currently stored at Scotia, NY, in drums holding about 180 kilograms each. The oxide averages about 76% Ni with less than 0.74% cobalt and 0.21% iron. The cathode dates from the same period and is stored at four different locations in the Mid-Atlantic and Ohio Valley region. All of the nickel is being sold on an as-is basis.

Strategic Considerations

Nickel is an essential ingredient in austenitic stainless steel and superalloys. As such, its availability is important to the national security. Domestic mine capacity was less than 14% of primary apparent consumption in 1992. Canada, however, a close ally and a geographically secure source, is capable of supplying U.S. needs under normal circumstances.

Issues

The U.S. Department of the Treasury continued to ban the importation of nickel and nickel-containing materials from Cuba. The ban has been in effect since 1962. In the past, more than two-thirds of the mixed nickel-cobalt oxide sinter from the Nicaro and Punta Gorda plants was exported to Europe. The mixed nickel-cobalt sulfide precipitate from the Pedro Sotto Alta smelter at Moa was shipped directly to refineries in the Ural Mountains of the former U.S.S.R. Since 1991, however, a significant amount of Cuban material has been going to Canada.

In June 1993, the Government of Cuba indicated that it might consider compensating the former owners of the nickel mines and plants that were nationalized in October 1960. The Cuban proposal, if followed up, would remove a major stumbling block to improving United States-Cuban relations.

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 50-50 venture of Cominco American Inc. and Cominco Resources International Ltd. 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.

Ore from the reopened section on Nickel Mountain was averaging 1.18% Ni and was expected to last at least 2 years. The Riddle smelter was also using spent hydrogenation catalysts containing 5% to 10% Ni as supplemental feedstock. In June 1992, the smelter produced a record high 762 tons of nickel contained in ferronickel from these materials. However, management had already realized that higher grade ores from overseas would have to be used if unit operating costs were to be reduced and smelter output raised further.

In mid-1991, management gave final approval to plans that would raise the capacity of the smelter from 11,000 mt/yr of contained Ni in FeNi to 16,300 mt/yr. The additional feed requirements were to be met by importing garnierite ore averaging 2.2% to 2.4% Ni from New Caledonia. Feasibility studies had shown that it was cheaper to buy and ship ore from New Caledonia than to expand the mine. Société Minière du Sud Pacifique agreed to supply ore twice as rich as the material being mined on Nickel Mountain. The Sud Pacifique ore would be unloaded at Coos Bay, dried, and then trucked to Riddle.

During the first half of 1992, Glenbrook spent $33 million rehabilitating the dock facilities at Coos Bay and constructing an ore crushing, screening, and drying plant at dockside. On July 31, 1992, the first commercial shipment of Sud Pacifique ore arrived at Coos Bay. In September, Glenbrook signed a contract with Sud Pacifique to deliver additional ore. One month later, though, the LME price began to fall, and Glenbrook had to ask its New Caledonian supplier to slow mine production and delay loadings.

Rehabilitation of the docks and construction of the dryer and crushing plant was completed in the fourth quarter of 1992. A shot casting facility was also built at the smelter as part of the project. The casting facility allows Glenbrook to market 6-millimeter (1/4-inch) ferronickel shot in addition to the 28-pound ingots already being produced.

In 1992, Glenbrook mined 606,000 tons (dry basis) of ore containing 6,671 tons of Ni. The ore received from New Caledonia contained an additional 3,584 tons of Ni. From the two feedstocks, the company was able to produce 8,962 tons of Ni contained in ferronickel.[10]

The Knox Nickel Corp., a subsidiary of Black Hawk Mining Inc., has been seeking to develop a nickel-copper-cobalt deposit in southern Maine, about 20 kilometers (km) inland from the Atlantic coast. The 0.777-square-kilometer (192-acre) site is on the southern side of Crawford Pond, between the towns of Warren and Union. The deposit, which was discovered in 1965, lies entirely within the town limits of Warren. Company officials estimate that the deposit contains 4 Mmt of sulfide ore grading 1.40% Ni, 0.64% Cu, and 0.12% Co at a Ni cutoff grade of 0.8%. The ore reserves are based on 165 diamond drill holes totaling about 18,000 meters (m).

On June 9, 1992, the residents of Warren approved a controversial set of local mining regulations by a vote of 651 to 534. The Warren ordinance closely follows a new metal mining law enacted by the State of Maine on August 26, 1991. The 1991 Maine mining law was already considered to be one of the most restrictive in the United States. The Warren ordinance incorporates 95% of the State regulations, but goes one step further. The local regulations require more restrictive setbacks for mine tailings than the State law and set stricter financial responsibility requirements for mining companies.

Knox officials said that they will continue with their plans to develop the deposit, despite the obstacles raised by the new ordinance. The company has already begun addressing issues that were raised by the Warren Planning Board, State officials, and the U.S. Army Corps of Engineers during public hearings that preceded the June vote.

Consumption and Uses

Western World nickel demand dropped slightly in 1992. Demand was estimated to be about 635,000 tons, down 35,000 tons from the record high set in 1990. Total U.S. apparent consumption, though, was about 8% higher than the figure for 1991 because of increased scrap purchases. Both U.S. and world demand continued to be driven by the stainless steel industry, which accounted for almost 50% 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 inched up to 1.81 Mmt and was 6% higher than the corresponding figure for 1991.[11] Nickel-bearing grades accounted for 70% of the production tonnage. Net shipments of all types of stainless totaled 1.373 Mmt. Shipments of sheets and strip jumped to 954,483 tons, breaking the record of 875,548 tons just set in 1991. The next largest category was plate [flat product 4.8 millimeter (3/16 inch) or more in thickness]. Shipments of plate were 158,033 tons, a slightly lower number than that of 1991. Together, plate and sheet accounted for 81% of total net shipments, compared with 79% in 1991.

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 1992, U.S. consumption of primary nickel in superalloys decreased 27%. The decrease was due primarily to recessionary forces and weakening demand. Jet engine manufacturers, in particular, were hard pressed by (1) reduced defense spending and (2) lower sales of commercial aircraft by The Boeing Co. and McDonnell Douglas Corp. The two companies continued to work off a backlog of orders received between 1988 and 1990 for civil jet transport. However, new orders from U.S. and foreign customers dropped from 670 aircraft in 1990 to 231 in 1992.[12] Orders for spare aircraft parts were also down significantly, further hurting upstream companies that produce castings for aircraft engines and airframes. *(See tables 2 through 4 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 decreased 14% during the year. At yearend, these stocks represented 31 days of apparent primary consumption. *(See table 1.)*

Markets and Prices

Nickel prices weakened significantly during the second half of 1992. The average LME cash price for the year was $7,001.227 per metric ton, which equates to $3.176 per pound. In terms of current dollars, this represented a drop of 14% from the 1991 average of $8,155.612 per metric ton. The four principal reasons for the weakening were as follows: (1) slumping demand for stainless steel in several developed countries, (2) a large buildup of stocks of Russian nickel in LME warehouses, (3) the increased availability of stainless steel scrap, and (4) improved productivity at primary production facilities.

LME stocks climbed precipitously in 1992, rising from 6,987 tons in December 1991 to 67,914 tons on December 21, 1992. This increase continued into 1993, passing the 85,000-ton mark at midyear. The inventory increase is largely the result of the influx of Russian cathode.

Despite growing stocks, the LME cash price was relatively stable during the first half of 1992, when compared to that of 1988 and 1989. Increased purchases by the Chinese and a moderate rise in U.S. stainless steel production helped support the price. A U.S. investment fund reportedly made a major purchase of LME nickel in early 1992, but did not take delivery. This meant that a large portion of the LME stocks was unavailable for immediate sale.

The weekly LME cash price began the year at $7,168 per metric ton ($3.25 per pound), gradually strengthened, and peaked at $8,044 ($3.65 per pound) in late February. In mid-March, the price, however, began to weaken. Some observers attributed the decline to the large increase in stocks at the LME warehouse in Rotterdam.

By August 14, the LME cash price had dropped back down to $7,259 ($3.29 per pound). At that point, the price continued to decline but at a considerably slower rate, eventually reaching a low for the year of $5,336 ($2.42 per pound) during the week of November 20. Uncertainty about the availability of stainless scrap caused the price to recover slightly at the end of the year. The last weekly price (for the week ending December 25) was $5,815 ($2.64 per pound). The settlement price on December 30 was $5,810 ($2.63 per pound).

Most North American producers cut back output in response to weakening nickel prices. The Norilsk Nickel Combine, the largest producer in the Commonwealth of Independent States (C.I.S.), also reportedly decreased its output. Few other overseas producers, however, followed suit.

On October 5, 1992, Inco Ltd. announced that it was reducing nickel production and curtailing capital expenditures in response to softening prices.

One month later, Falconbridge Ltd. announced that it would shut down its Sudbury Div. in Ontario, beginning June 27, 1993, for 10 weeks. Normally, the Ontario operation is closed 2 weeks each summer for vacation and maintenance. In 1992, Falconbridge's Sudbury Div. was down for 5 weeks instead of 2 because of reduced demand. The company's Nikkelverk refinery in Norway was also scheduled to shut down for 7 weeks during the summer of 1993. As a result of the two actions, Falconbridge was expecting to produce only about 54,000 tons of refined nickel in 1993, 7,000 tons less than had been planned. The company has delayed commissioning its new Craig shaft at Sudbury, lowering the 1994 production schedule by an additional 6,000 tons of contained nickel.

Glenbrook, faced with rising power costs and lower ferronickel prices, decided to shut down for the entire first quarter of 1993. The company tried to resume production during the second quarter but was further hurt by a U.S. International Trade Commission antidumping ruling in March 1993 that made the importation of ferrosilicon more expensive.

Foreign Trade

The U.S. net import reliance as a percentage of apparent consumption was 61% in 1992. The figure remained high, despite increased ferronickel production in Oregon, because of continued strong demand for stainless steel within the United States. Imports accounted for about 95% of primary supply in 1992. 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 relatively high level of demand for primary nickel in the United States also has meant high demand for nickel-bearing scrap. Scrap processing accounted for about 85% of total domestic nickel production. U.S. exports of stainless steel scrap remained strong in spite of weakening prices. Exported stainless scrap contained an estimated 16,740 tons of Ni, down less than 4% from the 17,407 tons of 1991. These figures are based on the assumption that stainless scrap has been averaging 7.5% Ni since 1989, when the changeover to the Harmonized Tariff System took effect.[13] *(See tables 5 through 9 and figure 2.)*

The USBM data base for nickel exports was expanded in 1991 to include both catalysts (Schedule B No. 3815.11.0000) and waste and scrap (No. 7503.00.0000). The expansion was made so that nickel export categories would correspond more closely to import categories. These changes and earlier classification modifications were made in conjunction with the Nation's ongoing conversion to the Harmonized System. The nomenclature of the Harmonized System was adopted by the United States on January 1, 1989, following the enactment of the Omnibus Trade and Competitiveness Act (Public Law 100-418) in August 1988.

In several instances, nickel trade data published since 1989 may not be directly comparable to data of earlier years as a result of the conversion. The nine Harmonized export categories for unalloyed wrought nickel illustrate this problem. Because of significant differences between the nine categories and their counterparts in the old tariff schedule, no comparable wrought data are available for 1988. All of the other data in tables 6 through 9 were revised to ensure future continuity.

Starting with this publication, the annual report will also contain foreign trade data on nickel alloys (HTSUS Nos. 7505.12, 7505.22, 7506.20, 7507.12, etc.). The trade data base is being expanded as part of a major effort by the USBM to develop a broader materials perspective and provide more information on the entire life cycle of each commodity.

On June 17, the United States granted most-favored-nation (MFN) status to the Russian Federation. The award, part of a comprehensive trade agreement signed by the Presidents of the two countries, was expected to encourage the importation of wrought nickel products from Russian fabricators who were formerly defense-oriented. Bars, plates, and tubes of nickel and nickel alloys are now exempt from stiff non-MFN duties, which vary from 25% to 45% ad valorem. The MFN duties on wrought nickel only range from 3% to 5.5%.

The change in trading status will be much less dramatic in the case of unwrought products, most of which come from operations of the Norilsk Combine in Siberia and the Kola Peninsula. Unwrought nickel, metal powder, and flake from Russia had carried a non-MFN duty of $0.066 per kilogram of gross weight. This $0.066 figure equates to $0.030 per pound and was slightly less than 1% of the average 1992 LME cash price. All unwrought Russian nickel can now enter the United States free of duty. Americhem, a subsidiary of International Metals and Chemicals Co. (IMC), has already begun marketing nickel powder in the United States for Norilsk. The material is apparently similar to the 123 grade sold by Inco Ltd. and is 99.9% pure Ni.

As part of a 1990 agreement with the former U.S.S.R., C.I.S. producers were still required to certify that their exports of nickel and nickel-bearing products were exclusively of Central EurAsian origin (and, ipso facto, free of Cuban material). 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 3,385 tons of cathode and 947 tons of powder and/or flake directly from Russia in 1992. No material was reported from the Ukraine. Combined imports of cathode from Russia and Estonia in 1992 were almost triple the 1991 figure. All of the Estonian material was believed to be of Russian origin. (See Russia section of this report.)

World Review

On April 1, 1992, the International Nickel Study Group (INSG) held its second general session at The Hague, the Netherlands. 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, Cuba, Japan, the Russian Federation, and nine other nations have joined the INSG. The EC also participates as a single entity. Together, the member countries account for about four-fifths of world nickel mine production, two-thirds of world primary nickel trade, and three-fifths of nickel consumption. The United States and another five countries have been sending observers to the meetings on an irregular basis.

Because of the global recession and continuing low prices for a number of metals, several natural resource conglomerates began rethinking long-term investment strategies. This rethinking, spurred by the entry of Russian and Kazakh producers into Western markets, has triggered a new round of company restructurings.

In September 1991, Outokumpu Metals & Resources Oy (OMR) and Mooney Chemicals Inc. (MCI) merged their chemical businesses. A newly incorporated holding company, OM Group Inc. (OMG), now controls Mooney Chemicals Inc. as well as two OMR production units—Kokkola

Chemicals Oy of Finland and Vasset S.A. of France. At the end of 1992, OMR increased its ownership in OMG from 47% to 96% by redeeming shares held by Finnish insurance and investment companies. The remaining 4% is held by the former president of MCI.[14]

The merger made OMG the largest producer of cobalt and nickel inorganic salts in the Western World. It is also a leading producer of cobalt carboxylates and extra-fine cobalt powder. OMG has three production facilities—Franklin, PA; Kokkola, Finland; and Ezanville, France—that manufacture a total of more than 250 specialty chemical products. In 1992, the company had net sales of $201 million. The Kokkola facility is one of only a few chemical plants in the world equipped to recycle industrial residues from nickel-plating operations and nickel-cadmium battery manufacturers.

Toward the end of 1992, Gencor Ltd., a South African group with important mining investments, moved to expand its foreign holdings. The South African conglomerate approached the Royal Dutch/Shell Group, seeking to buy selected metal and mineral operations owned or controlled by Shell's subsidiary, Billiton B.V. At least nine other commodities were involved besides nickel—alumina, aluminum, bauxite, copper, gold, lead, silver, tin, and zinc. Shell was receptive to Gencor's offer, triggering lengthy negotiations that continued well into 1993. Because many of Billiton's operations are joint ventures, the sale of individual mines and smelters would depend upon whether the other shareholders choose to exercise their preemptive purchase rights. (See Colombia and Republic of South Africa sections of this report.)

Capacity.—The rated capacity for mines, smelters, and refineries as of December 31, 1991, was published in the 1991 Annual Report. 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. (See table 10 of 1991 Annual Report.)

Australia.—Australia could conceivably double its output by the end of the decade. Western Mining Corp. Holdings Ltd. (WMC), one of the four largest nickel producers in the Western World, continued to increase production capacity in the face of weakening nickel prices.

Expansion and upgrading of WMC's Kalgoorlie smelter was proceeding on schedule. Management gave final approval to the project after WMC and the Western Australian Government reached an agreement on sulfur dioxide emissions. When the expansion is completed, the smelter will be able to treat at least 65,000 mt/yr of Ni in concentrate, up from 54,000 mt/yr. In December 1992, contractors began constructing a new oxygen plant for Kalgoorlie. Kalgoorlie has a flash furnace that has operated almost continuously since its commissioning in 1978. The smelter can treat limited amounts of high-grade nickel sulfide ores in addition to conventional concentrate. The bulk of the smelter feed has been coming from (1) the Kambalda Mine Group about 25 kilometers southeast of the smelter, (2) the revitalized Leinster Mine Group northeast of Agnew, and (3) the almost depleted Windarra Nickel Project near Laverton.

WMC also operates a refinery at Kwinana, near Perth, that produces metal powder and briquets. The capacity of the Kwinana refinery was being upgraded from 34,900 metric tons of metal per year to 42,000 mt/yr. Because smelter capacity will still exceed refinery capacity by about 20,000 mt/yr of contained Ni, part of the matte from Kalgoorlie 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. A new concentrate drier was commissioned at the Leinster mill in mid-September. Plans to expand the Kambalda Mine were on hold, pending resolution of issues aimed at improving work practices. The Western Australian Government was considering legislation that would amend the Western Australian Mines Regulation Act and modernize key labor laws.

In the spring of 1992, Sumitomo Metal Mining Co. Ltd. of Japan renewed its long-term purchase contract with WMC. The new 10-year contract, signed on April 8, runs retroactively from April 1, 1992, to March 31, 2002. Sumitomo has agreed to take 20,000 tons of nickel matte annually from Kalgoorlie, an increase of 33% from the previous contract level of 15,000 tons. The 20,000-ton figure accounts for approximately 30% of Kalgoorlie's output. (See Japan section of this report.)

In July 1992, WMC completed initial bulk sampling of the Bulong laterite deposit in Western Australia. The company sold the deposit to Resolute Resources Ltd. in 1987, but later decided to reexamine the property as part of a special agreement with Resolute Resources. Under the terms of the agreement, WMC is expected to spend A$16 million on a feasibility study of Bulong that began in early 1991. In exchange, WMC will earn a 70% interest in the project.

The Bulong deposit is about 35 km east of Kalgoorlie. According to Resolute officials, the deposit has measured resources totaling 11.34 Mmt averaging 1.32% Ni and 0.1% Co. The deposit reportedly has an additional 16 to 18 Mmt of inferred resources at approximately the same grade.

About 25,000 tons of ore has been mined from a trial pit and stockpiled sequentially at the surface in 20- by 20-m piles for orderly bulk sampling and metallurgical testing. The joint venture is hoping to use a continuous-pressure leaching process similar to those employed in Canada and Cuba to extract the nickel and cobalt. Water for the process would be obtained by desalinizing hypersaline water from area aquifers. The proposed open pit operation would produce about 12,800 mt/yr of nickel in concentrate and 800 mt/yr of cobalt.

WMC also began moving on the stalled Mount Keith project. The Mount Keith deposit contains an estimated 270

Mmt of sulfide ore averaging 0.06% Ni. Although the ore is considered low grade in terms of its Ni content, it is also low in pyrrhotite. Less sulfide in the concentrate translates directly into lower emissions of SO_2 and, thus, lower smelting costs.[15]

Mount Keith is about 70 km northwest of Leinster and Agnew and, up until mid-1991, had been controlled by Australian Consolidated Minerals Ltd. (ACM). The original plan called for the Mount Keith concentrate to be shipped to Finland for processing into ferronickel. OMR was to have built a new facility to handle the Australian concentrate while the mine was being developed. However, ACM and OMR decided to defer development of Mount Keith after some of the ore was found to contain as much as 10% magnesia (MgO). Because of the high magnesia, the ferronickel facility would have to be redesigned.

At that point, WMC moved in and tried to acquire Mount Keith through a complex takeover of ACM. The huge 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. In June 1992, the day before the expected takeover, OMR disrupted WMC's plans by purchasing one-half of ACM's stake in Mount Keith for $60 million. WMC went ahead with the takeover despite the change in equity. After the takeover was finalized, WMC and OMR 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 promised by ACM. OMR would make up the deficit from its European operations and from future production from the Forrestania project.

All of these plans had to be modified at the end of 1992 when the Finnish producer found itself caught up in a major restructuring of its parent company, Outokumpu. At this point, WMC decided to develop Mount Keith by itself and began negotiating to buy back the 50% interest held by OMR.

Because of all of the delays at Mount Keith, OMR had to accelerate the development of its Forrestania nickel deposit north of Lake King. Forrestania was Outokumpu's first major nickel investment in Australia. In 1989, OMR acquired the 55% interest in the project held by Metals Exploration Ltd. The other 45% was split between Arimco N.L. and Cyprus Gold Australia Corp. One year later, the Finnish nickel producer bought out the two remaining partners and took control of the entire project.

The Forrestania Mine was officially commissioned on January 14, 1993, but the A$100 million mine has been in production since November 1992. The Forrestania complex is about 170 km south-southeast of Southern Cross. It consists of an open pit at Digger Rocks and two underground operations still under development—Cosmic Boy and Flying Fox. The concentrator can handle 400,000 to 500,000 mt/yr of ore. At full capacity, the mine should be able to produce 7,000 to 8,000 mt/yr of Ni in concentrates. The concentrates are currently averaging 10% to 16% Ni, all of which go to the Harjavalta smelter. A loading facility has been constructed on the southern coast at Port Esperance. According to company officials, Forrestania has 4.4 Mmt of ore reserves, enough to permit the mine to operate for at least 10 years. There are about 1.2 Mmt of reserves, averaging 1.76% Ni, at Digger Rocks and another 2.3 Mmt, averaging 2.82% Ni, at Cosmic Boy.

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. 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. According to a feasibility study released in 1991, 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 m. Additional resources have been found 2 km to the south at the Golden North prospect. The Yakabindie mine plan called for a 350-m-deep open pit mine producing about 6 Mmt per year 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 tons 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. The entire project was put on hold in late 1992 when nickel prices began to crumble.

The Queensland Nickel Joint Venture imported 19,235 tons of Ni in lateritic ore from New Caledonia during 1992. An additional 8,413 tons of Ni in ore came from Gebe Island in Indonesia.[16] 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 the Great Barrier Reef Marine Park Authority blocked construction because of possible future damage to the reef.

In early 1992, Inco offered to purchase the 72% interest in Queensland Nickel previously held by Dallhold Nickel Management Pty. Ltd. and controlled at that time by a consortium of financial institutions. The consortium, led by the Hong Kong and Shanghai Banking Corp., had been running the joint venture since July 1991, when Dallhold was placed in receivership. The remaining 28% of the equity was held by the Nickel Resources North Queensland, a parastatal entity of the State of Queensland. The two principal assets of the venture are the 25,000-mt/yr refinery at Yabulu and the Greenvale Mine on the eastern slope of

the Great Dividing Range, 220 km west of Yabulu. However, the mine's reserves were almost depleted and had to be supplemented by imported ore. About 3.2 Mmt/yr of lateritic ore was being sent to Yabulu from Indonesia and New Caledonia for processing. Queensland Nickel was also considering importing ore from the Philippines.

Inco reportedly was interested in the Yabulu refinery because it would give the Canadian company a supply source closer to the expanding stainless steel industries of Japan, the Republic of Korea, and Taiwan. The acquisition would effectively double Inco's cobalt production at a time when cobalt prices were at near-record levels. It also would be more cost effective for Inco to upgrade the Queensland operation than to construct a new refinery elsewhere. Inco and Queensland Nickel were unable to reach an agreement. Inco agreed in principle to acquire Dallhold's interest for between $200 to $235 million, depending on which assets were sold, but later tabled its offer. In mid-July 1992, Inco finally withdrew from the negotiations.

After Inco withdrew, the consortium of financial institutions controlling the joint venture decided to take the company public. In August 1992, the consortium members transferred their assets to a new public company, QNI Ltd., and registered its prospectus with the Australian Securities Commission. The initial stock offering, valued at A$275 million, was quickly oversubscribed by the Australian investment community. According to the prospectus, QNI will have an 80% interest in the Queensland Nickel Joint Venture. The remaining 20% will be held by a vehicle of the Queensland Government. The State government also will have a 12.2% stake in QNI, for a total equity in the venture of almost 30%. The prospectus also disclosed that the Australian refinery has long-term nickel sales contracts with Metallgesellschaft AG (FRG), Allegheny Ludlum Corp. (USA), and Sammi Steel Co. Ltd. (ROK). The cobalt sulfides are sent to Outokumpu in Finland for further refining.

Botswana.—Falling nickel prices put Bamangwato Concessions Ltd. (BCL) in a difficult financial position. The Botswanan nickel and copper producer needed $10 to $40 million to deepen its Selebi and Phikwe Mines, but was already burdened by more than $300 million of debt.[17] 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.

Restructuring negotiations were under way between the Government of Botswana, the individual partners, and at least one key creditor. The mining operation is a joint venture of Botswana RST Ltd. (BRST) (85%) and the Government (15%). At the end of 1992, Amax Inc. and the Anglo-American Corp. of South Africa Ltd. each held about a 30% share in BRST, but Amax was unwilling to invest more money in the venture. The desert town of Selebi-Phikwe, which grew around the mine, is currently the fourth largest settlement in Botswana. Approximately 6,000 industrial jobs are at risk.

BCL produced 18,918 tons of nickel contained in matte in 1992. As in past years, the matte was shipped to Falconbridge's operations in Norway for refining. A new contract was negotiated with Falconbridge during the year. BCL has agreed to provide the Nikkelverk refinery with an average of 15,000 tons of Ni in matte each year until 2006.

Canada.—On October 5, 1992, Inco began reducing nickel production and curtailing capital expenditures in response to softening nickel prices. The company was planning to reduce mine production by 18,000 tons of contained nickel over the coming 12 months. Because of the cutbacks, the company's combined Canadian and foreign operations were expected to produce only about 170,000 tons of nickel in 1993, down from the 182,000 tons recovered in 1992.

Inco's mining and processing operations in Ontario bore the brunt of the cutbacks. The Shebandowan Mine, which was to have reopened on October 12, will remain closed until market conditions improve. The mine, west of Thunder Bay near the U.S. border, has been on standby along with its mill since May 15. The temporary shutdown of the Shebandowan Mine reduced the company's 1992 production by 4,500 tons of Ni. At the time of the shutdown, Shebandowan employed 360 contract workers and had been the highest-cost producer of the 13 operating mines in Inco's Ontario division. The entire Ontario division has about 7,200 employees. The company also extended the 1992 summer vacation shutdown at the division's other 12 mines from 4 weeks to 5 weeks. In mid-December, the mines and nickel refinery at Sudbury were shut down again, this time for 3 weeks. The smelter complex and copper refinery at Sudbury, however, continued to operate during the 3-week period, although at a reduced rate, to work down a backlog of copper concentrates.

The end-of-year production cutbacks also affected a number of other company operations, including the nickel-cobalt refinery at Port Colborne, Ontario; the mining, smelting, and refining complex at Thompson, Manitoba; and the nickel refinery at Clydach, Wales, in the United Kingdom. Inco's downstream alloys and engineered products operations in the United States and the United Kingdom underwent similar temporary shutdowns.

The shutdowns and other measures were designed to conserve cash during a period of rising operating costs and lower realized prices for nickel. Inco's unit production costs at its Canadian operations have nearly doubled since 1987 as a result of declining ore grades, higher labor costs, and the strengthening of the Canadian dollar against the U.S. dollar.

Despite market problems, Inco's management remained optimistic about the future. The company was to spend $40.1 million over the next 2 years to reopen its Garson Mine at Sudbury. The Garson Mine was closed in 1986 after a serious rockfall. Advanced mining methods and new technology were to be used to overcome bad ground conditions that existed in parts of the mine. Better pressure bolts and a new, much stronger

type of sandfill was to be used to help stabilize weak roof slabs and wallrock. The plan called for 179 workers to be transferred from the Little Stobie, Frood, and other area mines where reserves were almost depleted. The reopening still has to be approved by the Ontario Ministry of Labor.

The Garson Mine was scheduled to produce 1,800 tons of ore per day after it reaches full production in late 1995. According to company officials, the mine had 4.4 Mmt of ore grading 1.58% Ni and 1.09% Cu that would permit mining to continue at the 1,800-ton-per-day rate until 2004. Garson had additional proven reserves of 13.3 Mmt of even higher grade ore that could provide another 20 years of production.

In 1991, Inco 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. Subsequent drilling indicated that the Victor deposit may contain as much as 36 Mmt of ore. Copper-nickel sulfide mineralization is present in both the Sudbury Breccia and an adjacent granite breccia, but ore grades are highly variable because of the deposit's complex geology. One of the richer zones intersected in the Sudbury Breccia averaged 2.16% Ni and 4.73% Cu. The main ore zone in the granite breccia appeared to be leaner, averaging 1.64% Ni and 0.28% Cu. The Victor deposit was considered unlikely to be exploited at prevailing prices because the bulk of the ore lies at depths of 2,000 to 2,500 m.

The second deposit is only 925 m from Inco's existing McCreedy East Mine and is much more likely to be developed. The new McCreedy East find is extremely rich in copper and precious metals and occurs between depths of 1,075 and 1,540 m. New drilling raised reserves. The McCreedy East deposit was estimated to have 6.2 Mmt of proven and probable reserves averaging 9.9% Cu and 0.9% Ni.[18]

Inco has discovered additional mineralization in the Thompson nickel belt of Manitoba. The new discovery was close to the Pipe No. 1 Mine. The Pipe No. 1 was on standby, together with the Pipe No. 2, the Soab North, and Soab South Mines. More definitive drilling was scheduled for 1993. The company had already begun spending $248 million to develop the 1-D ore body and expand operations at the Birchtree Mine on the outskirts of the City of Thompson. The 1-D project was expected to be completed sometime in 1997.

Falconbridge had six mines in operation at Sudbury during 1992—the Craig, Fraser, Lindsley, Lockerby, Onaping, and Strathcona. The six underground mines hoisted a total of 2.4 Mmt of ore that yielded 35,400 tons of nickel, 37,600 tons of copper, and 800 tons of cobalt in matte.[19] The company continued to explore for nickel and copper in the Sudbury Basin and in the neighboring Wanapitie anomaly east of Levack. Efforts were being concentrated at the Nickel Rim prospect, 12 km north of Falconbridge. Company geologists believe that the Victor deposit recently discovered by Inco may extend onto Falconbridge's property at that point. A 2,950-m-deep drill hole intersected a very narrow zone of high-grade sulfide mineralization, but considerably more drilling is required.

Falconbridge embarked on a full-fledged feasibility study of its Raglan deposit. The world-class nickel deposit is in northeastern Quebec on the northern tip of the Ungava peninsula. Extensive drilling was carried out during the first 5 months of 1992. Work done through 1992 identified at least 18.1 Mmt of ore averaging 3.13% Ni and 0.88% Cu. The company cleaned up the original exploration site and completed an environmental baseline study in preparation for permitting. Falconbridge was also conducting exploratory drilling in Botswana, Labrador, and Manitoba. Significant mineralization was identified at William Lake, Manitoba, under 100 m of limestone at the southwest extension of the Thompson nickel belt.

Sherritt Gordon Ltd. experienced startup problems at its new refining complex in Fort Saskatchewan, Alberta, but these problems were largely overcome. The new facility replaced a less efficient operation that had been in operation at Fort Saskatchewan since the late 1950's. The first phase of the project was completed on schedule in May 1992. The new complex consisted of a nickel refinery and cobalt separation and reduction plants. The complex was designed to process nickel feedstock with a high cobalt content. Feed material was being supplied by Cubaniquel and Union de Empresas del Niquel under agreements concluded with the two Cuban organizations in 1991. Because of the switchover, Sherritt Gordon produced only 16,600 tons of nickel, down 17% from 20,000 tons in 1991. Cobalt production was also down 17%, dropping from 820 tons to 680 tons.[20]

The Cuban contracts came at an opportune time and solved some key problems for both parties. The Fort Saskatchewan refinery lost 60% of its feed material when Inco decided not to renew its 10-year feedstock contract with Sherritt in 1989. At one point, in 1990, the shortage of feed was so severe that Sherritt had to close the refinery for 2 months. Since then, the company had built up a feed stockpile to guard against future supply disruptions. In the case of the Cubans, the Sherritt sales helped offset reduced exports of nickel-cobalt feedstock to Russia and gained hard currency for the country. In 1992, Sherritt's oil and gas group began helping Cuba bring offshore oilfields in and around the Bay of Cardenas into production. Sherritt also had a contract to explore for oil onshore in central Cuba, south of the existing Pina oilfield. The new oil production should help ease fuel shortages at Cuba's nickel refineries.

Black Hawk Mining Inc. agreed to buy the Redstone nickel mine near Timmins, Ontario, from Timmins Nickel Inc. for $117,000 (C$150,000). The relatively small, high-grade underground mine had been producing 92,000 to 96,000 mt/yr of sulfide ore grading 2.32% Ni when it was idled in June 1992. Timmins was forced to halt operations after the company lost its lease on the nearby Carshaw mill where the ore was being treated. The 450 ton-per-day mill, in Shaw Township,

was owned by Marshall Minerals Corp. of Niagara Falls, Ontario. Redstone was originally a joint venture of BHP-Utah Mines Ltd. (49%) and Timmins Nickel (51%). As part of the agreement, Black Hawk was to pay Sherritt Gordon, which had been refining concentrates for Timmins, $78,000 plus a 2% net smelter return royalty on any future production. The royalty was not to exceed $244,000. In exchange, Sherritt was to cancel all of the debts owed the Albertan refiner by Timmins. Sherritt also would have the right to buy future concentrates from the mine at competitive prices.

Black Hawk was committed to spend $312,000 over the next 18 months exploring the property, but did not expect to reopen the mine until nickel prices return to the $3.50 per pound level. At the end of the 18-month period, Sherritt can elect to convert its royalty into a 40% working interest in the mine. According to Black Hawk officials, at the time of closure, about 36,000 tons of reserves had been developed to the 244-m (800-foot) level, with an average grade of 2.6% Ni. Timmins engineers estimate that the mine had proven and probable reserves of more than 300,000 tons averaging 2.2% Ni.

Hudson Bay Mining and Smelting (HBMS) has decided to close its Namew Lake Mine in northern Manitoba. Reserves at the mine, a joint venture of HBMS (60%) and Outokumpu Mines Ltd. (40%), are nearly exhausted, and exploration efforts had failed to locate any new ore zones in the area. The mine had been capable of producing concentrate containing 9,200 tons of Ni and 3,500 tons of Cu.

Colombia.—Cerro Matoso S.A. was caught up in the spinoff of Billiton from Shell. Billiton had a 47% equity in the Colombian ferronickel producer. Another 48% was controlled by Instituto de Fomento Industrial, an agency of the Colombian Government. The remaining 5% was owned by Cia. de Niquel Colombiano S.A. Cerro Matoso recovers laterite from an open pit mine near Montelibano in the Department of Cordoba. The lateritic ore, which averages 2.9% Ni, is smelted on-site in a 51-megavolt-ampere electric furnace built by Elkem A/S. In 1992, Cerro Matoso produced 20,195 tons of nickel contained in ferronickel ingots and granules. The ferronickel had traditionally assayed 40% to 42% Ni. Billiton had been planning to expand the capacity of the Colombian operation to more than 30,000 mt/yr of Ni, but these plans were put on hold in early 1993. Production had been running slightly below the 22,500-mt/yr design limit of the smelter when nickel prices began to weaken. The addition of a smaller, 12,000-mt/yr furnace would have given Cerro Matoso more flexibility during periods of peak demand and would have permitted the facility to produce as much as 35,000 mt/yr. The existing furnace was expected to operate at full capacity for the remainder of 1993.

Cuba.—The Cuban nickel industry had three plants in operation: the Rene Ramos Latour at Nicaro, the Pedro Sotto Alba at Moa, and the Ernesto Che Guvera at Punta Gorda, 3 km from Moa.[21] The Nicaro and Punta Gorda plants both employed an ammonium carbonate leach process to recovery nickel from serpentine laterites. The Nicaro plant could make four products: oxide sinter (90% Ni), nodular oxide (77% Ni), granular oxide (77% Ni), and oxide powder (76% Ni). The Moa plant used a sulfuric acid pressure leach to produce a mixed sulfide precipitate containing 50% Ni+Co from limonitic laterites. The leaching was carried out at 250° C and 4,000 kiloPascals to prevent large amounts of iron from dissolving along with the nickel and cobalt. Construction of a fourth plant, an ammonium carbonate leach operation at Las Camariocas, was behind schedule as the result of the political restructuring of Eastern Europe. The defunct German Democratic Republic had been providing substantial support for the 30,000-mt/yr Ni refinery project.

The Government of Cuba reportedly had given the three companies increased autonomy, making operations more efficient. However, fuel shortages continued to restrict production. The Punta Gorda plant was closed in September 1990 as part of a number of energy-saving measures announced by the Government, but reopened in April 1991 after modifications were made to the operation. New extractive technology and equipment would enable the Cubans to become more energy efficient and to produce higher purity nickel. Help in this area was being provided by the United Nations Development Program and undisclosed Canadian companies. Part of the nickel-cobalt sulfide precipitate that had been going to the Russian refinery of Orsk was being shipped to Sherritt Gordon's refinery at Fort Saskatchewan, Alberta.

A stainless steel plant was commissioned in neighboring Las Tunas Province sometime during 1992, but detailed information about its design was meager because of the embargo. By yearend, the plant had consumed about 500 tons of Ni contained in some type of oxide sinter. Nickel consumption was expected to increase to 1,500 mt/yr after startup problems were overcome.

Finland.—Outokumpu Oy was restructuring some of its operations in anticipation of total privatization. Although the Finnish Parliament had given the Government authority to decide on ownership structures, no decision had been made on whether the Finnish State will actually relinquish its majority holding in Outokumpu. The Ministry of Trade and Industry had initiated studies on different aspects of privatization. On December 31, 1992, the Finnish State still held 57.5% of the stock in Outokumpu. Another 16.0% was controlled by the Social Insurance Institution. The remaining 26.5% was owned by private Finnish investors and institutions.

In November 1992, the Forrestania Mine in Australia came on-stream. (See Australia section of this report.) The mine was owned by OMR, the company's base metals subsidiary that had interests in copper and zinc as well as nickel. The mine, together with the long-term contract with WMC for Mount Keith concentrate, secured feed material for the

Harjavalta smelter for years to come. The smelter in Turku-Pori Province was expanded and upgraded in 1991 at a cost of $17 million. In 1992, Outokumpu Harjavalta Metals Oy produced 14,800 tons of Ni, 110,500 tons of blister copper (a new record), and 70,900 tons of cathode copper (also a new record).[22] Plans were made to expand the nickel production of the operation from 18,000 mt/yr to 32,000 mt/yr, pending approval from senior management.

Greece.—On November 10, Hellenic Mining and Metallurgical Co. of Larymna S.A. (Larco) had to slash its output by 50% because of serious cash-flow problems, aggravated by declining nickel prices. The Greek ferronickel operation was to produce only about 800 to 1,000 tons of contained Ni per month. About 46% of Larco's 1,700 work force was to be suspended at half pay for 8 months. The Larymna smelter was capable of producing 25,000 mt/yr of Ni contained in ferronickel, but had been hampered by relatively low ore grades and high-priced electric power. Significant increases in productivity had been made since the mid-1980's, but production costs reportedly have been running about $3.65 per pound of contained Ni, with electric power accounting for 32% of the total cost. A new ore dressing plant commissioned in late 1992 was expected to help limit future power costs. Larco was controlled by the State-owned Industrial Reconstruction Organization, which had a 43% share in the operation since 1988. The next largest shareholder was the Public Power Corp. (DEH), with 27% equity. The parastatal operation reportedly was in arrears on its August and September power bills from DEH. The Greek Government had wanted to privatize the operation since 1990 and was being advised by the First Bank of Boston.

Indonesia.—P.T. International Nickel Indonesia produced a record high 36,300 tons of Ni in matte in 1992, up from 34,428 tons in 1991. The company continued to increase capacity, after having just completed a 3-year, $83 million expansion program in early 1991. Furnace No. 3, one of three electric furnaces at P.T. Inco's operation on the island of Sulawesi, was rebuilt during the first half of 1992 and was back in full operation by June. An improved modular electrode control system was added while the furnace was shut down. A new furnace roof was installed at the same time. The suspended roof was of advanced design and did not require water for cooling.

At the end of 1992, Furnace No. 2 was shut down for similar rebuilding and upgrading and was scheduled to return on-line by mid-1993. Construction of a 24-MW, three-unit diesel electric generating station began in March 1992. The additional power was to supplement the output of the company's existing hydroelectric facility. The furnace upgrading and other ongoing improvements were intended to raise the production capacity of the mining and smelting complex to 45,000 tons of Ni in matte by 1995. The bulk of the matte, which contained 77% to 80% Ni, had traditionally gone to Japan for refining under long-term contracts. The Sulawesi operation was a joint venture of Inco, Sumitomo Metal Mining, and the Indonesian public.

P.T. Aneka Tambang was also expanding capacity. The operation at Pomalaa produced 5,507 tons of Ni in FeNi, up 4% from 5,318 tons in 1991. Production of ore for export rose from 32,086 tons of contained Ni to 35,745 tons in 1992, but was scheduled to drop slightly in 1993.

Japan.—Two Japanese nickel producers joined the ranks of smelters and refiners planning to cut back output in 1993. Pacific Metals Co. Ltd. announced that it would reduce ferronickel production from its current level of 29,000 mt/yr of contained Ni to possibly 25,000 tons. The company's plant at Hachinohe in Aomori Prefecture is capable of making a total of 42,000 mt/yr of Ni in FeNi with its three electric furnaces. In 1991, the plant produced 37,682 tons of contained Ni—a record high for Hachinohe. Garnierite feed for the operation came from New Caledonia and the Indonesian island of Celebes.

Sumitomo Metal Mining was also considering reducing its output. The company operated a refinery at Niihama in Ehime prefecture on the island of Shikoku. The Niihama complex was expanded to be capable of producing 26,000 to 29,000 mt/yr of electrolytic nickel.

Sumitomo was switching from its existing solvent extraction-electrowinning process to a newer, more productive process called Matte Chlorine Leach Electrowinning (MCLE). The technology was developed in-house by Sumitomo. The company was in the final stages of completing a state-of-the-art refinery at Niihama based on the new technology. Construction of the new 24,000-mt/yr facility began in late 1991 and was scheduled for completion in March 1993 at a cost of $60 million. 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 was Japan's only producer of refined nickel and produced 23,658 tons of the metal in 1991.

As mentioned earlier, Sumitomo renewed its long-term purchase contract with WMC on April 8, 1992. The Japanese refiner was to receive 20,000 tons of nickel matte annually from WMC until the year 2002. Sumitomo began buying concentrates from WMC in 1967, but changed to matte in 1972. Sumitomo also used matte from P.T. Inco and had a 20% interest in the Indonesian operation since 1988.

Sumitomo had a ferronickel plant at Hyuga, Miyazaki Prefecture, capable of producing 18,000 mt/yr of Ni in FeNi. In 1991, the Hyuga plant made four grades of ferronickel containing a total of 17,457 tons of Ni. The nickel content varied from 18% to 28% depending on the carbon level and other grade characteristics.

New Caledonia.—Société Métallurgique le Nickel (SLN) shipped 32,081 tons of

nickel in ferronickel, down from 38,469 tons in 1991. The company's three furnaces at Doniambo had a combined capacity of about 48,000 mt/yr of Ni in ferronickel. The operation could also produce about 10,000 mt/yr of Ni in matte. The ferronickel was averaging about 29% Ni; the matte, 75% Ni.

In 1991, Inco signed an agreement with Le Bureau de Récherches Geologiques et Minières (BRGM) to evaluate lateritic reserves on New Caledonia. Inco officials were so impressed with the preliminary evaluation reports that they subsequently purchased Compagnie des Mines de Xere (formerly Société de Promotion des Mines) from BRGM, thus gaining title to large resources at the southeastern tip of the island.

A new company, Goro Nickel S.A., was set up to study the feasibility of mining the newly acquired property, with Inco owning 85% of the equity. The Goro deposit reportedly had 150 Mmt of ore averaging 1.57% Ni. Inco also controls an additional 10 Mmt averaging 2.13% at Tiebaghi on the opposite end of the island. If developed, the New Caledonian ore conceivably could be sent to Inco's Indonesian subsidiary for smelting. The Soroako smelter on Sulawesi should be capable of producing 45,000 mt/yr of Ni (in matte) by 1995 and would need 25% more ore than it was receiving locally to operate at full capacity. An alternative would be to build a Doniambo-type smelter on-site. (See Indonesia section of this report.)

Philippines.—Ore and concentrates containing 12,701 tons of Ni were shipped to Japan, down from 14,238 tons in 1991. The production came from the Rio Tuba Nickel Mining Corp. on Palawan Island and two smaller mines near Surigao in northern Mindanao. The larger of the Mindanao mines was operated by the Taganito Mining Co., a subsidiary of Japan's Pacific Metals.

Attempts to rehabilitate the shuttered Surigao Mine and refinery on Nonoc Island were stymied by declining nickel prices, large exports of nickel from Russia, and a global slowdown in stainless steel consumption. The laterite operation had been shut down since mid-1986, following the liquidation of its former owner, the Marinduque Mining and Industrial Corp., by the Philippine Government.

In early January 1993, Inco sent a team of engineers and geologists to evaluate the island complex off the northern tip of Mindanao, but nothing immediately materialized. In 1991, the Jesus Cabarrus investment group bought the Nonoc operation from the Assets Privatization Trust, the Government agency responsible for selling off State-owned enterprises. Since then, the group had arranged for some refinancing, settled with at least one major creditor, and tried to restart the operation under the name Philippine Nickel Co. (Philnico). Rehabilitation costs could easily exceed $200 million.

Russia.—The sales manager for the Norilsk Nickel Combine told wire services that the company produced 240,000 tons of nickel in 1992. Production was down 15% from that of 1991 because of heavy snowfalls and unusually high winds during the 1992-93 winter. This was the first time that the giant combine had ever disclosed its production data. As of mid-1993, no official figures had been released by the new Government of Russia. Before the dissolution of the former U.S.S.R., information of this type was considered a state secret. Some Western analysts believe that the combine's preliminary figure is too high and will eventually be revised downward to about 225,000 tons. The figure apparently represented the combined output of the Norilsk operation in north-central Siberia and the company's two other operations, Monchegorsk and Pechenga, in the Kola Peninsula. The combine accounted for about 80% of Russian nickel production, the rest being in the Urals.

The Norilsk-Talnakh district had one open pit and five underground mines, but only two concentrators and two smelters, creating an imbalance in the system. The two smelters had a combined output of 180,000 tons of Ni in matte, but the local refinery could handle only 100,000 tons. As a result, the excess ore, concentrate, and matte was being shipped to the combine's other refinery and two smelters on the Kola Peninsula. This material was being railed to Dudinka, near the mouth of the Yenisey River, and then loaded onto ocean vessels bound for the Port of Murmansk.

Official Russian customs data on 1992 nickel exports were still being compiled at the time of publication. According to data received by the INSG from importing countries, the former U.S.S.R. shipped a total of 93,192 tons of unwrought nickel (in unalloyed form) to 15 countries in 1991. A total of only 37,250 tons had been reported, as of this writing, from Russia for 1992, with the bulk going to Germany (11,093 tons), France (5,273 tons), the United States (3,385 tons), and Japan (3,300 tons). Norilsk also had been sending significant amounts of nickel matte to Norway for refining. In 1991, the former U.S.S.R. shipped 13,055 tons (gross weight) of matte to the Kristiansand refinery of Falconbridge Nikkelverk A/S. Preliminary data indicated that shipments of Russian matte to Kristiansand dropped off dramatically in 1992 and were partly replaced by matte from Canada.

In early 1992, the Russian Government became increasingly concerned about reports of massive smuggling of strategic raw materials through Estonia, the other two Baltic States, and the Kaliningrad enclave (formerly Königsberg). To prevent a massive flow of metals to Western markets, the Russian Government imposed a new series of export tariffs and tightened the export licensing process. Exporters were also being required to exchange 50% of their foreign currency earnings at a rate set by the Russian central bank. Officials in the Ministry of Foreign Economic Relations insisted that the new export tariffs, which took effect July 1, 1992, were less stringent than the previous system of regulations and controls. The new Government still requires Norilsk to allocate most of its production to domestic consumers and reportedly reduced the combine's 1993 export

license by 10,000 tons from the 1992 authorization level.

Norilsk officials, too, expressed concern about the flow of so-called "gray" (deliberately misclassified) or "black" (smuggled) nickel into Western markets but insisted that their company was powerless to prevent it. In early 1993, the price of nickel within Russia was about 2 million roubles (US$1,700) per metric ton compared with $5,800 to $6,100 on the LME. The flow to the West was expected to slow somewhat in 1993 because Russian consumers apparently had sold off the bulk of their excess stocks and the internal price for nickel continued to rise. Estonia, Latvia, and Lithuania promised to do more to discourage smuggling of Russian metals through their ports. Norilsk officials believed that it would take at least 2 to 3 more years to stabilize the new Customs Frontier.

Solomon Islands.—Kaiser Engineers Inc. was evaluating two deposits of nickeliferous laterite in the north-central island province of Isabel. The larger deposit had an estimated 21 million cubic meters of ore; the smaller, 13 million cubic meters. Both average about 1.4% Ni. The main island of Santa Isabel is about 80 km northwest of Guadalcanal. Laterites were first discovered on Santa Isabel in the 1960's. NSR Environmental Consultants Pty. of Australia has been hired to study the environmental impact of future nickel mining on the island group.[23]

South Africa, Republic of.—As previously mentioned, Gencor was seeking to buy selected metal and mineral operations owned or controlled by Shell's subsidiary, Billiton B.V. Gencor, which had holdings in coal, gold, manganese, and the platinum-group metals (PGM), reportedly wanted to concentrate on mining and divest its nonmining interests. Management was hoping to complete the unbundling by August 31, 1993. Under the plan, Gencor would relinquish control of its industrial arms—the paper and pulp company Sappi, the consumer products group Malbak, and the energy company Engen.[24] Part of the money from the unbundling would be used to buy equity in mines outside South Africa.

Gencor is the second largest mining company in the Republic of South Africa after the Anglo-American Group. Impala Platinum Holdings Ltd. (Implats), one of Gencor's subsidiaries, produced nickel powder and briquets as a byproduct of its PGM operations in Bophuthatswana. The subsidiary had four underground mines extracting PGM/base metal sulfide ore from the Merensky and Upper Group 2 (UG2) Reefs of the Bushveld Complex. The sulfides were being concentrated at a central processing plant and then shipped to the company's refinery at Springs.

Samancor, the ferroalloys subsidiary of Gencor, has been involved in the production of chromium and manganese alloys for many years. In September 1991, Samancor acquired Middelburg Steel and Alloys Holdings (Pty.) Ltd., an important South African stainless steel and ferrochromium producer. That transaction enhanced Samancor's reserves of chromite and increased its ferrochromium production capacity. Samancor is a partner in the Columbus Project, a joint stainless steel venture with Anglo American Corp. With the commissioning of the Columbus stainless plant in 1995, South African consumption of nickel is expected to increase significantly. By the year 2000, South Africa could become a net importer of nickel.

Tanzania.—On June 1, 1992, Kagera Mining Co. Ltd. concluded a comprehensive exploration and development agreement with the Government of Tanzania. Kagera Mining was given the exclusive right to explore for nickel and several associated metals (cobalt, copper, lead, platinum, and zinc) in the northwest corner of the African country for 1 year, with options to develop and mine any target areas of the company's choosing. Sutton Resources Ltd. and Romanex International Ltd. of British Columbia own 90% of the newly formed Tanzanian enterprise. The remaining 10% is held by the Tanzanian Government, which would also receive a 3% royalty on any minerals produced in addition to normal tax revenues.

Sutton Resources was already evaluating a major nickel-cobalt-copper deposit at Kabanga on the Burundi border under a 1990 agreement with Tanzania. Additional drilling on a tighter pattern delineated 25.5 Mmt of ore grading 1.19% Ni, 0.10% Co, and 0.20% Cu at a cutoff grade of 0.5% Ni.[25] The sulfide ore is associated with a series of ultramafic intrusives, primarily peridotites and pyroxenites. The Kabanga deposit lies in the southwest corner of the Kagera region and is only 1 of 101 anomalies identified by United Nations Development Program teams in the 1970's. At least 12 of the remaining 100 anomalies are also associated with ultramafic rocks.

Kagera Mining is named for the 26,400-square-kilometer region that is covered by the reconnaissance license, between the Rwanda border and Lake Victoria. The region includes the Biharamulo, Muleba, Ngara, Bukoba Rural, and Karagwe Districts. The new company must spend a minimum of $1 million on its exploration program during the first year. This figure represented an expenditure of $35 per square kilometer plus the license fees for the first year. Since the signing of the Government agreement, Sutton Resources has formed a joint venture with BHP Minerals International Inc. to evaluate certain unspecified properties in the Kagera region. The exploration work would earn BHP a 66.6% interest in the first mine developed in the Kagera belt and a 58% interest in the first mine at Kabanga. BHP was conducting an airborne geophysical survey of the entire concession.

Zimbabwe.—Bindura Nickel Corp. Ltd. (BNC) celebrated 25 years of operation. Although small-scale mining began in August 1964, the first nickel concentrates were not produced until July 1968.

A total of 2.817 Mmt of ore was milled in 1992, yielding 12,378 tons of Ni in concentrate.[26] The concentrates came from four underground mines: the Trojan (5,519 tons Ni), the Shangani

(3,677 tons), the Madziwa (1,731 tons), and the Epoch (1,451 tons). Mill head grades ranged from 0.47% to 0.73% Ni. Additional reserves were found at Madziwa and the Epoch Mines, extending their lives by 1 to 2 years. The smelting and refining complex at Bindura (BSR) produced 11,370 tons of nickel cathode, 1,134 tons of copper, and 100 tons of cobalt (in cake). Of the 11,370 tons of nickel produced, 10,328 tons came from BNC operations and 1,042 tons was toll work.

The prolonged drought continued to make problems for Bindura by driving up the cost of electrical power and putting restrictions on power consumption. Bindura's management claimed that power rates were already excessive because of inefficiencies at the regional generating stations. To help cut power costs, BNC agreed in October 1992 to purchase part of the power entitlement given to Zimbabwe Alloys Ltd.

BNC made several improvements to its smelting and refining complex. In December 1992, a new electrostatic precipitator was commissioned at the BNC smelter. The furnace, which had been in operation for 11 years, was shut down 4 months later for complete rebuilding. A new sodium sulfate crystallization plant was also commissioned in 1992. The byproduct sulfate was to go to the Zimbabwean detergent industry, where it would meet about one-half of that industry's needs. Until this development, all of the sulfate had to be imported. *(See tables 10 and 11 for individual country data.)*

Current Research

Queneau International Symposium.—A special international symposium was organized by The Minerals, Metals & Materials Society (TMS) to honor Dr. Paul E. Queneau, Sr., for his outstanding contributions to pyrometallurgy. Professor Queneau was coinventor of the Inco Flash Smelting Process and chief research officer at Inco Ltd. for many years. He coauthored The Winning of Nickel, a classic text on the metal, and is currently an emeritus faculty member at Dartmouth College.

The symposium was held in Denver, CO, from February 21 to 25, 1993, in conjunction with the annual TMS meeting. About 115 papers were presented on the extractive metallurgy of cobalt, copper, and nickel, highlighting much of the research, development, and upgrading that occurred around the world between 1988 and 1992.[27] The first half of the symposium dealt with fundamental aspects; the second, individual copper and nickel smelter operations. Many of the presentations dealt specifically with the production or recycling of nickel. Flash smelting, bath smelting, and reverberatory furnace smelting were all discussed. Updates were given on nickel operations in Australia, Canada, China, Colombia, Cuba, the Dominican Republic, Russia, and Turkey.

Sulfur Dioxide Abatement.—A large part of the Denver program focused on sulfur dioxide (SO_2) abatement technology—one of the keys to minimizing acid rain. The Provincial government of Ontario has ordered Inco to reduce the SO_2 emissions from its Copper Cliff smelter complex at Sudbury to less than 265,000 mt/yr by January 1, 1994. Inco was in the midst of streamlining its mill-smelter operation and expected to be in compliance by the deadline. The Copper Cliff abatement program was one of the largest environmental projects ever undertaken by a mining company. Inco had already spent $505 million on the project. More than 90% of the construction was completed by the beginning of 1993. A containment level of more than 75% was achieved in 1992, resulting in the recovery of 300,000 tons of sulfuric acid from smelter gases during the year.

The 1994 containment level will represent a 93% reduction in SO_2 from 1978 levels and will account for 90% of the sulfur mined.[28] Milling was being consolidated at one mill, instead of three. A single Cu-Ni bulk concentrate was to be flash smelted in two new flash furnaces, producing a matte of about 45% Cu+Ni. This matte was to be further processed to Bessemer matte in conventional Pierce-Smith converters and sent to an upgraded matte separation plant. After separation, the copper sulfides (primarily chalcocite with 3% to 6% Ni at this point) were to be oxygen converted to a semiblister in a reactor of new design. The nickel sulfides were to be roasted separately to nickel oxide. The streamlined operation sharply reduced the number of emission sources, was more energy efficient, and eliminated several copper processing problems. At least six copper producers have followed suite and were upgrading their flash smelting operations.

Advanced Smelting Technologies.—In May 1991, Mitsubishi Materials Corp. put a new, more efficient copper smelter into operation at its Naoshima smelting and refining complex in Kagawa, Japan.[29] The new continuous smelter cost $160 million and replaced two existing smelters—a Mitsubishi continuous furnace that had been in operation since 1974 and a conventional reverberatory furnace. The new smelter relied heavily on molten bath technology and differed significantly from both traditional matte smelting (where roasting, smelting, and converting are carried out in separate steps) and flash smelting (where the roasting and smelting stages are combined into a single step). At Naoshima, copper sulfide concentrates and flux materials were being injected together with 40% to 50% oxygen-enriched air into the molten bath through top-blowing lances. The injection had to be done at very high speed to prevent premature ignition. The molten bath was mostly matte with a thin layer of slag on top. Copper scrap and sludges also could be added to the bath via a drop chute. This process conceivably could be adapted to the smelting of nickel sulfides because nickel and copper have similar affinities for oxygen.

A great deal of effort has gone into studying the combustion of metal sulfide particles in the reaction shaft of the flash furnace. WMC and the Australian Government currently have a joint research program aimed at better understanding the burner environment in

WMC's nickel flash furnace at Kalgoorlie.[30] The Outokumpu-type furnace had been treating about 550,000 mt/yr of concentrate containing about 10% Ni. Special ports were constructed in the upper walls and roof of the shaft so that samples of solids and gas could be collected in the vicinity of the burners. The ports also allowed researchers to measure particle temperatures and determine shaft wall temperature profiles. The Commonwealth Scientific and Industrial Research Organization, the Australian Government agency collaborating with WMC, was also working with Mount Isa Mines Ltd. on adapting the Isasmelt lead smelting process to copper concentrate. In June 1992, Cyprus Miami Mining Corp. commissioned a full-scale Copper Isasmelt furnace at Miami, AZ, capable of handling 585,0000 mt/yr of concentrate.

Metallurgists in Russia and Kazakhstan spent more than 25 years developing and improving the Vanyukov furnace.[31] The Vanyukov process, based on bath smelting technology, is an alternative to flash smelting, but is not well known outside central Eurasia. Pilot plant work at Ryazan, 200 km south of Moscow, demonstrated that the process can be used to continuously smelt a variety of copper-nickel ores and concentrates. One of the principal advantages of the process is that the copper-nickel content of the matte can be adjusted over a wide range to compensate for differences in ore type. Mattes have been produced with a total nonferrous metal content ranging from 35% to 70%.

Commercial-size Vanyukov furnaces were treating copper and/or copper-nickel charge material at two locations in the C.I.S.—the Balkhash copper smelter in Kazakhstan and the Norilsk copper smelter in Siberia. The box-shaped furnace at Norilsk is divided into two parts by a partition. The first compartment is used to smelt the charge and is operated in a continuous mode under oxidizing conditions. Enriched air containing 70% oxygen (by volume) is blown through tuyeres in the compartment walls. The second compartment was originally designed for slag cleaning under reducing conditions. However, in actual practice, slag cleaning is minimal. The furnace walls are cooled by a series of copper water jackets.

A more revolutionary smelting process was being investigated at bench level. A thermal plasma arc can be used to produce high-grade matte directly from Ni-Cu concentrates. Work in this area was being conducted at the Kunming Institute of Technology in China and the University of Idaho. Thermal plasma arc smelting may prove especially useful for recovering nickel, chromium, and other transition metals from a variety of furnace dusts. The Kunming version of the process reportedly has worked well with nickel-bearing pyrrhotite from Jin Chuang. The Chinese were using a quartz-lined microwave reactor of special design to partially desulfurize the concentrates before smelting.

Intermetallics.—North American metallurgists were conducting research on fatigue and creep in nickel aluminides, titanium aluminides, titanium niobides, and similar intermetallic alloys as part of the domestic aerospace program. Both intermetallics and conventional superalloys, such as Waspaloy and Incoloy 907, can be reinforced with tungsten or molybdenum metal fibers. Nickel aluminides, a new class of lightweight and ductile high-temperature alloys, are six times as strong as stainless steel at 600° C. Nickel aluminide was first studied in the 1950's, but was found to be extremely brittle. In the late 1970's and early 1980's, researchers in Japan and at the Oak Ridge National Laboratory discovered that the addition of small amounts of boron and hafnium to Ni_3Al turned the brittle compound into a strong, ductile alloy. Armco Inc. has been licensed by Oak Ridge to produce the new alloy, which shows extreme resistance to cavitation, making it useful for pump and turbine parts. Nickel and titanium aluminides are potential weight-savings alternatives to superalloys in advanced gas-turbine engines if the brittleness problem can be completely overcome.

U.S. Bureau of Mines Projects.—Liquid emulsion membrane (LEM) extraction technology being perfected at USBM's Albany Research Center could help both the domestic electroplating industry and producers of nickel chemicals. Work to date has shown that more than 95% of the copper in dilute mine waste solutions can be recovered using LEM technology. Nickel behaves similarly to copper in certain chemical environments and may be able to be recovered from residual processing effluents with similar success.

Other researchers at the Albany Center succeeded in producing a nickel-chromium-iron master alloy directly from low-grade lateritic ores found in the coastal ranges of southern Oregon and northern California. These ores are associated with ultramafic ophiolite sequences of Jurassic age and typically contain only 1.1% Ni and 1.1% Cr. The smelting was carried out in a submerged arc furnace, using coke breeze, metallurgical coke, and wood chips as reductants. Pebble lime was added as a flux. The master alloy could be used to make inexpensive stainless steel if the process proves economically feasible.

The Rolla Research Center developed an electrochemical process for recovering individual metals directly from contaminated superalloy scrap. The process is based on controlled-potential electrolysis. Superalloy chips and/or turnings are placed inside a cage-shaped anode and immersed in an acidic chloride-sulfate solution. The migrating nickel and cobalt cations are codeposited as a 99%+ pure alloy at the cathode, while the chromium, molybdenum, and tungsten are precipitated from the anolyte in a side purification circuit as a mix of impure hydroxide residues. The process should work for a variety of de-oiled scrap materials, including turbine blades, turbine disks, grinding sludges, and machine turnings.

Rolla researchers were studying ways of recovering cobalt and nickel from lead tailings in Missouri. Their microscopy work showed that cobalt and nickel occur in the tailings primarily as minor siegenite [$(Co,Ni)_3S_4$] and bravoite

[$(Fe,Ni)S_2$].

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 former U.S.S.R. 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 material came at a time when Western nickel demand was already weakening, causing LME stocks to build to excessive levels. By September 1993, the LME warehouses in Rotterdam held more than 106,000 tons of nickel—almost a 2-month supply for the entire West. Export controls imposed by the new Russian Government have partially slowed the flow of cathode, but some smuggling will inevitably continue until the ruble completely stabilizes. Exports of cathode and nickel alloys masquerading as scrap have been especially difficult to control. Russian exporters of strategic metals now must have a license and provide detailed information on their foreign bank accounts to the Ministry of Foreign Trade.

The Russian push to export is being driven by two forces. First, demand for stainless within the former U.S.S.R. 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 metric ton, at a time when the LME price was about $8,000 per ton. This gap narrowed considerably in late 1991 and early 1992. By July 1992, the internal price had skyrocketed to $4,100 per ton and stood at about 55% of the LME price. Since then, the situation has deteriorated considerably. In March 1993, the internal price was only 43% of the LME cash price. The difference between 43% and 55% does not seem that large. However, during the 8-month period, the LME price gradually dropped from $7,498 per ton to $5,971 per ton and has been slowly sinking.

The global slowdown in economic activity and growing LME stocks have been putting more and more pressure on nickel prices. On September 16, 1993, the LME price fell below $4,410 ($2.00 per pound) for the first time in 6 years. This was a disaster for some marginal producers whose break-even point had been $6,610 ($3.00 per pound). All of the producers were being squeezed to some degree between declining prices for their products and rising operational costs. A fortunate few were partially protected by long-term sales contracts and were able to fill orders with material acquired through the LME.

The lower limit of the LME cash price will be determined by the willingness of producers in North America and the western Pacific Rim to retain market share by selling below cost. If the LME price continues to slide, several producers will have to begin slashing output at some point or face bankruptcy. 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. Norilsk signed a cooperative agreement with Outokumpu in September 1993 and has already strengthened ties to three or four Western trading companies. Outokumpu was considering helping Norilsk upgrade its facilities in exchange for nickel and copper. One or two Russian-Finnish joint ventures are also possible if the Russian Government acquiesces. Long-term financing could be provided by a consortium of Scandinavian and EC investment banks.

Austenitic stainless steel will continue to drive world nickel demand for both the short term (1994-96) and midterm (1997-99). 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. Prices could conceivably return to 1992 levels in early 1995 if Japan were to emerge from its current recession and dramatically increase stainless production.

Western demand for austenitic stainless in 1994 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. In recent years, there has been a significant shift in U.S. exports of stainless scrap from Japan and Western Europe to the Republic of Korea, Taiwan, and other rapidly developing "Tiger" countries. 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. 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. Production of stainless steel in Western Europe is expected to be flat in 1994 and could even decline slightly because of growing recessionary forces on the Continent.

The long-term (2000-2003) 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. Chemical 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.

Advanced batteries and electric vehicle technology probably will not significantly affect the nickel market before the year 2002. The nickel-metal hydride battery and the nickel-cadmium battery are both serious contenders for the power system of the futuristic automobile, but could lose out to their sodium-sulfur, advanced lead-acid, or zinc-air competitors. If a nickel battery were adopted universally, U.S. demand for the metal could easily double.

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[13]The 7.5% Ni estimate for stainless steel scrap is under investigation. Assigning meaningful content values to other types of nickel-bearing scrap is proving even more difficult. Methods of attacking the content problem are discussed in BuMines Information Circular 9275. For additional information on this problem, the reader should refer to: Papp, J. F. Chromium, Nickel, and Other Alloying Elements in U.S.-Produced Stainless and Heat-Resisting Steel. BuMines IC 9275, 1991, 41 pp.

[14]OM Group, Inc. (Cleveland, OH). Securities and Exchange Commission Registration Statement (Form S-1). Apr. 1, 1993, 58 pp. plus appendices.

[15]At Sudbury and some other deposits, the pyrrhotite may contain enough nickel to offset the costs of handling the additional sulfur.

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TABLE 1
SALIENT NICKEL STATISTICS

(Metric tons of contained nickel unless otherwise specified)

	1988	1989	1990	1991	1992
United States:					
Mine production	—	—	330	5,523	6,671
Plant production	—	347	3,701	7,065	8,962
Secondary recovery from purchased scrap:					
From ferrous scrap	r40,176	r32,330	r36,874	r31,216	39,148
From nonferrous scrap	r9,195	r10,235	r9,205	r9,088	11,991
Exports:					
Primary (nickel content)	5,561	4,242	8,873	9,104	8,560
Secondary (nickel content)	22,355	27,218	28,184	27,798	25,307
Imports for consumption:					
Ore (nickel content)	—	—	—	371	3,584
Primary (nickel content)	140,039	r127,880	r133,545	r132,446	118,760
Secondary	5,884	9,137	11,634	6,212	9,506
Consumption:					
Reported:					
Primary	r98,765	r99,835	r112,876	r102,636	95,557
Secondary (purchased scrap)	r49,371	r42,565	r46,079	r40,304	51,139
Total	r148,136	r142,400	r158,955	r142,940	146,696
Apparent:					
Primary	r132,745	r125,503	r127,358	r125,195	p119,257
Secondary (purchased scrap)[1]	r32,251	r23,285	r31,632	r18,486	p35,274
Total	r164,996	r148,788	r158,990	r143,681	p154,531
Stocks, yearend:					
Government	33,760	33,760	33,760	33,760	33,760
Producer and traders	r6,967	6,326	8,065	11,794	p10,140
Consumer:					
Primary	r10,463	r9,586	r8,862	r10,345	11,903
Secondary	4,618	r5,817	r3,714	r3,946	4,010
Employment, yearend:					
Mine	—	—	12	8	10
Smelter	—	245	300	277	250
Port facility	—	—	—	—	23
Price, cash, London Metal Exchange:					
per metric ton	$13,778	$13,308	$8,864	$8,156	$7,001
per pound	$6.250	r$6.036	$4.021	$3.699	$3.176
World: Mine production	r952,215	r984,078	r965,326	r948,796	e921,929

eEstimated. pPreliminary. rRevised.

[1]Secondary exports were included in apparent consumption for the first time in 1988.

TABLE 2

NICKEL RECOVERED FROM PURCHASED SCRAP IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons of contained nickel)

	1988	1989	1990	1991	1992
KIND OF SCRAP					
Aluminum-base[1]	r1,952	r2,165	r2,230	r2,147	2,303
Copper-base	r2,504	r3,362	r3,012	r2,379	1,991
Ferrous-base	r40,176	r32,330	r36,874	r31,216	39,148
Nickel-base	r4,739	r4,708	r3,963	r4,562	7,697
Total	r49,371	r42,565	r46,079	r40,304	51,139
FORM OF RECOVERY					
Aluminum-base alloys[2]	r1,952	r2,165	r2,230	r2,147	2,303
Copper-base alloys	r5,381	r5,676	r5,179	r4,663	7,931
Ferrous alloys	r40,225	r32,384	r36,921	r31,264	39,206
Nickel-base alloys	r1,762	r2,337	r1,587	r2,181	1,651
Miscellaneous and unspecified	51	3	162	49	48
Total	r49,371	r42,565	r46,079	r40,304	51,139

rRevised.

[1]Primarily used beverage cans and foundry borings and turnings. Data were revised significantly upward based on new information from the aluminum specialist.

[2]Includes can scrap converted to ingot by toll smelters for sale on open market. Data were revised significantly upward based on new information from the aluminum specialist.

TABLE 3

REPORTED U.S. CONSUMPTION OF NICKEL, BY FORM

(Metric tons of contained nickel)

Form	r1988	1989	1990	r1991	1992
Primary:					
Metal	77,020	r80,211	r84,065	78,234	70,006
Ferronickel	11,729	r10,162	r17,549	14,319	15,310
Oxide and oxide sinter[1]	7,077	5,883	5,578	3,901	4,578
Chemicals[2]	705	r1,272	1,155	1,293	1,236
Other	2,234	r2,307	r4,529	4,889	4,427
Total primary	98,765	r99,835	r112,876	102,636	95,557
Secondary (scrap)[3]	49,371	r42,565	r46,079	40,304	51,139
Grand total	148,136	r142,400	r158,955	142,940	146,696

rRevised.

[1]Includes chemical-grade oxide.

[2]Nickel salts consumed by plating industry are estimated for 1988.

[3]Based on gross weight of purchased scrap consumed and estimated average nickel content.

TABLE 4
U.S. CONSUMPTION OF NICKEL, BY USE

(Metric tons of contained nickel)

Use	Metal	Ferronickel	Oxide and oxide sinter	Chemicals	Other forms	Total primary	Secondary (scrap)	1992 Grand total	1991 Grand total
Cast irons	282	W	W	W	133	415	680	1,095	1,070
Chemicals and chemical uses	W	—	51	W	—	51	—	51	r1,363
Electric, magnet, expansion alloys	W	—	—	—	W	W	W	W	r431
Electroplating (sales to platers)	16,276	W	W	256	W	16,532	—	16,532	r15,452
Nickel-copper and copper-nickel alloys	2,544	W	W	W	W	2,544	7,614	10,158	r7,384
Other nickel and nickel alloys	14,650	W	9	—	W	14,659	1,297	15,956	r16,882
Steel:									
Stainless and heat-resistant	16,596	14,583	3,713	W	W	34,892	37,885	72,777	r65,740
Alloys (excludes stainless)	3,967	470	W	—	W	4,437	583	5,020	r5,741
Superalloys	10,872	W	—	—	W	10,872	354	11,226	r15,160
Other[1]	4,819	257	805	980	4,294	11,155	2,726	13,881	r13,717
Total reported by companies canvassed	70,006	15,310	4,578	1,236	4,427	95,557	51,139	146,696	r142,940
Total all companies, apparent	XX	XX	XX	XX	XX	p119,257	p35,274	p154,531	r143,681

pPreliminary. rRevised. W Withheld to avoid disclosing company proprietary data; included with "Other." XX Not applicable.
[1]Includes batteries, catalysts, ceramics, coinage, and other alloys containing nickel, and data represented by symbol "W."

TABLE 5
NICKEL IN CONSUMER STOCKS IN THE UNITED STATES, BY FORM

(Metric tons of contained nickel)

Form	1988	r1989	1990	1991	1992
Primary:					
Metal	r6,820	5,854	r7,144	r7,589	7,861
Ferronickel	1,379	1,885	p990	1,361	2,411
Oxide and oxide sinter	r1,796	1,313	288	r1,028	1,022
Chemicals[1]	192	269	r227	r186	214
Other	r276	265	r213	r181	395
Total primary	r10,463	9,586	r8,862	r10,345	11,903
Secondary (scrap)	4,618	5,817	r3,714	r3,946	4,010
Grand total	r15,081	15,403	r12,576	r14,291	15,913

rRevised.
[1]Formerly listed as "salts."

TABLE 6

U.S. EXPORTS OF NICKEL PRODUCTS, BY CLASS

(Metric tons of contained nickel unless otherwise specified)

Class	1989		1990		1991		1992	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
Unwrought:								
Primary:								
Cathodes, pellets, briquets, shot	885	$10,861	887	$7,913	650	$5,332	750	$4,302
Ferronickel	210	949	1,725	5,358	1,140	5,590	2,374	9,752
Powder and flakes	600	12,111	694	10,744	606	10,312	568	9,132
Metallurgical grade oxide[1]	531	2,709	4,073	8,454	5,064	14,018	3,443	6,701
Chemicals:[2]								
Catalysts	1,344	34,875	1,202	40,138	1,224	49,145	1,000	49,048
Salts	674	8,982	292	4,440	420	6,962	425	5,241
Total[3]	4,242	70,487	8,873	77,047	9,104	91,359	8,560	84,175
Secondary:[4]								
Stainless steel scrap	19,841	320,683	17,472	212,368	17,407	196,380	16,740	153,702
Waste and scrap	7,377	45,739	10,712	49,355	10,391	47,025	8,567	34,095
Total[3]	27,218	366,422	28,184	261,723	27,798	243,405	25,307	187,797
Grand total[3]	31,460	436,909	37,057	338,770	36,902	334,764	33,867	271,971
Wrought:								
Bars, rods, profiles and wire	256	4,399	181	1,786	206	2,242	242	2,543
Sheets, strips, and foil	220	4,107	224	3,102	106	2,382	149	3,592
Tubes and pipes	61	3,445	61	1,049	42	1,132	56	1,819
Total[3]	537	11,951	465	5,937	354	5,756	447	7,955
Alloyed (gross weight):								
Unwrought alloyed ingot	2,788	31,279	2,694	27,479	2,858	23,849	2,526	23,137
Bars, rods, profiles and wire	4,418	65,828	4,836	72,714	5,073	73,483	4,700	65,824
Sheets, strip and foil	5,636	73,868	4,867	76,379	4,691	76,820	5,453	67,861
Tubes and pipes	897	24,690	1,092	26,857	996	22,532	895	17,548
Other alloyed articles	13,927	29,907	1,754	23,306	2,440	30,700	1,610	33,735
Total	27,666	225,572	15,243	226,735	16,058	227,384	15,184	208,105

[1]Formerly "oxide sinter." Chemical-grade oxide is included with salts.

[2]For the different salts, the nickel contents are assumed to be as follows: chlorides (25%), sulfates (22%), other salts (22%), and oxide, sesquioxide and hydroxide (65%). The typical catalyst is assumed to have a nickel content of 22%.

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

[4]The nickel content of waste and scrap is assumed to be 50%, while that of stainless steel has been shown to be about 7.5%.

Sources: Bureau of the Census and Journal of Commerce.

TABLE 7

U.S. EXPORTS OF NICKEL PRODUCTS IN 1992, BY COUNTRY

(Metric tons of contained nickel[1])

Country	Cathodes, pellets, and briquets, (unwrought)	Powder and flakes	Ferronickel	Metallurgical-grade oxide[2]	Waste and scrap	Stainless steel scrap	Salts and catalysts	Total	Wrought nickel[3]
Australia	—	(4)	—	—	56	2	81	139	—
Belgium	—	14	—	—	79	231	84	408	5
Canada	126	71	235	3,397	4,795	1,682	241	10,547	55
China	20	3	—	—	66	253	24	366	6
Colombia	14	(4)	—	—	—	(4)	14	28	22
Dominican Republic	—	—	—	—	—	—	—	—	28
Finland	—	—	894	—	453	7	—	1,354	—
France	78	22	—	3	2	—	43	148	4
Germany	—	15	340	(4)	357	78	82	872	17
India	257	1	12	—	8	84	61	423	8
Italy	—	1	—	10	—	593	44	648	5
Japan	—	66	—	1	783	4,259	94	5,203	3
Korea, Republic of	3	3	323	—	196	4,844	114	5,483	13
Mexico	161	180	57	11	5	78	175	667	62
Netherlands	—	—	—	—	375	451	12	838	1
South Africa, Republic of	—	2	—	—	—	(4)	1	3	16
Spain	—	(4)	138	—	296	3,105	7	3,546	1
Sweden	—	1	—	—	99	233	—	333	4
Taiwan	66	49	—	2	165	559	59	900	30
United Kingdom	—	60	223	1	581	85	56	1,006	53
Other	25	80	152	18	251	195	233	954	114
Total[5]	750	568	2,374	3,443	8,567	16,740	1,425	33,867	447

[1]The nickel contents are assumed to be as follows: metallurgical-grade oxide (77%), waste and scrap (50%), and stainless steel scrap (7.5%). The salts and catalysts category contains the following: chemical-grade oxide and hydroxide (65%); chlorides, (25%), sulfates, (22%), other salts, (22%), and supported catalysts, (22%).
[2]Chemical-grade oxide is included with "Salts and catalysts."
[3]Not included in "Total."
[4]Less than 1/2 unit.
[5]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF NICKEL PRODUCTS, BY CLASS

(Metric tons of contained nickel[1] unless otherwise specified)

Class	1989		1990		1991		1992	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
Unwrought:								
Primary:								
Cathodes, pellets, briquets, shot	r100,432	r$1,254,865	104,501	$910,544	102,160	$844,670	89,502	$627,921
Ferronickel	r13,696	r135,710	14,273	116,484	14,547	113,267	13,015	88,035
Flakes	56	570	8	53	(2)	1	1	21
Powder	10,442	121,416	9,126	91,179	r8,913	86,011	8,992	83,419
Metallurgical grade oxide[3]	224	3,052	r3,303	r28,809	4,446	36,903	4,184	30,361
Chemicals:								
Catalysts	960	30,687	901	34,163	1,014	26,635	1,770	27,103
Salts	2,070	25,077	1,433	16,917	1,366	16,049	1,296	14,226
Total	r127,880	r1,571,377	r133,545	r1,198,149	r132,446	1,123,536	118,760	871,086
Secondary:								
Stainless steel scrap	3,997	29,826	7,661	31,284	2,478	23,139	5,701	21,807
Waste and scrap	5,140	78,089	3,973	46,764	3,734	35,499	3,805	25,984
Total	9,137	107,915	11,634	78,048	6,212	58,638	9,506	47,791
Grand total	r137,017	r1,679,292	r145,179	r1,276,197	[4]138,659	1,182,174	128,266	918,877
Wrought:								
Bars, rods, profiles and wire	386	7,739	600	7,963	669	8,323	472	5,421
Sheets, strip and foil	327	5,973	350	5,228	322	4,969	317	6,554
Tubes and pipes	113	2,799	84	2,304	140	3,588	162	3,344
Total	826	16,511	1,034	15,495	1,131	16,880	951	15,319
Alloyed (gross weight):								
Unwrought alloyed ingot	5,485	68,978	1,738	17,444	2,050	19,554	2,376	21,153
Bars, rods, profiles and wire	1,808	27,373	1,785	22,251	1,798	23,836	1,678	20,680
Sheets, strip and foil	963	18,255	1,173	19,312	1,094	18,232	923	12,961
Tubes and pipes	801	16,066	743	17,068	2,646	52,995	713	12,774
Other alloyed articles	356	6,003	231	8,132	206	4,849	254	4,949
Total	9,413	136,675	5,670	84,207	7,794	119,466	5,944	72,517

rRevised.

[1]The nickel content of metallurgical grade oxide from Australia is assumed to be, 90%; elsewhere, 77%. The salts category contains the following: chemical-grade oxide, 65%; chlorides, 25%; sulfates, 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.

[2]Less than 1/2 unit.

[3]Primarily oxide rondelles and sinter. Chemical-grade oxide is included with salts. Data for 1990 were revised significantly upward based on new information received from the U.S. Department of Commerce.

[4]Data 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, BY COUNTRY

(Metric tons of contained nickel[1])

Country	Cathodes, pellets, and briquets, (unwrought)	Powder and flakes	Ferronickel	Metallurgical-grade oxide[2]	Waste and scrap	Stainless steel scrap	Salts and catalysts	Total		Wrought nickel[4]
								1992[3]	1991	
Australia	8,743	1,408	—	3,778	18	—	95	14,042	13,271	—
Belgium	—	10	—	—	9	—	275	294	375	1
Brazil	108	—	1,648	—	7	18	20	1,801	3,015	2
Canada	52,554	5,719	—	406	1,796	3,068	1,269	64,811	71,746	37
Colombia	—	—	2,200	—	—	24	—	2,224	2,068	—
Dominican Republic	—	—	7,528	—	—	3	—	7,531	7,914	—
Finland	482	—	—	—	—	—	312	794	791	—
France	1,456	1	—	—	285	—	129	1,871	2,211	53
Germany	(5)	23	1	—	412	—	192	631	1,089	418
Japan	(5)	2	—	—	24	—	450	476	348	36
Mexico	—	—	—	—	320	889	(5)	1,209	821	—
New Caledonia	—	—	1,428	—	—	—	—	1,428	2,455	—
Norway	17,642	—	—	—	10	—	—	17,652	23,534	—
Russia[6]	3,385	947	—	—	22	—	(5)	4,354	—	—
South Africa, Republic of	1,755	475	16	—	—	—	17	2,263	2,296	—
U.S.S.R[7]	—	—	—	—	—	—	—	—	1,577	—
United Kingdom	95	241	—	—	578	2	58	974	1,261	24
Zimbabwe	3,221	—	—	—	—	—	—	3,221	2,968	—
Other	61	166	194	—	325	1,697	249	2,692	r919	380
Total[3]	89,502	8,992	13,015	4,184	3,805	5,701	3,066	128,266	138,659	951

rRevised.

[1]The nickel content of metallurgical-grade oxide from Australia is assumed to be 90%; from elsewhere, 77%. The salts category contains the following: chemical-grade oxide and hydroxides, 65%; chlorides, 25%; sulfates, 22%; and other salts, which are assumed to be 22% nickel. Waste and scrap is assumed to be 50% nickel; stainless steel scrap, 7.5% nickel.

[2]Primarily oxide rondelles and sinter. Chemical-grade oxide is included with "Salts and catalysts."

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

[4]Not included in "Total."

[5]Less than 1/2 unit.

[6]Formerly part of the U.S.S.R.

[7]Dissolved in Dec. 1991.

Sources: Bureau of the Census and Journal of Commerce.

TABLE 10

NICKEL: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons of nickel content)

Country	1988	1989	1990	1991	1992e
Albania (content of ore)e	10,100	11,200	8,800	7,500	150
Australia (content of concentrate)	62,358	67,041	67,000	69,000	2,64,000
Botswana (content of ore milled)e	26,000	23,700	23,200	r23,500	23,500
Brazil (content of ore)	18,677	18,826	18,788	r20,456	21,000
Burma (content of speiss)	104	184	r163	r e50	100
Canada (content of concentrate)3	r216,589	r200,899	r196,225	r192,259	2192,086
Chinae	r32,700	r34,250	r33,000	r31,000	37,000
Colombia (content of laterite ore)	r19,979	r21,425	r22,439	r20,590	223,063
Cuba (content of oxide, sinter, sulfide)	r43,635	r46,268	r40,778	r33,349	232,190
Dominican Republic	29,345	31,264	e28,700	r29,062	25,000
Finland (content of concentrate)	r11,699	10,480	11,524	r9,900	29,171
Germany: Eastern states	r1,367	r1,476	r872	r—	—
Greece (content of ferronickel produced)	13,131	16,097	r15,727	r16,005	15,400
Indonesia (content of ore)	57,982	62,987	68,308	r71,681	278,100
New Caledonia (content of ore)e	r71,200	r96,200	r85,100	r114,492	2113,100
Norway (content of concentrate)	e500	780	3,100	2,200	23,398
Philippines	10,349	15,380	15,818	r13,658	15,400
Russia4	—	—	—	—	215,000
Serbia and Montenegro5 6	—	—	—	—	2,000
South Africa, Republic of (content of concentrate)	r30,000	r28,900	r29,000	r27,700	228,400
Ukraine4	—	—	—	—	5,000
U.S.S.R. (content of ore)e 7	280,000	280,000	r280,000	r245,000	—
United States (content of ore shipped)	—	—	330	5,523	26,671
Yugoslavia (content of ore)e 6 8	3,900	4,000	3,800	3,500	—
Zimbabwe (content of concentrate)	r e12,600	r12,721	r12,654	r12,371	12,200
Total	r952,215	r984,078	r965,326	r948,796	921,929

eEstimated. rRevised.

[1]Insofar 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. Finland and the United States both reported receiving ferronickel originating from Macedonia in 1992, but definitive information on the output of the Kavadarci operation was not available. Table includes data available through Aug. 18, 1993.

[2]Reported figure.

[3]This series (assay content of concentrates produced) differs from that published previously. The earlier series—refined nickel and nickel content of oxides and salts produced, plus recoverable nickel in exported matte and speiss—was as follows: 1988—198,744; 1989—195,554 (revised); 1990—195,004 (revised); 1991—188,098 (revised); and 1992—180,947.

[4]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[5]Formerly part of Yugoslavia.

[6]All production in Yugoslavia from 1988-91 came from Serbia and Montenegro.

[7]Dissolved in Dec. 1991.

[8]Dissolved in Apr. 1992.

TABLE 11

NICKEL: WORLD PLANT PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Metric tons of nickel content)

Country[2] and product	1988	1989	1990	1991	1992[e]
Albania: Metal[e]	2,500	r1,800	r2,500	r2,200	50
Australia:					
Metal[e]	23,000	24,000	25,000	25,000	25,000
Oxide[e]	19,000	20,000	20,000	r21,000	20,000
Total	42,000	44,000	45,000	r46,000	45,000
Austria: Ferronickel	2,000	2,800	3,300	3,500	2,500
Brazil:[3]					
Ferronickel	9,216	r9,445	8,847	r8,620	8,700
Metal	3,885	r4,228	r4,375	r5,220	6,000
Total	13,101	r13,673	r13,222	r13,840	14,700
Canada:					
Metal	r106,561	r91,990	r e96,500	r95,300	109,000
Oxide	39,139	38,010	e30,300	e25,000	25,000
Total	r145,700	r130,000	r e126,800	r e120,300	134,000
China: Metal[e]	24,700	25,600	27,000	27,500	28,000
Colombia: Ferronickel	r17,502	r16,939	r18,424	r20,194	20,195
Cuba: Oxide[4]	r23,824	r26,251	r21,126	r18,756	16,920
Czechoslovakia: Metal[e]	3,800	r3,800	2,970	2,500	1,500
Dominican Republic: Ferronickel	29,345	31,264	28,700	29,100	27,400
Finland:					
Chemicals	1,573	1,953	1,643	2,190	r2,890
Metal	15,721	13,355	16,882	13,850	r14,781
Total	17,294	15,308	18,525	16,040	r17,671
France:					
Chemicals	1,400	1,400	1,090	1,000	1,200
Metal	r9,000	r8,632	r8,540	r7,400	6,800
Total	r10,400	r10,032	r9,630	r8,400	8,000
Germany: Eastern states: Metal	r2,379	r2,271	r1,657	r850	—
Greece: Ferronickel	13,131	16,097	r15,727	r16,005	15,400
Indonesia: Ferronickel	4,905	4,964	5,005	r5,318	r5,507
Japan:					
Ferronickel	57,556	62,834	56,474	68,045	r57,447
Metal	19,961	21,938	22,274	23,658	r22,038
Oxide	24,744	21,444	21,500	r22,500	26,000
Total	102,261	106,216	100,248	r114,203	105,485
Korea, Republic of: Metal	—	4,173	5,987	e11,340	10,000
New Caledonia: Ferronickel	37,352	36,285	32,278	r34,411	r31,895
Norway: Metal	52,547	54,886	57,812	58,730	r55,686
Russia:[e 6]					
Ferronickel	—	—	—	—	10,000
Metal	—	—	—	—	190,000
Oxide	—	—	—	—	10,000
Chemicals	—	—	—	—	5,000
Total	—	—	—	—	215,000
Serbia and Montenegro:[7 8]					
Ferronickel[e]	—	—	—	—	2,000
South Africa, Republic of: Metal	29,217	r28,100	r28,200	26,863	r27,621

See footnotes at end of table.

TABLE 11—Continued

NICKEL: WORLD PLANT PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Metric tons of nickel content)

Country[2] and product	1988	1989	1990	1991	1992[e]
Taiwan: Metal	10,435	10,000	[e]10,400	[e]11,340	10,000
Ukraine: Ferronickel[e 6]	—	—	—	—	5,000
U.S.S.R.:[e 9]					
Ferronickel	25,000	25,000	22,700	20,000	—
Metal	255,000	255,000	236,000	225,000	—
Oxide	15,000	15,000	13,600	12,000	—
Total	295,000	295,000	272,300	257,000	—
United Kingdom: Metal	27,700	26,100	26,800	29,030	28,000
United States: Ferronickel	—	347	3,701	7,065	[5]8,962
Yugoslavia:[10]					
Ferronickel[e]	5,300	5,100	3,600	2,500	—
Metal	—	956	—	—	—
Total[e]	5,300	6,056	3,600	2,500	—
Zimbabwe: Metal	11,490	11,633	11,426	[r]11,297	[5]16,460
Grand total	[r]923,883	[r]923,595	[r]892,338	[r]894,282	852,952
Of which:					
Chemicals	2,973	3,353	2,733	3,190	9,090
Ferronickel	[r]201,307	[r]211,075	[r]198,756	[r]214,758	195,006
Metal	[r]597,896	[r]588,462	[r]584,323	[r]577,078	550,936
Oxides	[r]121,707	[r]120,705	[r]106,526	[r]99,256	97,920

[e]Estimated. [r]Revised.

[1]Table includes data available through July 6, 1993.

[2]In 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. Finland and the United States both reported receiving ferronickel originating from Macedonia in 1992, but definitive information on the output of the Kavadarci operation was not available. 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 (estimated): 1988—45,000; 1989—45,000; 1990—45,000; 1991—45,000; and 1992—45,000; Botswana: 1988—22,539; 1989—19,759 (revised); 1990—19,022 (revised); 1991—19,294 (revised); and 1992—18,873; Canada: 1988—57,703; 1989—44,320; 1990—43,300 (estimated); 1991—40,000 (estimated); and 1992—40,000 (estimated); Indonesia: 1988—28,864; 1989—29,030; 1990—24,949; 1991—27,433 (revised); and 1992—39,307; and New Caledonia: 1988—10,470; 1989—10,650; 1990—9,683; 1991—9,041; and 1992—7,475.

[3]Brazil is believed to also produce nickel oxide, but information is not available on which to base estimates.

[4]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: 1988—19,811 (revised); 1989—20,017 (revised); 1990—19,652 (revised); 1991—14,593 (revised); and 1992—15,270.

[5]Reported figure.

[6]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[7]Formerly part of Yugoslavia.

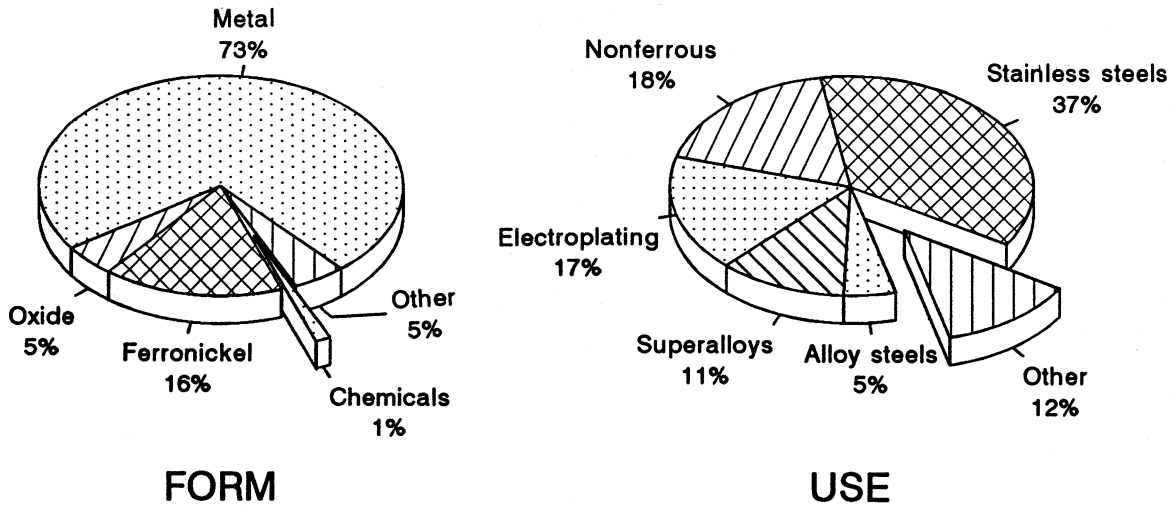
[8]All production in Yugoslavia from 1988-91 came from Serbia and Montenegro.

[9]Dissolved in Dec. 1991.

[10]Dissolved in Apr. 1992.

FIGURE 1

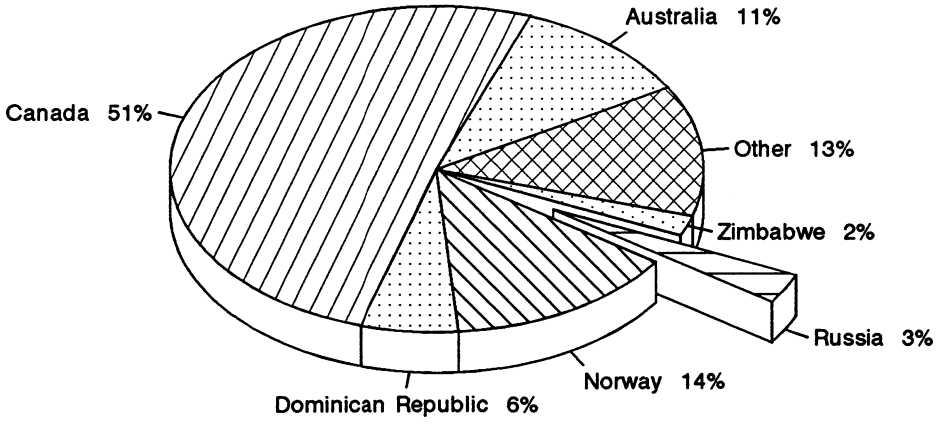
U.S. PRIMARY NICKEL CONSUMPTION IN 1992, BY FORM AND USE



95,557 METRIC TONS

FIGURE 2

COMBINED U.S. PRIMARY AND SECONDARY NICKEL IMPORTS, BY COUNTRY



128,266 METRIC TONS

NITROGEN

By Raymond L. Cantrell

Mr. Cantrell joined the U.S. Bureau of Mines as a physical scientist in 1988. He formerly conducted fertilizer market research for the W. R. Grace & Co. Agricultural Chemicals Group (1972-87); plastics and rubber product development for Hasbro Industries (1968-72); and fertilizer and organics research and development for Columbia Nitrogen Corp. (1964-68). Domestic survey data were prepared by Gail D. Mason, statistical assistant; the world ammonia production table was prepared by Doug Rhoten, international data coordinator.

All life forms in the air, on land, and in the seas assimilate the Earth's renewable atmospheric nitrogen to sustain life and procreate. Elemental nitrogen gas and liquid, together with synthetic anhydrous ammonia—a derivative of atmospheric nitrogen and fossil fuels—form the base for a significant global agricultural fertilizer and industrial product industry.

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 is produced in about 75 countries around the globe and provides more than 50% of the world's essential plant nutrient demand for food and fiber. In the industrial sector, anhydrous ammonia derivatives are important for the production of synthetic fibers, resins and polymers, explosives, animal feeds, and a wide variety of inorganic and organic compounds.

U.S. ammonia output in 1992 rose to the highest level in 10 years, and total domestic demand reached levels not achieved since 1980; new production records were established for urea and ammonium phosphates. Industrial nitrogen gas demand continued to surge, and production reached a record 810 billion cubic feet, valued at $0.9 billion. Record yields were established for U.S. corn and soybeans and near record yields for wheat under ideal weather conditions.

Heavy demand for domestic nitrogen products in 1992 was precipitated by a significant increase in U.S. planted crop acreage, inordinately low carryout grain inventories at the domestic and global levels during the previous year, and a continuing trend of high production rates by the U.S. ammonium phosphate industry. Another factor of major significance was the entry of India as a major importer of global urea and the continued large-volume purchases by China and Vietnam. Producers outside the United States were hard pressed to meet urea demand in the face of product shortfalls in Eastern Europe and the Persian Gulf.

Ironically, global ammonia production plunged for the third consecutive year largely because of democratization initiatives in the former Eastern bloc, together with the dissolution of the U.S.S.R. in late-1991. Fertilizer production and consumption in these two regions fell collectively by 10% and 25% in 1992, although the former U.S.S.R. did manage to hold up nitrogen fertilizer trade in a quest to generate hard currency.

The ill-fated Uruguay Round of General Agreement on Tariffs and Trade (GATT), under negotiation since 1986, ended in a stalemate at the end of the year without any substantive progress toward removing agricultural trade barriers between the United States and the European Community. A last-ditch effort was made to finalize the negotiations by signing an Oilseed Accord between the two factions, but the French Government and farmers with the most to lose were apparently successful in quelling the agreement.

Ammonia futures commenced trading on the Chicago Board of Trade (CBOT) on September 11, 1992. This action linked ammonia futures to the existing CBOT diammonium phosphate futures market and to the New York Mercantile Exchange (NYMEX) natural gas futures market, resulting in a valuable risk management tool for fertilizer producers and consumers alike.

The Environmental Protection Agency (EPA) issued Standards for the Use or Disposal of Sewage Sludge, final rule, under 40 CFR Parts 257, 403, and 503, in the Federal Register, Vol. 58. No. 32, February 19, 1993.

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 nitrogen compounds that are in compliance with Public Law 100-418, will begin to report nitrogen data in metric units. *(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, the Bureau of the Census adopted a quarterly format and replaced monthly series M28B with the quarterly series MQ28B, under the same title. Final data

are subsequently published in a companion annual report MA28B. During 1992, 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 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.

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 (CO_2), methane (CH_4), and nitrous oxide (N_2O).

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 Scottish botanist, Daniel Rutherford.[1]

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 (HNO_3); (2) the cyanamide process, discovered by Frank and Caro in Germany, synthesized calcium cyanamide ($CaCN_2$) from calcium carbide (CaC_2) and N_2; (3) the cyanide process, developed by Bucher of Brown University in Rhode Island, produced sodium cyanide (NaCN) from N_2 and sodium carbonate (Na_2CO_3) as an intermediate to ammonia production; and, (4) the ammonia process, developed by Haber and Bosch in Germany, reacted N_2 and hydrogen (H_2) under high temperatures and pressures in the presence of a catalyst to form ammonia (NH_3).

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 from fossil fuels (natural gas, petroleum, coal), and water.

Definitions, Grades, and Specifications[2]

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. 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 ($NaNO_3$) and potassium nitrate (KNO_3) 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 1992, 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 (K_2O). Sodium nitrate was also blended with potash to produce a mixed fertilizer containing 13% N and 44% K_2O.

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 where nitrogen and hydrogen are manufactured from natural gas, compressed air and steam, while an iron-promoted catalyst is used to combine nitrogen and hydrogen to synthesize ammonia.

Urea is formed when ammonia is reacted with byproduct carbon dioxide (CO_2) generated during ammonia synthesis. The materials are reacted under high pressure in a two-step process at about 400° F to first form ammonium carbamate, which then decomposes to urea (NH_2CONH_2).

Nitric acid is formed when ammonia is passed over a platinum-rhodium catalyst at about 1,700° F and 120-pound-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-base reaction between ammonia and nitric acid, and urea and ammonium nitrate may be blended to produce the popular U.S. urea-ammonium nitrate (UAN) fertilizer solutions containing 28% to 32% N.

Economic Factors

Between 1970 and the early 1980's, natural gas prices rose dramatically, causing ammonia production costs to become much more sensitive to feedstock costs. Natural gas feedstock costs as a percentage of total production costs rose from 45% in 1970 to 75% by 1982. Natural gas prices have declined since 1985, and feedstock costs in 1992 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 profitability in the domestic converted nitrogen industry. The profit margin for straight nitrogen compounds (urea, ammonium nitrate, and UAN solutions) has been more consistent, on average, than the more volatile, cyclical price swings experienced by the export-dependent ammonium phosphate industry.

On April 3, 1990, 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. NYMEX futures trading suggested that a renewed upward spiral in natural gas prices would continue into 1993.

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] introduced several creative mechanisms designed to promote environmentally sound and cost effective agricultural management practices, with the added objective of cutting discretionary Federal spending for farm programs. The 1990 farm bill provided the U.S. farmer with planting flexibility options ("triple base flexibility"), long-term Conservation Reserve and Wetlands Reserve Programs (CRP and WRP) designed to protect the environment and control grain inventories, and an Export Enhancement Initiative that would allow U.S. grain to compete in a global marketplace laden with unfair trade practices.

Under triple base, farmers lost Government deficiency payments 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 11th CRP signup in mid-1991, the U.S. Department of Agriculture (USDA) reported that total CRP acreage had increased to 35.4 million acres. Another 1.1 million acres was expected to be accepted following the 12th CRP signup in June 1992, raising the CRP to about 36.5 million acres. Congress, however, did not include money for the fiscal year 1993 signup, and allocations would reportedly be directed toward the WRP in the future. Lands available for WRP include restorable farmed wetlands that were converted to cropland prior to December 23, 1985, and functionally related wetlands, uplands, and riparian areas. In fiscal 1993, USDA was expected to accept about 50,000 acres in WRP.

The Alternative Agricultural Research and Commercialization Center (AARC) in Washington, DC, was empowered under title XVI (subtitle G) of the 1990 farm bill to create the world's most effective organization in generating new industrial (nonfood, nonfeed) market demand for U.S. farm and forestry products. AARC includes a distinguished board of directors from private industry whose mission is to apply sound business and technical practices that will facilitate the prudent development and commercialization of cost effective, environmentally friendly renewable industrial and consumer products. The new private ventures will create jobs, enhance rural economic development, and diversify agricultural markets.

AARC will serve to expand the commercial use of agricultural raw materials—traditional and new crops, forestry materials, and animal byproducts—through the introduction of new industrial products such as biodegradable automotive and industrial lubricants, biodegradable polymers for food packaging and eating utensils; and motor fuels and composites. The AARC legislation authorized two to six regional centers, and funds were appropriated to establish two centers in fiscal 1993. A major part of regional center work will be in developing private-public partnerships to submit applications for support from the AARC Center; at least 50% of the funding for a project must come from the applicant(s). By mid-1993, the AARC Board was to announce a $10 million investment in projects.

The Clean Air Act of 1990 (Public Law 101-549)[6] contained 11 titles that targeted 3 principal forms of pollution: acid rain, smog, and toxic air pollutants. One of the major impacts of the new clean air bill will be the emphasis placed on clean burning alternative fuels and the use of oxygenated fuels as air pollution control strategies. This strategy 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).[7]

EPA's Oxygenated Fuel Program became 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). Information Resources Inc., a Washington, DC, consulting firm, estimates that in 1992, approximately 1.1 billion gallons of ethanol (419 million bushel corn equivalent) may 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]

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).

Acid rain is caused primarily by sulfur dioxide (SO_2) and nitrogen oxide (NO_x) emissions from coal-fired electrical powerplants. Under title IV, SO_2 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.

Section 313 of EPA's Emergency Planning and Community Right-to-Know Act of the Superfund Amendments and Reauthorization Act (SARA) of 1986 (Public Law 99-499) required EPA to establish a national inventory of toxic chemical emissions from certain facilities, called the Toxic Release Inventory (TRI). The 1990 TRI indicated that for 275 chemicals surveyed, a total of 2.2 million tons was released to the environment or transported to publicly owned treatment works (POTW's).

In 1990, a total of approximately 240,000 tons of ammonia was released into the environment: 40% to the air; water, 8%; injection into underground wells, 49%; and disposal in landfills, 3%. Another 40,000 tons was disposed of in POTW's. The 1990 TRI data could not be compared statistically with prior surveys because of a change in survey methodology.

Between 1987 and 1989, ammonia losses to the atmosphere declined by 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%. Ammonium nitrate and ammonium sulfate solutions of unknown concentration were released to the environment in an aggregate total of about 65,000 tons in 1990.

The Energy Policy Act of 1992 (H.R. 776) was signed into law by the President on October 24, 1992. The comprehensive energy bill contained 30 titles covering nonrenewable and renewable energy

resources and was underscored by environmental and energy efficient mandates for the implementation of new technology and for long-range research and planning. Some of the provisions that apply to agriculture and the Department of the Interior may be found in Title III—Alternative Fuels, General—the economic development of an 85% mixture of ethanol with gasoline or other nonrenewables; Title XII—Renewable Energy—biomass chemical conversion or direct combustion technology development; and Title XIII—Coal—clean coal technology that would reduce sulfur dioxide and nitrogen oxides in commercial powerplants and in nonfuel uses. The Secretary of the Interior was to provide consulting services to the Secretary of Energy for research and development of effective utilization of coal wastes and for the administration of mineral rights for coalbed methane projects on Federal lands. Title XVI—Global Climate Change—includes provisions for a 75% increase in energy derived from renewable resources over 1988 levels by the year 2005 and a reduction in the Nation's oil use from a level of approximately 40% of total energy consumption in 1990 to 35% by the year 2005.

Issues

Proposed Btu energy tax legislation on fossil fuels, together with environmental and transportation taxes, could result in a significant runup in prices for fertilizers and other agricultural commodities. An all-out assault against new taxes by The Fertilizer Institute (TFI) member companies and related agricultural organizations has drawn the attention of Congress and major media, including the Wall Street Journal and the Associated Press. A second wave of legislation involving fertilizer use taxes may also be proposed to help pay for the health care reform plan.

If the energy tax bill is passed at $0.257 per million Btu as proposed, domestic production costs for fertilizer and industrial-grade ammonia will increase about $10 per metric ton (10%), or an additional $160 million annually, and for urea about $0.70 per ton, or $6 million annually. The total Btu tax for all fertilizer products could easily reach the $200 million mark annually.

The passage of an inland waterway user fee tax for fertilizer transport would amount to $64 million in 1993 and gradually escalate to $150 million by 1997. Therefore, the U.S. fertilizer industry and agricultural sector could be looking at total tax increases in excess of $0.5 billion annually.

The large Saskferco ammonia and urea project came on-stream in the fall of 1992 at Belle Plaine, Saskatchewan, and continued to be monitored 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 had been lobbied by the groups in 1991 regarding 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.

EPA's phase 2 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 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

The U.S. ammonia industry operated at 101% of design capacity in 1992, indicative of the tight supply-demand conditions for ammonia and downstream conversion products. Thirty-four firms in 24 States across the country, including Alaska, produced 16.3 million metric tons of anhydrous ammonia (82.2% N), 5% more than in 1991. (Louisiana, Oklahoma, and Texas, in order of importance, provided about 60% of total U.S. production; the Midwest, 15%; South and Southeast, 16%; and the Western States and Alaska, 9%.)

Natural gas feedstock was available in the $1.80-per-million-Btu range, providing the industry with favorable profit margins at the wholesale level in the case of straight nitrogen fertilizers and for industrial products. The TFI Production Cost Survey for 1992 indicated that overall ammonia production costs were up about 3%, from roughly $99 per metric ton in 1991 to $102 per ton in 1992. Production costs rose principally because of moderate increases in natural gas and electrical power.

About 90% of the ammonia produced in U.S. plants was allocated to domestic fertilizer use and trade, and about 10% went into industrial products. Major downstream ammonia fertilizer derivatives included urea, 46% N; diammonium phosphate (DAP), 18% N; monoammonium phosphate (MAP), 11% 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 2 and 3.)*

CF Industries of Long Grove, IL, one of North America's largest interregional cooperatives, supplies nitrogen, phosphate, and potash fertilizer products to more than 1 million farmers and ranchers in 46 States and 2 Canadian Provinces. CF's ammonia, urea, and

UAN Nitrogen Complex at Donaldsonville, LA, is the largest facility of its kind in the United States. The company also holds a joint-venture interest in Canadian Fertilizers Ltd., a large ammonia and urea complex at Medicine Hat, Alberta. CF also operates a wholly owned ammonium phosphate facility at Plant City, FL, having an annnual capacity of 2 million product tons.

CF's $87 million expansion project at Donaldsonville, LA, approved in mid-1991, was well advanced and scheduled for completion by mid-1993. This project will increase production capacity for granular urea and UAN solutions and provide CF with cost effective nitrogen fertilizers to meet the projected demand of its members during the 1990's.[9]

The Donaldsonville ammonia plants were capable of operating at 1.8 million tons per year—120% of design capacity—because of recent revamp and retrofit initiatives that led to further improvements in the cooperative's competitive economics. CF management reported that ammonia emissions were reduced by 60% and NO_x emissions by 33% from 1987 levels.

On July 22, 1992, CF acquired an ammonia terminal at Tampa, FL, for $22 million, owned most recently by Mulberry Phosphates and earlier by the Royster Co. The primary acquisitions included an ammonia terminal on the Port of Tampa having a 40,000-ton storage tank and related distribution equipment, together with an ammonia pipeline joint venture with Seminole Fertilizer. The location of the storage facility is strategic in that only 37 rail miles will be required to deliver ammonia to CF's Plant City ammonium phosphate plant as an alternative to sourcing ammonia from Donaldsonville, about 850 rail miles. The Tampa Bay Pipeline system supplies ammonia to major producers of ammonium phosphates in Polk County, FL.

Mississippi Chemical Corp. (MCC) completed a $32 million state-of-the-art nitric acid plant and ammonium nitrate neutralizer section at Yazoo City, MS, late in the year. The new 550-ton-per-day nitric acid plant was scheduled to replace two obsolete plants having a combined capacity of 330 tons per day. The new plant will provide for both a production increase and simultaneous output of Amtrate solid ammonium nitrate and N-Sol UAN solution. MCC joined Arcadian Corp. and Agricultural Minerals Corp. as a member of the UAN Solutions Export Association during the year.

In early 1992, MCC's ammonium phosphate facility at Pascagoula, MS—Mississippi Phosphates—was brought to full capacity, based on the reaction between ammonia and wet-process phosphoric acid produced from imported Moroccan phosphate rock. Atlantic Fertilizer and Chemical Corp. contracted to market the DAP output rated at 700,000 tons per year.

Early in the year, Koch Industries, Inc., assumed control of the large ammonia complex at Sterlington, LA, formerly owned by the IMC Fertilizer Group, Inc. (IMCF). The Sterlington complex consists of two ammonia trains having a total capacity of 1 million tons per year. The acquisition provided a good fit for Koch Industries, owner of the Gulf Central Ammonia Pipeline that serves the Sterlington plant. An ammonia supply contract for a portion of IMCF's New Wales, FL, DAP-MAP complex was also to be negotiated. During October, IMCF reached an agreement in principal to purchase the Conserv, Inc. 550,000-ton-per-year DAP plant at Nichols, FL, owned by EniChem Agricoltura S.p.A. of Milan, Italy.

In August, Cargill Fertilizer of Minneapolis, MN, commissioned 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 designed to produce 510,000 tons per year of ammonia and 680,000 tons per year of granular urea.[10]

More than one-half of the Saskferco output was scheduled to move through Cargill retail and wholesale distribution outlets. Agreements were reportedly reached with other large retail distributors for the sale of the remaining product, including Land O'Lakes, Inc., and Farmland Industries, Inc. in the United States. Product was to be marketed in western and eastern Canada, the north-central region of the United States, and offshore.

Farmland Industries, Inc. and J.R. Simplot assumed joint-venture ownership of the former Chevron phosphate rock mine at Vernal, UT, and DAP plant at Rock Springs, WY, in early 1992. Annual DAP production capability at Rock Springs is 410,000 tons. Farmland was moving the former Chevron Finley, WA, nitrogen solutions plant to its primary nitrogen production complex at Enid, OK.

In late July, Arcadian Corp's. urea synthesis reactor at Lake Charles, LA, sustained irreversible damage that resulted in the closure of the complete facility. The closure represented a loss of 190,000 annual tons of urea capacity and about 400,000 annual tons of ammonia, tightening U.S. nitrogen supplies for the fall season. Arcadian ultimately decided to mothball the ammonia facility for an indefinite period.

BP International completed a $17 million, 90,000-ton-per-year nitric acid replacement-expansion at Lima, OH, that came on-stream in September 1992. Weatherly Inc. was contracted to build the plant, which increased capacity by 27%, improved the ammonia efficiency and energy recovery, and lowered NO_x emissions by 95%. At Lima, BP produces about 500,000 tons of ammonia, 310,000 tons of urea, and 200,000 tons of nitrogen solutions per year.

Unocal permanently closed the former Chevron 130,000-ton-per-year ammonia plant at Finley, WA, purchased in 1991, but continued to use the complex 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 operating a wholly owned 80,000-ton-per-year ammonia plant at St. Helens, OR, until a buyer could be found and planned to sell its 1,000-ton-per-day nitric acid plant at Riverton, KS, shuttered since 1982. *(See*

table 4.)

In late October, Nitrogen Products Inc's. 190,000-ton-per-year ammonia plant at Helena, AR, was closed in bankruptcy proceedings by the Dutch-owned bank NMB and was reportedly to be dismantled. The fledgling former Big River ammonia project 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, and 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 70,000-ton-per-year plants on-site in early 1991. The second train was reactivated during 1992.

Agricultural Minerals Corp. (AMC) of Tulsa, OK, went public on the New York Stock Exchange as Agricultural Minerals Co. LP. AMC was founded by former Agrico executives to facilitate a leveraged buyout of the firm's nitrogen fertilizer production facilities at Verdigris, OK, and Blytheville, AR, on March 1, 1990. 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.

Coastal Chem, Inc. planned a 175,000-ton-per-year ammonia expansion at Cheyenne, WY, based on the reconstruction of a plant to be purchased and moved from another nitrogen complex. Coastal completed a 130,000-ton-per-year nitric acid plant at Elko, NV, to be used for the production of ammonium nitrate-based explosives.

Hydro Agri Ammonia, Inc. (HAAI), a U.S. affiliate of the Norwegian firm Norsk Hydro, continued to market ammonia from the former W.R. Grace & Co. joint-venture Tringen plants now run by Norsk and the Government of Trinidad and Tobago at Point Lisas. HAAI is headquartered in Tampa, FL, for this purpose and is staffed by key personnel from the former Grace marketing team in Memphis, TN.

In late 1991, Norsk became a joint-venture partner in Farmland Industries' Green Bay, FL, phosphate operation. The Farmland Hydro Ltd. Partnership group began operating from headquarters in Bartow, FL, on November 16. The Green Bay facility had a DAP/MAP production capability of about 1 million tons per year.

Terra International, Inc. completed a 70,000-ton-per-year ammonia expansion at Port Neal, IA, in late 1992 that was to bring total annual capacity to about 270,000 tons. Emissions were also to be reduced 30%. Terra also announced a $15.5 million retrofit project that would provide for the optional production of up to 400 tons per day of methanol in the existing 1,200-ton-per-day ammonia plant at Woodward, OK, by early 1994. Ammonia capacity would reportedly be reduced by up to 20% because of the swing with methanol, but there was an upside advantage in hedging against fertilizer market seasonality. Methanol was to be sold to producers of methyl tertiary butyl ether (MTBE), the leading automotive fuel oxygenate.

American Cyanamid's 680-ton-per-day ammonia plant at Fortier, LA, idle since 1983, was also to be converted to methanol production for MTBE synthesis. Lurgi and the U.S.-based Pritchard Corp. were contracted to execute a detailed engineering design for a 1,700-ton-per-day methanol plant to be operated as a joint ventrue between Cy Tech., the new American Cyanamid chemicals business, and the firm Methanex.

Consumption and Uses

U.S. apparent domestic consumption of ammonia reached 13.4 million tons N in 1992—5% above the prior year—representing a level that had not been achieved since 1980. Fertilizer materials accounted for about 80% of domestic ammonia demand and industrial applications accounted for about 20%.

Urea and ammonium nitrate found extensive use in the fertilizer and industrial sectors in both solid and liquid form. 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 ruminate 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 5.)*

Other uses for ammonia and ammonia-base compounds included consumption as ammonia refrigerant, in specialty horticultural and lawn and garden fertilizers, home and industrial cleaners, fuel ethanol derived from corn and other biomass species, and as sodium azide 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 1992, ammonia and ammonia derivatives accounted for 55% of the 18.7-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 2.3:1, respectively.

U.S. nitrogen fertilizer consumption reached 10.3 million tons N in 1992 compared with 10.2 million tons N in 1991. Single-nutrient compounds led by direct application ammonia, UAN solutions, urea, and ammonium nitrate, in order of importance, provided 80% of the total. Nitrogen solutions were up 5% in 1992, but direct application ammonia fell 2%. *(See table 6.)*

The six States that comprise the Midwest Corn Belt—Illinois, Indiana, Iowa, Missouri, Nebraska, Ohio—together with Minnesota, consumed 4.3 million tons N, 41% of the U.S. total. Texas, Kansas, California,

North Dakota, and Oklahoma, in order of importance, accounted for 2.5 million tons N, 24% of the total.

Planted crop acreage rose 6 million acres to a total of 343 million acres in 1992, from 337 million acres in 1991, and another 54 million acres was idled by crop programs and the CRP. Record yields were recorded for corn and soybeans, and near record yields recorded for wheat and cotton. Carryout inventories of major feed and food grains did not increase significantly, except for corn. U.S. net cash farm income in 1992 was expected to approximate $60 billion, only $1 billion below the record $61 billion established in 1990. The Secretary of Agriculture raised the acreage setaside (ARP) on corn to 10% for next year, but dropped the wheat and barley setaside to 0%. In the fall of 1992, Doane Agricultural Services Co., St. Louis, MO, reported that net cash farm income could reach a record $63 billion in 1993.

Stocks

U.S. stocks of major nitrogen compounds increased about 11% at the producer level and ended the year at 1.8 million tons N. There was a 9% drawdown in ammonium nitrate inventories. *(See table 7.)*

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.[12] The inhalation hazard label requirement, including nurse tanks, became effective October 1, 1992.

International shipments, however, were classified as a Division 2.3 "poison gas" consistent with United Nations regulations. International shippers were originally 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.

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. The annual capacity of this pipeline is about 2 million tons, and storage tanks along its path have an additional capacity of more than 1 million tons. Koch Nitrogen, a subsidiary, purchased four Midwest ammonia terminals from ConAgra Fertilizer in 1991 having a combined capacity of 150,000 tons. The pipeline was to be extended 15 miles to the firm's Wood River, IL, terminal by the end of the year.

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. The Mapco pipeline has an annual capacity of about 1 million tons, and 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 and CF Industries were operating the Tampa Bay Pipeline system, a joint-venture ammonia pipeline that serves ammonium phosphate producers in Polk County, FL.

Markets and Prices

Anhydrous ammonia prices continued to decline through the first quarter, following a trend established during December 1991, and reached a low of $91 per metric ton, f.o.b. barge, New Orleans, in early March. Prices reached about $111 per ton near the end of the strong domestic spring fertilizer season, but declined to first quarter levels during July and August. Ammonia prices rose steadily thereafter as supplies tightened owing to steady demand, the closure of Arcadian's Lake Charles, LA, plant in late July, and gas shortages on the gulf coast precipitated by Hurricane Andrew in the fall. Ammonia prices peaked at $130 per ton by yearend. At yearend, September 1993 ammonia futures contracts were trading on the Chicago Board of Trade (CBOT) for $136 per ton, f.o.b. barge, Louisiana.

In contrast, urea and ammonium nitrate prices were stable to firm for most of the year. Granular urea prices peaked at a heady $165 per ton, f.o.b. New Orleans, from mid-May to mid-June and averaged $150 per ton for the year.

DAP prices, f.o.b. Central Florida, continued to trend downward following a pattern established in the fourth quarter of 1991. In January, prices stood at $151 per ton, but gradually deteriorated to a meager $125 per ton at yearend. The U.S. DAP industry was plagued by an inordinate supply overhang during 1992 that was accompanied by a combination of record production, stagnant domestic demand, and a significant decline in export sales to China and India. At yearend, September 1993 DAP futures were trading on the CBOT for $136 per ton, f.o.b. central Florida. *(See table 8.)*

Foreign Trade

In 1992, the U.S. ammonia trade deficit was estimated at 2.8 million product tons, slightly larger than the 2.6-million-ton deficit of 1991. A trade deficit occurs whenever more product is imported than is exported.

Ammonia imports originated from Trinidad, Canada, the former U.S.S.R., and Mexico, in order of importance. Ammonia imports from the former U.S.S.R. were down about 30% from 1991 levels because of a substantial drop in fall shipments. Most of the loss was made up by an increase in Mexican shipments, however. U.S. ammonia imports in 1992 were valued at $366 million, representing an average landed price of $112 per ton, c.i.f., in comparison to $392 million, or $118 per ton, in 1991. *(See tables 9 and 10.)*

Anhydrous ammonia import tonnage data from the former U.S.S.R. continued to be withheld from the public domain during 1992 because of a previous ruling by the Bureau of the Census that determined Occidental Petroleum to be the proprietary U.S. agent. Occidental's long-term trade pact with the former U.S.S.R. involving ammonia for superphosphoric acid may no longer apply, however, owing to the dissolution of the U.S.S.R. in late 1991. Although Occidental was successful in dealing for ammonia, the new independent Republics were forced to discontinue purchases of Occidental superphosphoric acid because of a lack of hard currency; only one shipment was known to occur in 1992.

Ammonia shipments originated predominately from the Black Sea port at Yuzhnyy in the Ukraine with minor shipments from Estonia and Latvia on the Baltic Sea. MAP shipments from Russia and the Ukraine to the United States were 122,000 tons, somewhat of a surprise in light of the depressed U.S. ammonium phosphate market, but in line with the global press for hard currency. Russia and the Ukraine landed MAP at a value of $16.4 million, or $134 per ton, c.i.f.

The United States continued to experience a significant urea trade deficit amounting to 0.6 million product tons in 1992, about the same as in 1991. Approximately 1.6 million tons of urea was imported from 19 countries in 1992 that carried a landed value of $204.5 million, or $131 per ton, c.i.f. Urea import volume and landed prices did not change significantly in 1992. Canada shipped 75% of the total; Mexico, Trinidad, Brazil, and Venezuela, 13% in aggregate; Italy, the Netherlands, and France, 8%; and Poland and Bulgaria, 3%. The landed price of Bulgarian urea was reported to be $82 per ton, c.i.f., well below average. Germany shipped only 403 tons at a value well above the average. ITC urea antidumping duties levied against the former U.S.S.R., the former German Democratic Republic, and Romania have been effective in preventing the subject countries from landing urea at prices below fair market value.

Ammonium nitrate was also imported in significant quantities amounting to 0.4 million tons, valued at $55.5 million, or $125 per ton, c.i.f. More than 93% of the total was Canadian product. The United States exported a modest 40,000 product tons in 1992.

U.S. ammonium phosphate exports in 1992 fell to 9.2 million product tons (1.6 million tons N equivalent), representing a net decline of 1.3 million tons, 13% below the 10.5 million tons shipped in 1991. The major decline can be traced to DAP trade with China, where volume plunged 1.4 million tons (29%), and to India, where volume fell 0.4 million tons (23%). Industry analysts reported that the actual decline was lower than indicated because Chinese DAP tonnage in 1991 had been double counted in certain instances. MAP trade was up about 5% to 0.9 million tons in 1992.

The United States experienced a total converted nitrogen trade deficit of 1.0 million tons N in 1992, about 67% above the 0.6-million-ton N deficit established in 1991. In total, the United States imported about 3.8 million tons of N in compounds that carried a landed value of $866.3 million. *(See tables 11 and 12.)*

World Review

Global ammonia production fell precipitously for the third consecutive year to a level of 92.5 million tons N, representing a decline of 1.6% from 94.0 million tons N in 1991 and 6.8% from the near-record 99.3 million tons N produced in 1989. Since 1989, production in the former Eastern bloc countries has declined 4.2 million tons N (-43%); the former U.S.S.R., 3.8 million tons (-19%); Western Europe, 1.0 million tons (-11%); and the Middle East, 0.6 million tons (-15%). This 9.6-million-ton N drop has been tempered somewhat by rising net production in other regions, especially Asia and North America.

Anhydrous ammonia N was produced in some 75 countries during 1992, of which about 10 million tons N (10%) was directly traded. Ammonia was converted into about 35 million tons of urea N in 59 countries, of which about 9 million tons (26%) was traded. Total world nitrogen fertilizer consumption fell about 4% to a level of 74 million tons N, according to data available in November, and trade accounted for about 19 million tons N, or 26% of the total. China, the world's largest urea importer, together with the recent entry of India and Vietnam as large-volume urea importers, served to maintain a relatively tight global nitrogen materials trade balance in 1992.

Eastern Europe and the former U.S.S.R. have suffered significant losses in domestic production and consumption because of sweeping political reforms, accompanied by high inflation and foreign exchange problems. Western Europe has been negatively impacted by inflated natural gas prices, an attendant decline in competitive economics, and a downturn in domestic agriculture. Recession, the reunification of Germany, transition to the new European Community reform (EC-92), and declining demand in Eastern Europe and the former U.S.S.R. have also been contributing factors. The Mideast downturn was primarily a result of events surrounding the Persian Gulf Crisis and ensuing Operation Desert Storm initiatives of 1990 and 1991.

It is estimated that between 1989 and

1992, domestic nitrogen fertilizer consumption has declined 3.7 million tons N (-37%) in the former U.S.S.R.; 2.8 million tons (-62%) in Eastern Europe; and 1.5 million tons (-14%) in Western Europe.

The dissolution of the centrally planned economy of the U.S.S.R. commanded global attention in 1992 and resulted in the evolution of 15 independent republics. The new republics were plagued by a combination of high inflation and drastic cuts in domestic nitrogen fertilizer production and consumption. Ironically, the region continues to dominate global nitrogen trade, accounting for 3.5 million tons N, or 37% of global ammonia exports, and 2.8 million tons N, or 29% of global urea exports in 1991.

In 1992, the former U.S.S.R. was further pressed to generate hard currency through ammonia and urea export volume, at the expense of domestic production and consumption. Urea export volume rose another 8% to 3.0 million tons N, but ammonia trade may have fallen by as much as 10% to the 3-million-ton N level. Exports of ammonium phosphates may also have reached significant proportions in 1992.

Ammonia was produced in 9 of the 15 new independent republics in 1992, of which Russia accounted for 56% of the total; the Ukraine, 25%; Uzbekistan, 8%; Belarus, 6%; Estonia and Lithuania, 3%; together with Kazakhstan, Georgia, and Turkmenistan, 2%. The ammonia plants were designed for output but not efficiency, and gas costs were reported to have risen dramatically in 1992. Natural gas in the Russian Republic at midyear was about $16 per thousand cubic meters, or $0.45 per million Btu, equating to an ammonia production cost of about $40 per metric ton.

If gas is fully deregulated by the end of 1993 in Russia, as planned, feedstock prices may increase to roughly $60 per thousand cubic meters, or $1.70 per million Btu. This could potentially escalate ammonia production costs to about $90 per metric ton and urea to $100 per ton, values that may be prohibitive to export competitiveness on the U.S. gulf coast. A full-scale revamp of Russian ammonia and urea plants was needed. Russian gas was deregulated and priced at $2.55 per million Btu to Europe.

All Eastern European countries are now forced to rely heavily on costly, deregulated Russian gas for ammonia and urea production and other uses. Romania, Hungary, Poland, and the former Yugoslavia, in order of importance, have sizable gas production, but still require significant imports. Bulgaria and Czechoslovakia rely almost exclusively on Russian gas imports. Romania, Poland, Bulgaria, the former Yugoslavia, Czechoslovakia, and Hungary, in respective order of importance, are all major participants in the Eastern European ammonia industry. In 1992, about 47% of the natural gas consumed in Eastern Europe was supplied from domestic production and 53% was imported from the former U.S.S.R. Escalating natural gas prices have driven ammonia and urea production costs up to near-prohibitive levels, precipitating critical shortages of nitrogen fertilizers for domestic use and export.

Operation Desert Storm resulted in severe damage to nitrogen plants in both Kuwait and Iraq during January and February 1991. Information available on the damage and destruction of nitrogen production facilities in the two countries last year indicated that it would take a minimum of 5 years to bring nitrogen output back to normal, but recent information indicates that production facilities will come back into operation on a more timely basis.

In Kuwait, a 271,000-ton-per-year N ammonia plant and 216,000 annual tons of urea N came back into operation during 1992 at Shuaiba, and preinvasion capacity levels were scheduled to be operational by 1994. In Iraq, the new 272,000-ton-per-year N ammonia plant at Baiji was operational in 1992, together with a 265,000-ton-per-year N urea facility. Preinvasion capacity was also scheduled to be restored to full operation by 1994.

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.

Industry Structure.—Global ammonia was produced in 75 developed and developing countries that had 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 former U.S.S.R., accounting for more than 60% of the global ammonia supply capability and 58% of production in 1992. The developed regions—North America (United States and Canada), Western Europe, and Oceania—produced ammonia primarily for domestic use and accounted for about 26% of world supply capability and 30% of global production in 1992. The energy-rich countries of the Middle East accounted for about 5% of the world supply capability and 4% of global production in 1992 and exported significant quantities of ammonia and urea to the global community. Latin America and Africa, in order of importance, accounted for the remaining 7% of global ammonia supply capability.

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.

In 1992, there was a net gain in global ammonia capacity of about 1.6 million annual tons N (1.4%) and about 2.1 million annual tons N (5%) of urea. At

yearend, world ammonia capacity stood at about 119 million annual tons N and urea at 46 million annual tons N.

New ammonia and urea capacity was brought on-stream during 1992 in Asia: Bangladesh, China, India, Indonesia, and Pakistan; the Middle East: Kuwait and Iraq (repairs), and Turkey; Western Europe: Belgium; North America: Canada; and, Africa: Egypt, in relative order of importance. Approximately 1.3 million annual tons of ammonia N and 0.3 million annual tons of urea N was closed in Eastern Europe: Hungary, Romania, and the former Yugoslavia.

Major world ammonia and urea capacity contracted or under construction and scheduled on-stream during 1992-95 approximates 7 to 8 million annual tons of ammonia N and 4 to 5 million annual tons of urea N. Potentially, up to 1 million annual tons of ammonia N could close in Western Europe during this timeframe, assuming that the following capacity materializes as planned.

Asia.—China.—1.5 million annual tons ammonia N and 1.3 million tons urea N. Bangladesh—0.4 million annual tons ammonia N and 0.3 million tons urea N. India—2.0 million tons ammonia N and 1.1 million tons urea N. Indonesia—0.8 million tons ammonia N and 0.7 million tons urea N. Pakistan—0.5 million tons ammonia N and 0.5 million tons urea N.

Middle East.—Iran.—0.3 million tons ammonia N and 0.2 million tons urea N. Iraq (reconstruction)—0.3 million tons ammonia N and 0.3 million tons urea N. Kuwait (reconstruction)—0.6 million tons ammonia N and 0.2 million tons urea N. Saudi Arabia—0.4 million tons ammonia N and 0.3 million tons urea N. Turkey—0.2 million tons ammonia N.

Eastern Europe.—Romania—0.3 million tons ammonia N (restart idle plant). Former Yugoslavia—0.2 million tons ammonia N (restart idle plants).

Africa.—Egypt.—0.1 million tons ammonia N. Republic of South Africa—0.2 million tons ammonia N.

Former U.S.S.R.—Ukraine.—0.4 million annual tons urea N.

Latin America.—Trinidad and Tobago.—0.1 million tons ammonia N and 50,000 tons urea N. *(See table 13.)*

Current Research

USDA and DOE's "memorandum of understanding" on biomass research will accelerate 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.

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 began 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.

Tetra Technologies, Inc. of The Woodlands, TX, developed a continuous countercurrent ion exchange (CCIX) method for the removal of nitrate contaminants from mine waste streams, including residual unreacted ammonium nitrate-fuel oil explosives, and in gold mining where waste nitrates result from the nitric acid washing of activated carbon and the oxidation of cyanide during heap detoxification. The system was also reported to be effective in controlling nitrate effluent levels in dairy and other agricultural operations.

Exxon Research and Engineering Co. of Florham Park, NJ, developed a process that significantly reduced NO_x emissions by injecting ammonia into flue gas streams emanating from stationary combustion sources. It 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]

The SNOX catalytic process was developed for the cleanup of flue gas from fossil fuel burning equipment. Nitrogen oxides and sulfur oxides emanating from industrial and utility boilers burning fossil fuels are converted to elemental nitrogen, water vapor, and sulfuric acid. The SNOX Process was

developed in Denmark by Haldor Topsoe A/S and is offered under license in North America by ABB Environmental Systems.

Deshen International of Newton, MA, continued to develop markets for mobile power-intensive nitrogen plants based on the electric arc nitrogen fixation process. Several electrical power utility facilities worldwide were interested in the process, which could be used to improve powerplant efficiencies during off-peak periods.

OUTLOOK

Global ammonia demand and operating rates continued to fall for the fourth consecutive year, dropping to an exceptionally weak 78% in 1992, 3% below the 81% operating rate estimated in 1991. The downturn can be traced largely to the dramatic fall in domestic demand in the former U.S.S.R., Eastern Europe, and Western Europe, in respective order of importance. Global per capita nitrogen consumption dropped to 17 kilograms in 1992 compared with the pre-1991 norm of about 19 kilograms.

The world ammonia supply-demand outlook anticipated by the U.S. Bureau of Mines suggests that soft market conditions will continue into 1993 and persist for an indefinite period because of significant new additions to world capacity and a protracted period of recovery anticipated in the former U.S.S.R. and Europe.

The upside to the global ammonia supply-demand situation is that demand may gradually rise 8 million tons N during the next 5 years to a new record level of about 100 million tons N, principally in regions outside of Europe and the former U.S.S.R. Furthermore, there is much uncertainty surrounding the future geopolitical and agronomic events that may surface in the former U.S.S.R., Eastern Europe and Western Europe. Fertilizer consumption has conceivably dipped to levels that could result in future plant closures, and/or the diversion of more nitrogen export materials to domestic use. This could potenitally result in a tighter global supply-demand situation than indicated.

The U.S. Bureau of Mines ammonia nitrogen demand forecast was developed from World Bank-United Nations Fertilizer Working Group projections[17] taking into consideration world per capita consumption trends and geopolitical factors in the former U.S.S.R., Europe, and the Mideast. Steady-state conditions were assumed for weather. World ammonia capacity projections were provided by the International Fertilizer Industry Association Ltd. (IFA), Paris, France. It should be pointed out that IFA's most recent analysis of the global fertilizer N supply-demand situation was less optimistic. *(See table 14.)*

In the United States, the outlook for continued strength in the nitrogen fertilizer and grain sectors is anticipated. The U.S. ammonia industry is running at near capacity, grain stocks are still relatively low at the global level, and U.S. and North American ammonia capacity expansion plans are minimal.

The mechanisms of the new CRP and WRP programs, together with regular farm program acreage reductions, should hold U.S. crop acreage at about the current 340-million-acre level. This, together with the Export Enhancement Initiative, should control crop inventories and provide favorable crop prices for the U.S. farmer.

The U.S. nitrogen supply-demand outlook will be critically dependent upon the following: (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, and USDA's new AARC initiative; (3) new markets for the Saskferco ammonia and urea nitrogen complex, which came 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 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 former U.S.S.R. and other Eastern European countries; (6) a more expedient transition in democratic reforms in Eastern Europe and the former U.S.S.R., and (7) resolution of the MFN status debate with China.

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TABLE 1
SALIENT AMMONIA STATISTICS[1]

(Thousand metric tons of contained nitrogen unless otherwise specified)

	1988	1989	1990	1991	1992[p]
United States:					
Production	12,544	12,280	[r]12,680	[r]12,801	13,404
Exports	582	346	482	580	354
Imports for consumption	2,751	2,861	2,673	2,742	2,690
Consumption, apparent[2]	14,742	14,871	[r]14,923	[r]14,825	15,619
Stocks, Dec. 31: Producers'	925	849	797	[r]936	1,057
Average annual price per ton product, f.o.b. gulf coast[3]	$109	$104	$106	$117	$106
Net import reliance[4] as a percent of apparent consumption	[r]14	[r]17	[r]14	[r]13	13
Natural gas price: Wellhead[5]	$1.69	$1.69	$1.71	[r]$1.64	$1.86
World:					
Production	[r]99,265	[r]99,234	[r]97,110	[r]93,995	[e]92,532
Trade[6]	[r]9,453	[r]9,823	[r]10,004	[p]9,544	[e]9,000

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Synthetic anhydrous ammonia, calendar year data, Bureau of the Census; excludes coke oven byproduct.

[2]Calculated from production, plus imports minus exports, and industry stock changes.

[3]Green Markets, Fertilizer Market Intelligence Weekly, Pike & Fischer, Inc.

[4]Defined as imports minus exports, adjusted for industry stock changes.

[5]Monthly Energy Review, U.S. Department of Energy. Average annual cost at wellhead in dollars per thousand cubic feet.

[6]International Fertilizer Industry Association statistics—World Anhydrous Ammonia Trade.

TABLE 2
FIXED NITROGEN PRODUCTION IN THE UNITED STATES

(Thousand metric tons of contained nitrogen)

	1988	1989	1990	1991	1992[p]
Anhydrous ammonia, synthetic:[1]					
Fertilizer	11,400	11,131	[r]11,573	[r]11,624	12,066
Nonfertilizer	1,144	1,148	1,107	[r]1,178	1,338
Total[2]	12,544	12,280	[r]12,680	[r]12,801	13,404
Byproduct ammonia, coke plants:[3]					
Ammonium sulfate[e]	[r]50	[r]48	[r]47	[r]42	41
Ammonia liquor[e]	5	5	5	4	4
Total[e 2]	[r]54	[r]53	[r]52	[r]45	44
Grand total[2]	[r]12,598	[r]12,332	[r]12,731	[r]12,847	13,448

[e]Estimated. [p]Preliminary. [r]Revised.
[1]Current Industrial Reports, MA28B, M28B, and MQ28B Bureau of the Census.
[2]Data may not add to totals shown because of independent rounding.
[3]Quarterly Coal Report, U.S. Department of Energy. Production estimates (1985-92) based on reported coke production trend.

TABLE 3
MAJOR DOWNSTREAM NITROGEN COMPOUNDS PRODUCED IN THE UNITED STATES[1]

(Thousand metric tons)

Compound	1988	1989	1990	1991	1992[p]
Urea:					
Gross weight	7,179	7,261	[r]7,453	[r]7,379	7,637
Nitrogen content	3,302	3,340	[r]3,428	[r]3,395	3,513
Ammonium phosphates:[2]					
Gross weight	13,718	14,862	[r]15,871	[r]15,756	16,009
Nitrogen content	2,351	2,517	[r]2,673	[r]2,635	2,733
Ammonium nitrate:					
Gross weight	6,808	7,140	[r]6,997	[r]7,055	6,955
Nitrogen content	2,382	2,499	[r]2,449	[r]2,469	2,434
Ammonium sulfate:[3]					
Gross weight	2,116	2,163	[r]2,285	[r]2,035	2,142
Nitrogen content	445	454	[r]480	[r]427	450
Nitric acid, direct use:[4]					
Gross weight	1,889	1,951	[r]1,686	[r]1,634	1,817
Nitrogen content	420	434	[r]375	[r]363	404
Acrylonitrile:					
Gross weight	1,168	1,183	1,373	1,201	1,283
Nitrogen content	308	312	363	318	338
Caprolactam:					
Gross weight	572	595	626	582	624
Nitrogen content	71	73	78	73	78
Total:[5]					
Gross weight	33,451	35,155	[r]36,291	[r]35,642	36,467
Nitrogen content	9,279	9,630	[r]9,846	[r]9,680	9,950

[p]Preliminary. [r]Revised.
[1]Ranked in relative order of importance.
[2]Diammonium phosphate (DAP), monoammonium phosphate (MAP), and other ammonium phosphates.
[3]Excludes coke plant ammonium sulfate.
[4]Gross nitric acid production adjusted for use in production of ammonium nitrate.
[5]Data may not add to totals shown because of independent rounding.

Sources: Bureau of the Census and International Trade Commission.

TABLE 4

DOMESTIC PRODUCERS OF ANHYDROUS AMMONIA IN 1992

(Thousand metric tons per year of ammonia)

Company	Location	Capacity[1]
Freeport-McMoRan (Agrico)	Donaldsonville, LA	454
Agricultural Minerals Corp.[2]	Blytheville, AR	363
Do.	Verdigris, OK	907
Air Products and Chemicals Inc.	New Orleans, LA[3]	263
Do.	Pace Junction, FL	91
Allied Chemical Corp.	Hopewell, VA[3]	390
American Cyanamid Co.	Fortier, LA[3]	404
Ang Coal Gas	Beulah, ND	22
Arcadian Corp.[4]	Augusta, GA	494
Do.	Clinton, IA	236
Do.	Geismar, LA	372
Do.	Lake Charles, LA	399
Do.	LaPlatte, NE	172
Do.	Woodstock, TN	308
Borden Chemical Co.	Geismar, LA	363
Carbonaire Co. Inc.	Palmerton, PA	32
CF Industries Inc.	Donaldsonville, LA	1,606
Chevron Chemical Co.	El Segundo, CA	18
Do.	Pascagoula, MS	(5)
Do.	St. Helens, OR	73
Coastal Chem, Inc.	Cheyenne, WY	154
Cominco American Inc.	Borger, TX[3]	381
Diamond Shamrock[6]	Dumas, TX	127
E.I. du Pont de Nemours & Co. Inc.	Beaumont, TX	445
Farmland Industries Inc.	Beatrice, NE[3]	227
Do.	Dodge City, KS[3]	200
Do.	Enid, OK[3]	816
Do.	Fort Dodge, IA	191
Do.	Hastings, NE	(7)
Do.	Lawrence, KS[3]	399
Do.	Pollock, LA[3]	408
First Mississippi Corp. (Ampro)	Donaldsonville, LA[3]	408
Green Valley Chemical Corp.	Creston, IA	32
Koch Industries	Sterlington, LA	953
Jupiter Chemicals	West Lake, LA	27
LaRoche Industries Inc.	Cherokee, AL	159
Mississippi Chemical Corp.	Yazoo City, MS[3]	454
Monsanto Co.	Luling, LA[3]	445
Nitrogen Products, Inc.	Helena, AR[3]	191
Occidental Chemical Corp.	Tacoma, WA	25
Pennwalt Chemical Co.	Portland, OR	7
Phoenix Chemical Co.[8]	East Dubuque, IL	216
PPG Industries Inc.	Natrium, WV	45
J.R. Simplot Co.	Pocatello, ID	98
Sohio Chemical Co. (BP Intl. Ltd.)	Lima, OH[3]	481
Terra International, Inc.[9]	Port Neal, IA	249
Do. (Oklahoma Nitrogen)	Woodward, OK[3]	408

See footnotes at end of table.

TABLE 4—Continued

DOMESTIC PRODUCERS OF ANHYDROUS AMMONIA IN 1992

(Thousand metric tons per year of ammonia)

Company	Location	Capacity[1]
Triad Chemical Co.[10]	Donaldsonville, LA[3]	408
Union Chemical Co. (Unocal)	Kenai, AK[3]	1,134
Wil-Grow Fertilizer Co.[8]	Pryor, OK	85
Total		16,140

[1]Engineering design capacity adjusted for 340 days per year of effective production capability.
[2]Plants purchased from Freeport-McMoRan Feb. 28, 1990.
[3]Revamp and/or retrofit.
[4]Plants purchased late May through early Nov. 1989.
[5]Large 530,000-ton-per-yearplant idle for more than 3 years reportedly dismantled.
[6]Capacity doubled in 1992 via reactivation of second train.
[7]Plant (140,000 tons per year) mothballed.
[8]Former N-Ren Corp. plants acquired by Great American Management and Investment, Aug. 1987.
[9]Expansion (70,000 tons per year) complete late 1992.
[10]Joint 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, Feb. 1993, and, Blue, Johnson and Associates. North American NPK Plants and Capacities. Foster City, CA, Jan. 1, 1992.

TABLE 5

CONSUMPTION TRENDS FOR MAJOR NITROGEN COMPOUNDS PRODUCED IN THE UNITED STATES[1]

(Thousand metric tons of contained nitrogen)

	1988	1989	1990	1991	1992[p]
Fertilizer materials:					
Urea:					
Solid	1,840	1,831	[r]1,917	[r]1,871	1,926
Solution	1,090	1,118	[r]1,158	[r]1,139	1,177
Total	2,930	2,949	[r]3,075	[r]3,010	3,103
Ammonium phosphates[2]	2,351	2,517	[r]2,673	[r]2,635	2,733
Ammonium nitrate:					
Solid	704	719	[r]697	[r]696	679
Solution	1,082	1,170	[r]1,018	[r]1,167	1,171
Other[3]	9	-12	[r]68	[r]2	•—
Total	1,795	1,877	[r]1,783	[r]1,865	1,850
Ammonium sulfate:					
Synthetic and byproduct	445	454	[r]480	[r]427	450
Coke oven byproduct[e]	54	53	52	45	44
Total	499	507	[r]532	[r]472	494
Total fertilizer	7,575	7,850	[r]8,063	[r]7,982	8,180
Nonfertilizer materials:					
Urea:[2]					
Feed	155	175	[r]82	[r]95	116
Industrial	219	217	[r]270	[r]288	295
Total	374	392	[r]352	[r]383	411
Ammonium nitrate[2]	587	621	[r]667	[r]605	585
Nitric acid	420	434	[r]375	[r]363	404
Acrylonitrile	308	312	363	318	338
Caprolactam	71	73	78	73	78
Total nonfertilizer	1,760	1,832	[r]1,835	[r]1,742	1,816
Grand total[4]	9,333	9,682	[r]9,898	[r]9,725	9,994

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Ranked in relative order of importance.

[2]Solid and solution.

[3]Unaccounted distribution.

[4]Data 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 6
U.S. NITROGEN FERTILIZER CONSUMPTION, BY PRODUCT TYPE[1]

(Thousand metric tons nitrogen)

Fertilizer material[2]	1991[r]	1992[p]
Single-nutrient:		
Anhydrous ammonia	3,816	3,721
Nitrogen solutions[3]	2,039	2,133
Urea	1,432	1,471
Ammonium nitrate	570	583
Ammonium sulfate	157	155
Aqua ammonia	63	62
Other[4]	181	184
Total[5]	8,256	8,310
Multiple-nutrient[6]	1,983	2,032
Grand total	10,239	10,342

[p]Preliminary. [r]Revised.
[1]Fertilizer years ending June 30.
[2]Ranked in relative order of importance by product type.
[3]Principally urea-ammonium nitrate (UAN) solutions.
[4]Includes other single-nutrient nitrogen materials and all natural organics.
[5]Data may not add to totals shown because of independent rounding.
[6]Various combinations of nitrogen (N), phosphate (P), and potassium (K): N-P-K, N-P, and N-K.

Source: Economics and Marketing Research Section, Tennessee Valley Authority. Commercial Fertilizers, Dec. 1992.

TABLE 7
U.S. PRODUCER STOCKS OF FIXED NITROGEN COMPOUNDS AT YEAREND[1]

(Thousand metric tons nitrogen)

Material[2]	1991	1992[p]
Ammonia	[r]936	1,057
Nitrogen solutions[3]	298	313
Urea	171	204
Ammonium phosphates[4]	[r]89	100
Ammonium nitrate	[r]77	70
Ammonium sulfate	35	41
Total[5]	[r]1,607	1,784

[p]Preliminary. [r]Revised.
[1]Calendar year ending Dec. 31.
[2]Ranked in relative order of importance.
[3]Urea-ammonium nitrate and ammoniacal solutions.
[4]Diammonium, monoammonium, and other ammonium phosphates.
[5]Data may not add to totals shown because of independent rounding.

Source: Current Industrial Reports, MA28B and MQ28B, Bureau of the Census.

TABLE 9
U.S. EXPORTS OF ANHYDROUS AMMONIA, BY COUNTRY

(Thousand metric tons ammonia)[1]

Country	1991	1992[p]
Korea, Republic of	327	277
South Africa, Republic of	112	54
China	—	57
Belgium	80	—
Norway	60	—
Sweden	10	—
Australia	40	—
Philippines	18	—
Brazil	15	—
Chile	8	—
Morocco	15	15
Canada	15	15
Other[2]	5	13
Total	705	431

[p]Preliminary.
[1]Value data suppressed by Bureau of the Census. Ranked in relative order of importance by country and geographics.
[2]Eighteen countries, principally in Latin America.

Source: Bureau of the Census.

TABLE 8
PRICE QUOTATIONS FOR MAJOR NITROGEN COMPOUNDS AT YEAREND

(Per metric ton product)

Compound	1991[r]	1992
Ammonium nitrate: F.o.b. Corn Belt[1]	$108-$130	$138-$149
Ammonium sulfate do.	118- 125	121- 132
Anhydrous ammonia:		
F.o.b Corn Belt	138- 154	147- 160
F.o.b. gulf coast[2]	116- 118	129- 130
Diammonium phosphate: F.o.b. central Florida	144- 149	122- 127
Nitrogen solutions (28% to 32%):		
F.o.b. South Central[3]	95- 106	95- 103
Urea:		
F.o.b. Corn Belt, prilled	146- 160	149- 160
F.o.b. gulf coast, granular[2]	142- 143	142- 146
F.o.b. gulf coast, prilled[2]	133- 134	139- 141

[r]Revised.
[1]Illinois, Indiana, Iowa, Missouri, Nebraska, and Ohio.
[2]Barge, New Orleans.
[3]Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Tennessee, and Texas.

Source: Green Markets, Fertilizer Market Intelligence Weekly, Dec. 23, 1991, and Dec. 21, 1992.

TABLE 10

U.S. IMPORTS OF ANHYDROUS AMMONIA, BY COUNTRY

(Thousand metric tons ammonia)[1]

Country	1991		1992[p]	
	Gross weight	Value[2] (thousands)	Gross weight	Value[2] (thousands)
Trinidad and Tobago	1,068	$131,515	1,031	$113,594
Canada	1,027	117,636	1,000	117,395
U.S.S.R.[3]	912	101,138	644	71,824
Mexico	311	38,501	542	57,318
Bermuda	11	1,401	—	—
Australia	—	—	21	2,012
Denmark	—	—	12	1,381
Norway	—	—	10	1,122
Estonia[4]	NA	NA	10	1,068
Other[5]	[r]19	[r]2,272	1	112
Total	[6]3,336	[r]392,463	3,271	365,826

[p]Preliminary. [r]Revised. NA Not available.

[1]Tonnage data suppressed by Bureau of Census effective Jan. 1, 1989. Reinstated Jan. 1, 1990, excluding the U.S.S.R. Ranked in relative order of importance by country and geographics.

[2]Bureau of Census c.i.f. data.

[3]Dissolved in Dec. 1991. In 1992, principally Russia and Ukraine.

[4]Formerly part of the U.S.S.R.

[5]Ten countries; Japan in 1992.

[6]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11

U.S. EXPORTS OF MAJOR NITROGEN COMPOUNDS IN 1992

(Thousand metric tons)

Compound	Gross weight	Nitrogen content	Value[1] (thousands)
Fertilizer materials:			
Ammonium nitrate[2]	40	14	NA
Ammonium sulfate[2]	801	169	NA
Anhydrous ammonia	431	354	NA
Diammonium phosphate	8,272	1,489	NA
Monoammonium phosphate	890	98	NA
Nitrogen solutions	369	111	NA
Sodium nitrate	5	1	NA
Urea	914	420	NA
Mixed chemical fertilizers[3]	284	44	NA
Other ammonium phosphates[4]	82	13	NA
Other nitrogenous fertilizers[5]	117	5	NA
Total[6]	12,205	2,717	NA
Industrial chemicals:			
Ammonia, aqua (ammonia content)	23	19	$1,830
Ammonium compounds[7]	5	2	7,292
Ammonium phosphate (ortho)	(8)	(8)	96
Potassium cyanide	(8)	(8)	766
Sodium cyanide	59	17	53,063
Other cyanides and cyanates	1	(8)	4,399
Hydrazine, hydroxylamine and related inorganic salts	14	7	27,937
Bismuth/silver nitrates	(8)	(8)	5,471
Potassium nitrate	19	3	6,054
Other nitrates	5	1	6,372
Nitric/sulfonitric acids	14	2	4,657
Nitrites	4	1	2,794
Total[6]	142	50	120,731
Grand total[6]	12,347	2,767	NA

NA Not available.
[1]Export values f.o.b.
[2]Includes industrial chemical products.
[3]Harmonized codes 3105.10.0000 and 3105.20.0000.
[4]Codes 3105.51.0000, 3105.59.0000, and 3102.70.0000.
[5]Codes 3101.00.0000, 3102.29.0000, 3102.60.0000, and 3102.90.0000.
[6]Data may not add to totals shown because of independent rounding.
[7]Carbonates, chloride, fluorides, and tungstate.
[8]Less 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 12

U.S. IMPORTS OF MAJOR NITROGEN COMPOUNDS IN 1992

(Thousand metric tons)

Compound	Gross weight	Nitrogen content	Value[1] (thousands)
Fertilizer materials:			
Ammonium nitrate[2]	444	149	$55,520
Ammonium nitrate-limestone mixtures	1	(3)	142
Ammonium sulfate[2]	336	71	30,203
Anhydrous ammonia[4]	3,271	2,690	365,826
Calcium nitrate	(3)	(3)	10,811
Diammonium phosphate	23	4	4,907
Monoammonium phosphate	162	18	28,792
Nitrogen solutions	108	33	10,948
Potassium nitrate	39	5	12,575
Potassium nitrate-sodium nitrate mixtures	37	5	6,197
Sodium nitrate	142	23	24,852
Urea	1,560	718	204,521
Mixed chemical fertilizers[5]	161	19	25,763
Other ammonium phosphates[6]	62	10	8,488
Other nitrogenous fertilizers[7]	159	31	29,435
Total[8]	6,505	3,775	818,978
Industrial chemicals:			
Ammonia, aqua (ammonia content)	8	2	693
Ammonium compounds[9]	14	4	18,725
Calcium cyanamide	1	(3)	591
Potassium cyanide	1	(3)	1,238
Sodium cyanide	5	1	4,923
Other cyanides and cyanates[10]	3	(3)	5,234
Hydrazine, hydroxylamine and related salts	2	1	7,132
Bismuth/silver nitrates	(3)	(3)	995
Strontium/other nitrates	5	1	4,089
Nitric/sulfonitric acids	10	2	2,496
Sodium/other nitrites	2	(3)	1,205
Total[8]	49	12	47,321
Grand total[8]	6,554	3,787	866,299

[1]Import values c.i.f.
[2]Includes industrial chemical products.
[3]Less than 1/2 unit.
[4]Anhydrous ammonia tonnage data for the former U.S.S.R. in 1992; as reported by U.S. Bureau of Mines; includes industrial ammonia. Tonnage data, excluding the former U.S.S.R., Bureau of Census.
[5]Harmonized codes 3105.10.0000 and 3105.20.0000.
[6]Codes 3105.51.0000, 3105.59.0000, and 3105.40.0050.
[7]Codes 3101.00.0000, 3102.29.0000, 3102.60.0000, 3102.90.0000, and 3105.90.0050.
[8]Data may not add to totals shown because of independent rounding.
[9]Carbonates, chloride, fluorides and tungstate (exports and imports); bromide, molybdate, orthophosphate, and perrhenate (imports).
[10]Data 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 13

AMMONIA: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons of contained nitrogen)

Country	1988	1989	1990	1991	1992[e]
Afghanistan[e]	40	40	40	40	40
Albania[e]	100	110	100	80	50
Algeria	197	132	r288	r269	2408
Argentina	78	74	70	r75	72
Australia	386	344	385	e414	400
Austria	408	410	410	400	400
Bahrain	r296	r319	r325	320	2323
Bangladesh	673	775	701	667	2770
Belarus[3]	—	—	—	—	2916
Belgium	365	292	e300	e300	300
Bosnia and Herzegovina[4]	—	—	—	—	15
Brazil	935	979	938	793	2877
Bulgaria	1,342	e1,300	1,309	1,300	1,300
Burma	112	120	125	e130	130
Canada	3,289	3,339	3,054	3,016	23,104
China[e]	16,500	17,000	17,500	18,000	18,000
Colombia	r84	92	98	e90	90
Croatia[4]	—	—	—	—	350
Cuba	135	r134	r e140	r e140	135
Czechoslovakia	771	797	793	551	385
Egypt	788	728	e735	r863	860
Estonia[3]	—	—	—	—	2117
Finland	43	42	r23	r24	210
France	1,832	1,476	1,586	e1,604	21,407
Germany:					
Eastern states	1,156	e1,150	r e700	—	—
Western states	1,824	1,732	1,671	—	—
Total	2,980	2,882	r2,371	r2,123	2,160
Georgia[3]	—	—	—	—	296
Greece	263	242	257	e210	200
Hungary	692	673	445	291	185
Iceland	9	9	8	9	9
India[5]	6,205	6,661	7,022	7,044	7,000
Indonesia	2,367	2,526	e2,600	r2,706	2,700
Iran[e]	146	336	420	2468	2658
Iraq[e]	r313	2474	330	r50	70
Ireland	417	386	395	e429	400
Israel	r48	r48	r42	r34	34
Italy	1,561	1,446	1,197	e1,147	21,098
Japan	1,524	1,539	1,531	1,553	21,602
Kazakhstan[3]	—	—	—	—	2220
Korea, North[e]	500	500	500	550	550
Korea, Republic of	506	480	411	r407	400
Kuwait	r498	665	292	—	2140
Libya	217	212	200	e200	200
Lithuania[3]	—	—	—	—	2275

See footnotes at end of table.

TABLE 13—Continued

AMMONIA: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons of contained nitrogen)

Country	1988	1989	1990	1991	1992e
Malaysia	301	279	229	286	[2]331
Mexico	2,067	2,100	2,164	r2,221	2,222
Netherlands	r2,695	r2,901	r3,188	r3,033	[2]2,667
New Zealand	73	70	70	e70	70
Nigeria	310	299	333	r303	300
Norway	424	382	431	384	[2]343
Pakistane	1,173	1,175	1,180	1,185	1,187
Perue	95	91	90	r95	95
Poland	2,338	2,360	2,006	1,669	1,500
Portugal	191	151	198	r198	[2]100
Qatar	r598	r587	r584	r569	[2]622
Romania	r2,795	r2,736	r1,785	1,130	1,100
Russia[3]	—	—	—	—	[2]8,786
Saudi Arabia	867	863	942	827	[2]904
Serbia and Montenegro[4]	—	—	—	—	250
South Africa, Republic of	472	455	456	457	[2]541
Spain	476	552	483	r557	[2]479
Switzerland	e32	e32	32	r33	31
Syria	79	123	104	e105	105
Taiwan	279	203	216	243	224
Trinidad and Tobagoe	r1,388	r1,550	1,520	r1,524	[2]1,568
Turkey	309	r380	r373	r357	[2]365
Turkmenistan[3]	—	—	—	—	[2]25
U.S.S.R.e[6]	20,200	19,400	18,200	17,100	—
Ukraine[3]	—	—	—	—	[2]3,882
Uzbekistan[3]	—	—	—	—	[2]1,309
United Arab Emirates	r297	324	r295	e286	290
United Kingdom	1,105	1,037	r1,148	r1,011	[2]869
United States[7]	12,544	12,280	r12,680	r12,801	[2]13,404
Venezuela	563	532	r557	r450	404
Vietname	36	36	36	36	35
Yugoslavia[8]	858	680	802	e700	—
Zambia	16	12	r4	r5	5
Zimbabwe	64	e62	r63	r e63	63
Total	r99,265	r99,234	r97,110	r93,995	92,532

eEstimated. rRevised.

[1]Table includes data available through May 25, 1993.

[2]Reported figure.

[3]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[4]Formerly part of Yugoslavia; data were not reported separately until 1992.

[5]Data are for years beginning Apr. 1 of that stated.

[6]Dissolved in Dec. 1991.

[7]Synthetic anhydrous ammonia; excludes coke oven byproduct ammonia.

[8]Dissolved in Apr. 1992.

TABLE 14

WORLD ANHYDROUS AMMONIA SUPPLY-DEMAND RELATIONSHIPS[1 2]

(Million metric tons nitrogen)

	1987	1988	1989	1990	1991	1992e	1993[3]	1994[3]	1995[3]	1996[3]	1997[3]
Capacity[4]	112.6	115.8	117.1	115.8	117.3	118.9	119.4	122.9	124.6	126.5	127.9
Demand:[5]											
Fertilizer	84.7	88.8	88.6	86.9	84.0	82.5	83.0	84.8	86.5	88.1	89.3
Industrial	10.4	10.5	10.6	10.4	10.0	10.0	10.0	10.1	10.2	10.3	10.4
Total	95.1	r99.3	r99.2	r97.1	r94.0	92.5	93.0	94.9	96.7	98.4	100.2
Operating rate[6] (percent)	84	86	85	84	80	78	78	77	78	78	78
Consumption:											
Pounds per capita[7]	41.9	42.9	r42.1	r40.4	r38.4	37.1	36.6	36.7	36.8	36.8	36.8
Population:											
Billion[8]	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0

eEstimated. rRevised.

[1]Calendar years.

[2]Data may include revisions.

[3]Forecast.

[4]Design capacity, 340-day-per-year effective operation.

[5]Ammonia consumed in the production of fertilizer and industrial products, including process losses.

[6]Total demand as a percent of design capacity.

[7]Ammonia demand expressed in pounds per person.

[8]Statistical Abstract of the United States 1991; Bureau of the Census.

Source: Division of Mineral Commodities, Branch of Industrial Minerals, U.S. Bureau of Mines.

NONRENEWABLE ORGANIC MATERIALS

By Raymond L. Cantrell and Deborah A. Kramer

Mr. Cantrell and Ms. Kramer are physical scientists in the Branch of Industrial Minerals. In combination, they represent more than 40 years of diverse technical experience in the public and private sectors, including the industrial organic chemicals, plastics, rubber, agricultural chemicals, and nonferrous metals industries. Ms. Michele R. Simmons, industry program manager, Branch of Materials, prepared the salient organic materials statistics table. Ms. Deborah A. Nolan, statistical specialist, Division of Statistics and Information Services, researched and updated the information contained in other data tables.

This report is the third annual series prepared by the U.S. Bureau of Mines (USBM) to address the situation and outlook for nonrenewable organic materials in the U.S. and global marketplace. Nonrenewable organic materials refer to nonfuel derivatives of finite fossil fuel feedstocks of petroleum, natural gas, and coal, as opposed to those derived from renewable natural organic biomass sources. All organic materials contain carbon, most commonly associated with hydrogen, oxygen, nitrogen, and sulfur, and comprise a vast number of chemical compounds.[1] Organics range from the simplest hydrocarbon compound, methane (CH_4), to high-molecular-weight thermoplastic and thermoset polymers and complex biological matter associated with all life forms on Earth. The terms "plastics," "resin," and "polymers" are often used interchangeably by the synthetic organic chemicals industry.[2]

Polymeric materials, including thermoplastic and thermoset polymers, synthetic fibers, and synthetic rubber, are important products derived predominately from nonrenewable organic feedstocks. In addition, lubricants, asphalt, road oil, waxes, solvents, and numerous other petrochemicals fill many important nonfuel uses. Products manufactured from nonrenewable organic materials include a variety of items such as household goods, beverage containers, food packaging, cosmetics, sporting goods, paints and coatings, ink, pigments, pipe and hose, electrical devices and computer goods, textiles, automotive components, tires, battery casings, engine oil, grease, construction materials, fertilizers, pesticides, pharmaceuticals, medical devices, eyewear, and a multitude of other items vital to modern society.

In 1992, restricted economic growth in the United States, Europe, Japan, and the former U.S.S.R. continued to suppress overall profitability and limit consumer spending for nonrenewable organic goods, even though fossil fuel feedstocks were in a general state of oversupply. Although production increased about 6% in the high-volume U.S. resin industry, for example, profitability was down 6%, and gross revenues did not change significantly from the prior year, according to The Society of the Plastics Industry, Inc. U.S. synthetic rubber production and apparent consumption were up 12%, according to the Rubber Manufacturers Association, but value information was not available. Crude oil prices dipped to the lowest level since 1986, averaging $16.18 per barrel, and natural gas and coal prices were also depressed.

Fossil fuel feedstock and byproduct consumption for the manufacture of U.S. nonrenewable organic materials did not change significantly from 1991 levels, and in 1992, was estimated at 121 million metric tons valued at about $13.4 billion. *(See table 1.)* Petrochemical feedstocks, intermediate and finished organic chemicals, resin, synthetic fibers, and rubber continued to account for about 61% of total consumption. The remaining 39% was converted into asphalt and road oil (23%); lubricants and waxes (9%); and petroleum coke and coal products (7%).

The U.S. International Trade Commission (ITC) annual survey of U.S. synthetic organic chemicals estimated producer sales for noncaptive use at about $90 billion, representing a turnover, or value added aspect, of roughly sevenfold relative to feedstock values.[3] Data reported by the International Trade Administration (ITA), U.S. Department of Commerce, estimated the value of all U.S. nonfuel petrochemical shipments at about $130 billion.[4] The United States experienced a positive trade balance in petrochemicals of about $15 billion in 1992 and continued to be a major net exporter of polymers and resin, synthetic fibers, paints and coatings, synthetic rubber, and agricultural pesticides.

Domestic merchant sales values for many of the high-volume thermoplastic resins declined significantly in 1992. The large high-density polyethylene (HDPE) and polystyrene businesses were particularly hard hit by a combination of overcapacity and depressed prices. Occidental Chemical Corp., the Nation's second largest producer of HDPE, responded by closing its HDPE plant at Orange, TX, at yearend.[5]

E.I. du Pont de Nemours & Co. Inc. announced a major long-term

reorganization of its 200-year-old organic chemicals business. A five-point program was announced that included divesting the acrylics business and focusing on core businesses such as nylon, pharmaceuticals, and energy. Du Pont officials unveiled a comprehensive antipollution initiative that would reduce the firm's toxic air emissions by 60% in 1993 and airborne carcinogens by 90% toward the end of the decade. Du Pont also announced a major work force reduction designed to reduce overhead and improve efficiency, together with a renewed commitment to research and product development (R&D).[6]

The U.S. Department of Energy (DOE) reported that about 6.2% of total U.S. energy consumption in 1992 was for direct nonfuel organics feedstock purposes, excluding external energy used in chemical processing.[7] Feedstock costs were estimated at the closest point of delivery based on reported DOE data. Energy conversion efficiency in the chemical industry has improved dramatically in recent years; thus, it is possible that chemical production may have increased in 1992 although energy consumption was about the same as that in 1991.

DOMESTIC DATA COVERAGE

Data were obtained from a variety of government sources, including the ITC publication, Synthetic Organic Chemicals, derived from an annual canvass of the U.S. organic chemicals industry under the authority of Section 332g of the Tariff Act of 1930; the Annual Energy Review 1992, Petroleum Supply Annual 1992, and coal reports published by the Energy Information Administration, DOE; U.S. Department of Commerce reports; U.S. Bureau of Labor statistics; and the U.S. Environmental Protection Agency (EPA).

Several private groups assisted the USBM, including The Society of the Plastics Industry, Inc.; American Plastics Council; Chemical Manufacturers Association; Federation of Societies for Coatings Technology; Fiber Economics Bureau, Inc.; American Fiber Manufacturers Association, Inc.; Rubber Manufacturers Association; International Institute of Synthetic Rubber Producers; The Asphalt Institute; Asphalt Roofing Manufacturers Association; The Fertilizer Institute; and National Agricultural Chemicals Association. Information was also sourced from industry trade journals.

BACKGROUND

The Industrial Revolution that commenced in Europe during the early 1700's gave birth to innovative technologies for the manufacture of iron and steel, the spinning machine, agricultural harvesting equipment, and inorganic chemicals production. It was not until the late 1700's, however, that America began to gradually emerge from its traditional agrarian posture, based primarily on manual labor.

Eli Whitney's invention of the cotton gin in 1793 revolutionized the industry, and Robert Fulton's invention of the steamboat in 1807 opened river traffic to industrial commerce. The roving-frame spinning machine and reaping machine were invented by Charles Danforth and Cyrus McCormick between 1829 and 1831. Charles Goodyear invented the vulcanization process for natural rubber in 1841. Commerce in the United States continued to gather impetus with the advent of rail traffic, and by the 1860's the United States was evolving into a substantial heavy-duty industrial economy based on renewable agricultural resources, together with steel and other nonrenewable mineral commodities.

In the mid-1800's, John Wesley Hyatt and his brother Isaiah experimented with the natural polymer cellulose nitrate, a reaction product of nitric acid and cellulose, with the idea of coming up with a viable substitute for billiard balls made traditionally from expensive ivory. This is just one example of how many American scientists/entrepreneurs like the Hyatt brothers made a meaningful materials substitution. In 1872, the term "celluloid" was coined by Isaiah Hyatt for materials made from cellulose nitrate and camphor, and the Hyatt's firm, Celluloid Manufacturing Co., is known today as Hoechst Celanese Corp. In 1907, Leo Bakeland introduced Bakelite, an industrially significant phenolformaldehyde thermosetting heat-resistant polymeric resin.

The Petroleum Age

A major wildcat oil strike by Edwin L. Drake near Titusville, PA, on August 27, 1859, gave birth to a new technological era in the United States—the petroleum age. An abundant source of fluid organic chemical feedstock containing a multitude of carbon compounds had been found that was relatively easy to pump and process, unlike solid coal minerals. Although the first U.S. petroleum refinery was built in 1860 near the Titusville oilfield, the major contributing factor that transformed petroleum into an industrial giant was the commercial development of the internal combustion engine in the early 1900's, merging minerals technology with the nonrenewable organics sector. The horse and buggy days gradually became a thing of the past as oil production began to increase, and California and Oklahoma alternated as production leaders until 1928, when Texas took the lead.

The 1920's served as the benchmark for major oil discoveries in the United States, and during the 1930's there were enormous finds in east Texas, and at Prudhoe Bay, AK, by 1967. U.S. oil output exceeded 3 billion barrels in 1966 and reached a peak of more than 3.5 billion barrels in 1970. During this period, the United States was the world's leading oil producer, but by 1974 the U.S.S.R. assumed first place, and Saudi Arabia captured second place in 1976. Today, the United States continues as the world's leading consumer of petroleum, with about 20% of world consumption, by carrying a significant net import dependency in the mid-40% range.

The petroleum industry initially supplied crude oils for lighting, etc., and later developed sophisticated distillation and associated technologies for the production of gasoline and lubricants for the growing automotive industry. Heating oils, diesel fuel, asphalt for road building, and a number of consumer products were also produced. Many light

fractions of petroleum manufacture such as ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}) were vented and flared because technology had not been developed for their use. Natural gas, or methane, also was found to be associated with petroleum and was contained in deposits by itself. Natural gas was found to be an excellent clean burning fuel source, but much was flared as a nuisance item of oil production.

Petrochemicals

During World War II, important organic synthesis technology, developed earlier by noted research scientists, was put to practical use. Petroleum engineers learned how to recover the lighter, more reactive organic molecules and crack both small and large ones into forms that could be turned into nonrenewable organic chemical feedstocks and downstream polymers and other items of commerce. Nylon was developed by Wallace Carothers and Du Pont between 1927 and 1940, and used in parachutes during the war. Following the war, nylon hosiery and other nylon fabrics precipitated a major synthetic fiber revolution. Synthetic rubber (styrene-butadiene, neoprene, and butyl) was developed to augment supplies of natural rubber cut off from Indonesia, Malaysia, Singapore, and Thailand during the war. Military explosives also were involved in the organics revolution, including trinitrotoluene (TNT) and nitroglycerine (dynamite).

Rapid growth in the U.S. economy was experienced during the postwar years through the 1970's. The early 1980's marked the beginning of a major downturn in the global economy and in most major U.S. commodity businesses, but petrochemicals trends were anomalous to the general trend. HDPE and other nonrenewable organic materials continued to displace minerals and renewable organic resources traditionally used in the manufacture of bottles, "wax paper," "butcher paper," oil cans, fiber, and rubber, for example. There also was solid demand for polyvinyl chloride (PVC) materials compounded with industrial minerals such as calcium carbonate, clays, talc, and titanium dioxide, and extruded into pipe, vinyl siding, and garden hose, or fabricated into vinyl sheet as a superior substitute for "linoleum" flooring. Athletic goods were improved by the substitution effect of high strength, low density polymeric materials. Polyvinyl acetate water-based emulsions and many other polymers continued to replace natural resins and oils in glue and paints. Microcircuitry revolutionized the computer, communications, and timepiece industries. Integrated circuits and computer chips merged high-tech polymeric resins and minerals-derived materials. Synthetic organic urea nitrogen fertilizers replaced low analysis fertilizers and, along with more effective organic pesticides, improved crop yields.

Acrylic resin is integral to the manufacture of various water-based paints, sheet film, and coatings; polystyrene is integral to fabricated housewares and industrial applications; and polypropylene is integral to the production of fishing line, bottles, and safety helmets. A multitude of polymeric substitutions in the automotive industry has resulted in reduced weight, improved gas mileage, and improvements in structural stability, safety, and performance. Other significant nonrenewable organic materials include epoxy adhesives and plasticizers, polyamide hotmelt adhesives, solventless powder coatings, medical equipment, and pharmaceuticals.

Polyethylene terephthalate (PET) soda bottles and the popular polyurethane roller blades are recent successful entries in the marketplace, along with a growing repertoire of other new polymeric materials such as aromatic copolyester and liquid crystal polymers for electrical applications introduced in 1984 and 1985, together with polymethylpentene, a high-temperature, transparent polymeric material introduced in 1988.

The petrochemicals materials expansion and sweeping development of new materials technologies during the past 40 years has revolutionized life in the United States and around the globe, driving demand for high-tech skills in the workplace.

Definitions, Grades, and Specifications

Petrochemical feedstocks for nonfuel organics use are obtained principally from crude oil, natural gas, and to some extent from coal. There are about eight primary organic chemical feedstocks needed to produce intermediate and finished petrochemical materials, as shown by figure 1. It is interesting to note that of the eight, only methane is directly available from petroleum and natural gas. The other seven must be synthesized from crude petroleum and liquid hydrocarbon fractions of natural gas by processes such as catalytic cracking (cat cracking), reforming, and other chemical engineering processes to obtain chemically reactive ("unsaturated") bonds between the carbon atoms. *(See table 2.)*

Crude Oil.—Petroleum is a complex mixture containing thousands of different organic compounds ranging from the most simple hydrocarbon form, methane, to some high molecular weight compounds containing as many as 85 carbon atoms. Most of the compounds are straight chain saturated hydrocarbons called alkanes or paraffins, which are in the family of compounds grouped with methane. This simply means that the four available reaction sites for each carbon atom are filled. But, for C_3 saturated forms and higher, the molecules also can be arranged in a ring structure as well.

Benzene is an important ring compound found in petroleum in limited amounts (0.5% to 1.0%), but synthesized in large quantities from petroleum feedstock. Benzene is an organic ring compound belonging to a unique family of organic compounds known as aromatics. The benzene ring (C_6H_6) contains only one-half as many hydrogen atoms as its saturated cyclic paraffin cousin cyclohexane (C_6H_{12}). This means that benzene is "unsaturated," and has three "double bonds" between the carbon atoms that can be reacted with other elements. All aromatic organic molecules

are arranged in rings and contain reactive "unsaturated" carbon bonds of a special type.

Crude oil is characterized as being "sweet" or "sour" depending upon its sulfur content and "heavy" or "light" depending upon its particular distribution of large and small organic chemical compounds, as measured by specific gravity or weight per unit volume. Oil is measured by the barrel, containing 42 gallons. A significant amount of elemental sulfur is recovered from refinery oil, typically through the Claus process, wherein hydrogen sulfide and sulfur dioxide are reacted to produce elemental sulfur.

Most of the components of oil can be separated by fractional distillation, taking advantage of a wide range of boiling points. The distillate fractions that are made into reactive, petrochemical feedstocks include the gaseous C_1 to C_4 components removed overhead, the C_5 to C_{20} naphthas and gas oil liquid fractions, the heavy residues beyond C_{20}, and the asphalt and petroleum coke residues.

Lubricating Oils.—Lubricating oils used in vehicles and in industrial machinery and processes are made from a relatively small number of crude oil-base stocks blended with several additives designed to achieve specific properties. Special additives allow for relatively constant or variable viscosity change with temperature, promote oxidation resistance, and regulate acidity and pour points.

Asphalt.—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 kerosene material added so that it sets up faster), medium cure, and slow cure, for use as road base at different ambient temperatures.

Not all refinery operations produce asphalt because it is a natural product only from heavy crude oils; the amount of asphalt produced will be in rough proportion to the specific gravity of the crude oil. Further processing is necessary to make the asphaltic material suitable for roofing applications.

Asphalt serves as an highly effective binder in roadway construction. Asphalt roadways typically consist of only 5% to 10% asphalt, filled with an enormous quantity of crushed stone and modified with hydrated lime to facilitate impact resistance.[8]

Petroleum Coke.—Petroleum coke is obtained by severe thermal cracking of the bottom residues remaining after petroleum refining. The feed is heated to about 560° C and charged to the bottom of a coking drum. The cracked lighter product is drawn off overhead; the heavier product remains and, because of the retained heat, cracks to coke, a solid coal-like substance. Coke yields may approximate up to 30% of the feed.

Coke comes in two principal forms—"sponge coke" and "needle coke." Sponge coke varies from a hard, porous, irregular-shaped lump to a fine powder. The main uses for sponge coke are in the manufacture of electrodes and anodes, as a carbon source for carbides, and for the manufacture of artificial graphite used in motor brushes. The strength of sponge coke is not sufficient for its use in blast furnaces for pig iron or in foundry work.

"Needle coke" derives its name from its microscopic elongated crystalline structure. Needle coke requires special coker feeds and more severe operating conditions. Its qualities make it the preferred material for graphite electrodes because of its lower electrical resistivity and lower coefficient of thermal expansion. Graphite electrodes are integral to the production of steel based on the electric arc process.

Carbon Black.—This significant carbonaceous black pigment is an extremely fine soot, primarily carbon (90% to 99% C), that contains some hydrogen and oxygen and is produced by the partial combustion or thermal decomposition of hydrocarbons in the vapor phase. Although carbon blacks are available as furnace black, thermal black, lampblack, acetylene black, and bone black, furnace black is the dominant commercial material of choice. Carbon black is one of the most important pigments in industrial use today; significant quantities are used as a reinforcing agent in tires and other rubber products and as the primary black pigment in printing inks, paints, and plastics.

Petroleum Waxes.—Waxes are also a natural product of the refining processes and 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.

Natural Gas.—Methane must be separated from various components before sale as "dry gas" for fuel use and as chemical feedstock. According to recent DOE statistics, about 83% of the total process feed is recovered as dry natural gas, 2% was removed as nonhydrocarbon gases (carbon dioxide, helium, hydrogen sulfide, and nitrogen), with some of the remainder being injected for repressurizing. Substantial amounts of other natural gas liquids (ethane, propane, and butane) also may be recovered during methane processing. Natural gas is sold on a dollars per million British thermal unit (Btu) basis. Substantial amounts of elemental sulfur also may be recovered as a marketable byproduct depending on the hydrogen sulfide content of the gas.

Natural gas is used extensively in catalytic steam reforming processes to produce inorganic ammonia (NH_3) and byproduct carbon dioxide, both of which are subsequently used to synthesize organic urea (NH_2CONH_2) for fertilizer and industrial use. Ammonia is also integral to the production of nylons and other important polymers and synthetic organic chemicals. Methanol, or methyl alcohol (CH_3OH), also may be produced from methane by a similar reforming process.

Coal.—Coal is a black or brownish-black combustible sedimentary organic rock that contains more than 50% carbonaceous organic material by weight. In popular usage, coal commonly is called a mineral because it was formed in the earth. However, the scientific use of the term "mineral" is reserved for a naturally occurring inorganic material that has a definite chemical composition and a regular internal structure. Coal has neither of these. Coal is called a fossil fuel because it is derived from plants that grew in vast swamps millions of years ago and was subsequently reworked and metamorphosed. Recoverable coal reserves in the United States are considered to be the largest in the world, and the United States ranks as the leading producer at about 1 billion tons per year.

Outside of fuel uses for electrical power generation, the most important use of coal is for the production of metallurgical coke from bituminous coals sourced principally from the Appalachian region of the United States. Typically, a 1-ton charge of low-sulfur bituminous coal when heated in a high-temperature coking oven in the absence of air will yield about 700 kilograms of coke containing 97% carbon and a variety of organic byproducts, including about 32 liters of crude tar containing creosote, naphthalene, phenol, pitch, pyridine, and other aromatic hydrocarbons, and 10 liters of crude light oil containing benzene with smaller quantities of the aromatics toluene ($C_6H_5CH_3$), xylene ($C_6H_4(CH_3)_2$), naphtha, and related hydrocarbons.[9]

Products for Trade and Industry

Approximately 50% of all U.S. polymeric materials derived from nonrenewable organics is currently fabricated into packaging, and building and construction materials, while consumer and institutional products account for another 10%; transportation equipment, 5%; electrical and electronic goods, 5%; furniture and furnishings, 4%; adhesives, inks, and coatings, 3%; and other merchandise, 11%. Exports account for 12% of the total.

Packaging materials include bottles, jars, vials and food containers, refuse bags and film, and items such as tubes, tape, pallets, shipping crates, blister and bubble containers, buckets, and drums. Building and construction materials vary from pipe, conduit and fittings—including drainage, irrigation, plumbing fixtures, and septic tanks—to siding, flooring, and insulation materials. Other construction materials consist of panels, doors, windows. skylights, bathroom units, gratings, and railings.

Consumer and institutional products encompass disposable food serviceware, dinner and kitchenware, toys and sporting goods, health care and medical products, hobby and graphic arts supplies, together with footwear, luggage, credit cards, and other items. Transportation equipment includes parts and composites for motor vehicles and bicycles, railroad equipment, travel trailers, campers, golf carts, snowmobiles, aircraft, ships, and boats.

Electrical equipment is composed of wire and cable coverings, and industrial equipment, while electronic components include resistors, magnetic tape, records, and batteries. Furniture and furnishings include household and office furniture, bedding, carpets, rugs, backing, curtains, blinds, awnings, lamps, picture frames, and wall coverings. Adhesives, inks, and coatings consist of adhesives and sealants, printing ink, magnet wire enamels, core binders, foundry facings, paper coating and glazing, paints, varnishes, and enamels.

A variety of products ranging from pipe to window trim may be produced from PVC and polypropylene resins. These rigid, high-strength polymeric products contain significant quantities of reinforcing fillers, extenders, and pigments that include varying combinations of organic pigments, titanium dioxide, calcium carbonate, talc, treated kaolin, wollastonite, mica, feldspar, alumina trihydrate, barytes, silica, stearic acid, and derivatives.

Plastic coated handles on pliers, tin snips, scissors, and other items like the coated wire trays in dishwashers are derived from finely divided PVC dispersion resins processed into fluid plastisols or organisols that cure out or plasticize with heat. Plastisols are most commonly made by dispersing PVC resin in a suitable phthalate plasticizer. Organisols are made the same way except that an organic solvent is added to produce more solvation and fluidity.[10]

Phenolic thermosetting resins are used in the production of foundry sand molds that withstand high temperatures associated with the molding of products such as engine blocks. Thermoset polymers also are used as a binder with organic and inorganic fillers in automotive brake linings, drum brake blocks, disk brake pads, clutch facings, and abrasives grinding wheels.[11]

Synthetic rubber containing carbon black reinforcement pigment is used extensively in automotive components, including tires, motor mounts, nylon reinforced V-type drive belts, and high-temperature radiator, heater, and power-assist hoses. The modern-day radial tire comes equipped with steel-reinforced belts that span the tire circumference. Tire walls generally consist of tough, molded natural rubber vulcanized with sulfur and sulfur curing accelerators, while tire treads consist predominately of the more flexible molded and vulcanized styrene-butadiene synthetic rubber forms, which provide for better handling and wear characteristics.

Synthetic organic materials are integral to the construction of shingles and other roofing materials. Bitumen materials ranging from asphalt to coal tars comprise the major components of shingles, while protective roofing granules in shingles are derived from the minerals industry. "Built-up roofing" (BUR) systems are commonly employed in the industrial roofing sector. At the heart of the roofing system are two components: bitumens and felts. There are two types of roofing felts: organic and fiberglass-based. The roofing membrane is protected from solar radiation by a cap sheet of gravel embedded in bitumen.[12]

Technology

The production of petrochemical

feedstocks, downstream intermediates, and end-use products encompasses an enormous array of organic chemical reactions and technologies as demonstrated by the descriptive flow diagrams contained in this report. *(See figures 1-9.)*

Oil Refining and Petrochemical Feedstocks.—The feedstocks for petrochemical plants are sourced from oil refineries and from light fraction hydrocarbon extracts of natural gas and from natural gas itself. Several industrial minerals and other minerals-related catalysts are used to effect the complex chemical reactions required to produce the essential petrochemical feedstocks shown in figure 1.

Cracking catalysts are used in oil refineries to facilitate the conversion of heavier molecules into lighter, more desirable products. High temperatures are needed, but pressures can be more moderate. Bentonitic clays in the form of granular pellets are typical natural cracking catalysts, while synthetic catalysts generally are silica-alumina, silica-magnesia, or silica-zirconia-alumina. One process uses a platinum catalyst to reform naphthas into petrochemical compounds. The catalytic cracking process uses operating pressures ranging from about 15 pounds per square inch (psi) to 700 psi [1 to 49 kilograms per square centimeter (kg/cm^2)] and temperatures ranging from 425 to 590° C.

Polymerization.—A number of highly complex chemical reaction mechanisms and technical processes are involved in the synthesis of polymers from petrochemical feedstocks. In 1929, W. H. Carothers subdivided polymers into two general groups, "condensation" and "addition" polymers. Polyester resins, for example, are formed by typical condensation reactions between bifunctional organic acid and alcohol monomers, with the elimination of water. Addition polymers, unlike condensation polymers, are formed by direct molecular linkup mechanisms in which no byproduct is generated. Polyethylene is an example of addition polymerization whereby ethylene molecules combine in large numbers to form continuous chains of high molecular weight polymer. The terms "step reaction" and "chain reaction" are used in deference to the more classical condensation and addition polymerization terminology whenever a more precise definition between reaction mechanisms is needed.

There are two basic types of polymers, "thermoplastic" and "thermoset." Thermoplastic polymers soften repeatedly at elevated temperatures and may be processed under pressure into a variety of products and recycled. Polyethylene, PVC, nylon, and polypropylene are examples of thermoplastic resins. Thermoset resins, once processed, will not soften again as the temperature is raised, but eventually degrade or decompose at highly elevated temperatures. Phenol-formaldehyde, phenol-furfural, urea-formaldehyde, melamine, and epoxies are typical thermosetting resins.

Ethylene Synthesis.—Ethylene (C_2H_2) is the simplest unsaturated hydrocarbon, or "olefin," and is by far the largest of all the petrochemical feedstocks shown in figure 1 in terms of volume, sales value, and number of downstream derivatives. Figure 3 details the enormous family of downstream derivatives obtained from ethylene, the most important of which are the polyethylenes, PVC, styrene, vinyl acetate polymers, and ethylene-propylene elastomers. Other important derivatives include ethylene oxide and linear alcohols such as ethyl alcohol (C_2H_5OH).

Thermal cracking of hydrocarbons in the presence of steam is the most widely used process for producing ethylene. Cracking is accomplished at about 1,600° C and 30 psi, followed by rapid quenching to below 1,000° C. Ethylene is recovered by low-temperature fractionation at 500 to 550 psi and purified by low-temperature (-65° C) gas-separation processes to remove hydrogen, methane, and ethane.

In the United States, hydrocarbon gases—ethane through the butanes—from natural gas condensates and petroleum refinery offgases dominate the feedstocks used to produce ethylene. With these clean feedstocks, yields may approach 80%. Liquid refinery products such as naphthas and gas oils also may constitute up to 25% of process feedstocks, but yields are less than 40%, and process costs are relatively higher. Ethylene also may be recovered by petroleum cat cracking, but the only practical source is from the hugh refineries in the United States owing to economies of scale.

Ethylene Polymerization.—Ethylene is a colorless gas that condenses to a liquid at -169° C. In high concentrations, it is a simple asphyxiant without other significant physiologic effects. Ethylene is commonly transported by pipeline to downstream processing facilities. About 50% of ethylene production in the United States is used to manufacture polyethylene polymers—HDPE; low-density polyethylene (LDPE), and linear low-density polyethylene (LLDPE). LLDPE has made significant inroads relative to the other polyethylene resins because of its unique properties derived from a number of copolymer derivatives, versatility of usage, and breakthroughs in synthesis technology. Polyethylene resin density varies between about 0.90 to 0.96 g/cm^3.

HDPE resins are produced by a variety of low-pressure processes. Since the introduction of novel LLDPE technology in the 1970's, also based on low-pressure processes, the classic process-based distinction between LDPE and HDPE has become obsolete. Many of the newer polyethylene plants are designed with LLDPE/HDPE swing capabilities to meet changing market demands.

HDPE resins are characterized by greater toughness and by superior mechanical strength and high modulus, low gas-permeability, coupled with higher service temperature limits. HDPE resins compete with polypropylene resins in a variety of molding applications. Resin price and other factors affecting total conversion economics may favor one or the other material for a given end-use

article. As a result, some back-and-forth substitution is always taking place. Most HDPE resins are converted to end products by various polymer processing technologies: blow molding, injection molding, and variations of the extrusion process.

HDPE manufacturing processes fall under three basic categories: gas-phase, fluid-bed, or stirred-bed reactor polymerization; slurry-phase polymerization using isobutane diluent or C_6 or higher diluents; and solution-phase polymerization processes using cyclohexane or a paraffinic hydrocarbon.

Major advances in polymerization technology have resulted from the introduction of innovative catalyst systems incorporating either complex chromium compounds impregnated in silica or silica-alumina support or complex titanium compounds chemically bound to a solid magnesium-containing support. Recently, single-site metallocene catalysts have been developed or are under development. These new catalysts allow precise control of molecular properties, enabling products to be specifically tailored to match the performance needs of a given application.

LDPE resins, conversely, are derived under high-pressure environments ranging from 15,000 to 50,000 psi, using organic peroxide initiators. Two types of reactors are used: a continuous-flow stirred autoclave; and tubular reactors. Autoclave reactors produce homopolymers with a high degree of long-chain branching, resulting in polymers useful for extrusion-coating markets and high-strength industrial heavy-duty film. In contrast, tubular reactors produce resins that have much lower degrees of long-chain branching. These resins are well suited for clear packaging film production.

Other commercial synthesis reactions include the palladium-catalyzed oxidation of ethylene to produce acetaldehyde (CH_3COH), or if synthetic acetic acid (CH_3COOH)—"vinegar" in nature—is used as the solvent, vinyl acetate. Chlorination and oxychlorination processes are used to make vinyl chloride monomer (CH_2CHCl), which in turn is polymerized to the industrially significant PVC and PVC copolymers like polyvinyl alcohol and polyvinyl acetate. Ethylene oxide, a ring compound containing oxygen (C_2H_4O), is produced by the silver-catalyzed oxidation of ethylene. About 50% of the ethylene oxide produced is converted to ethylene glycol ($HOCH_2CH_2OH$), most commonly sold as automotive "antifreeze" and used in the manufacture of polyester resins. Acid catalyzed hydration of ethylene produces ethanol, ethyl alcohol, competitively priced with alcohol from traditional fermentation processes.

Methane and Propylene.—These petrochemical feedstocks are eclipsed only by ethylene in terms of volume. The flow diagrams of figures 4 and 8 track the downstream synthesis products of propylene and methane, respectively. Some of the more familiar reaction products of propylene are isopropyl alcohol, used as a solvent and rubbing alcohol, acrylonitrile that goes into acrylic-based resin and fibers, and the significant polymer polypropylene.

Methane (natural gas), as already described, is the feedstock for ammonia and methanol. Ammonia is used to produce nitrogenous-based organic compounds including urea, TNT, amines ($-CNH_2$), and downstream polymers, such as nylon-6; urea-formaldehyde, phenolic, and melamine thermosetting resins; and many other important resin intermediates. Methanol is important to the synthesis of methyl methacrylate from which acrylics ("plexiglass") are made, together with polyester fibers and resins. Methanol is commonly used in automotive windshield washer and deicing fluids.

Benzene.—This important petrochemical feedstock ranks fourth in terms of volume behind ethylene, methane, and propylene. Benzene is probably most notable for its use in the production of polystyrene, one of the more important resins in commercial use. It is also essential to the production of cyclohexane, cyclohexanol, and cyclohexanone, precursors of the important nylon polymers nylon-6 and nylon-6,6.

Properties of Organic Chemicals.—Organic chemicals are highly useful participants in chemical synthesis, in purification processes, and as end-use products themselves. Many organic synthesis processes require an aqueous-free environment and may be conducted in an organic solvent system. Organic solvents are important extractants in the purification of products owing to different affinities for contaminants and end-use synthesis materials. Some organic synthesis materials such as caprolactam, the monomer for nylon-6, may be cycled back and forth between organic and aqueous phases to effect purification.

Many separation processes use the azeotropic properties of organic compounds whereby two organic compounds boil at a constant temperature and composition, and may be removed by simple distillation. Undesirable organic carboxylic acid (-COOH) byproducts may be removed by countercurrent extraction using aqueous sodium hydroxide. Other undesirable ionic impurities may be removed by ion exchange resins—polymerized organic beads having cationic (positive charge) or anionic (negative charge) exchange properties. Another interesting feature of organic chemicals is that separation may be more easily effected by distillation under reduced pressure, or vacuum conditions, creating a wider variation in the vapor pressures of the various organic components. Organic products may be further purified and decolorized by filtration through a medium of activated charcoal.

Materials Processing.—The processing of solid polymeric resin and rubber materials into marketable products is accomplished through a series of operations ranging from the initial compounding of ingredients to the final process steps of molding, calendaring, or extrusion. Liquid products or intermediates, such as paints and coatings, are commonly produced by shear milling processes and special-high-

intensity liquid mixing from aqueous or organic dispersion resins incorporating solid fillers and pigments.

Both resins and rubber may be compounded or blended with varying combinations of ingredients—fillers, extenders and pigments, processing aids, blowing agents, curing agents and accelerators, antioxidants, etc. Compounding usually is effected in high-intensity steel alloy pressure mixers containing a pair of rotating sigma, or Z-shaped, mixer arms and jacketed for temperature control. Following compounding, the formulated mixtures may be processed on an alloyed steel roller mill consisting of two horizontal rotating drums revolving at different speeds to provide shear to complete the mixing process, sheet out the mix, and remove moisture and other volatiles.

In rubber compounding, extra care must be taken to shear, or "break down," the elastomeric molecules into rheological forms suitable for compounding and to precisely control the mix temperature to prevent "kick-off" of sulfur and associated curing accelerators. Many rubber compounders prepare "master batches" containing premixed rubber, curing agents, and pigments that are added during the processing step to facilitate more exacting quality control.

Compounded plastics and rubber materials may be prepared for downstream processing by "dicing" or "extrusion chopping" to produce granules or pellets that provide uniform flow or by "calendaring" sheets through vertically mounted compression drums that more precisely control thickness or gauge. Calendaring also may represent the final step in processing.

Extrusion, injection molding, and blow molding are the most popular methods of production of thermoplastic materials, while compression molding dominates the thermoset resin and rubber arena. Several important rubber items of commerce—hoses, gaskets, and pencil erasers, etc.—are extruded and cured under pressure in autoclaves.

Thermoplastic extruders are made of heavy-duty special alloy materials capable of withstanding high temperatures and pressures. The integral parts of a typical extruder consist of a feed hopper; high-alloy steel internal chamber or barrel; specialty feed/shear screw; a die of suitable geometry, together with a face plate. Plastic pellets or granules flow from the extruder hopper to the screw chamber where plasticization is effected through a combination of barrel temperature and screw shearing rheology. The plastic medium is then forced through a die, producing the desired shape. Typical marketable products range from writing elements, soda straws, plastic pipe and hose to vinyl siding and window trim.

Coextrusion is a process in which two extruders facilitate the cojoining of materials in a mutual chamber, creating a two-component or multilayer system. The inner polymeric resin component is extruded through a die of desired shape and is then sheathed or coated by the second extruder system whose shape is determined by a mutual die exiting the mixing chamber. One unusual and commercially significant form of coextrusion involving metals and plastics is wire and cable coating. In this process, a thermoplastic resin of suitable dielectric properties is extruded around a continuous feed of wire or cable that passes through an individual and common die. The coated wire is wound on drums after cooling.

In the production of wide film or sheeting, resin is extruded in the form of a tube that may be split as it comes from the die and then stretched and thinned to the desired dimensions of the finished film. An alternate method involves inflating the tubing as it comes from the die, with the degree of inflation regulating the thickness of the final film.

Injection molding is a process in which the hopper feed is pushed into a long heating chamber by a plunger, where the polymer is softened to a fluid state. The fluid resin is then forced at high pressure through a nozzle into a cold mold. As soon as the material cools to a solid state, the mold opens and the finished product is ejected from the press.

Blow molding is the most popular process for producing thermoplastic bottles. Blow molding consists of stretching and then hardening a polymeric resin against a mold. There are two general methods, direct and indirect, each encompassing several variations. These processes basically involve the air blowing of a glob of resin or heated thermoplastic sheet into a mold or die of the desired shape.

Compression molding is simply the squeezing of a material into a desired shape by application of heat and pressure to the material in a mold. The three compression molding factors—pressure, temperature, and time—vary with the design of the finished article and the material being molded.

Thermoforming of resin sheet has developed rapidly in recent years. This process consists of heating thermoplastic sheet to a formable state and then applying air and/or mechanical assists to shape it to the contours of a mold. Pressures of up to 14 psi may be obtained by evacuating the space between the sheet and the mold in a process called "vacuum forming," which is used in the majority of thermoforming applications. *(See tables 3 and 4.)*

Operating Factors

Both ethylene and vinyl chloride prices rose by about 20% during the year, reflecting significant improvement in demand for LDPE, LLDPE, and PVC resins and an apparent tightening of inventories. Butadiene prices were up 43% by yearend, indicative of strong growth in the demand for synthetic rubber and synthetic rubber elastomers. The steady decline in benzene and styrene prices as the year progressed was anticipated in light of declining domestic merchant sales and profitability. *(See table 5.)*

Total industrial employment in the synthetic resin, fiber, and rubber sectors fell by about 2% to 133,000 workers in 1992, compared with roughly 136,000 workers in 1991. The average hourly workweek and wages of those employed increased, however. Average hourly wages of employees engaged in the synthetic organic chemicals business

increased about 4% to $15.37 in 1992, 34% ahead of all manufacturing jobs, and indicative of the high-tech skills required by employees in this industry. *(See table 6.)*

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Legislation and Government Programs

The Energy Policy Act of 1992 (H.R. 776) was signed into law by the President on October 24, 1992. This comprehensive energy bill contained 30 titles covering nonrenewable and renewable energy resources and was underscored by environmental and energy efficient mandates for the implementation of new technology and for long-range research and planning. Under Title XIII—Coal—clean coal technology, the Secretary of the Interior was to provide consulting services to the Secretary of Energy for research and development of effective utilization of coal wastes and for the administration of mineral rights for coalbed methane projects on Federal lands.

Title XVI—Global Climate Change-included provisions for a 75% increase in energy derived from renewable resources over 1988 levels by 2005 and a reduction in the Nation's oil use from a level of approximately 40% of total energy consumption in 1990 to 35% by 2005.

Section 313 of EPA's Emergency Planning and Community Right-to-Know Act of the Superfund Amendments and Reauthorization Act (SARA) of 1986 (Public Law 99-499) required EPA to establish a national inventory of toxic chemical emissions from certain facilities, called the Toxic Release Inventory (TRI).

The 1991 TRI indicated that for 285 chemicals surveyed, a total of 3.3 million tons was released to the environment or transported to publicly owned treatment works (POTW's), of which about 1.5 million tons (45%) was released directly to the air, water, land, or injected underground. Based on available information, about 60% of this total was organic chemicals.

The remaining 1.8 million tons (55%) was transported to POTW's, where approximately 61% was recycled and another 11% was recovered in the form of energy. About 35% of the organics was recycled. *(See table 7.)*

Under TRI is a voluntary industry toxic chemicals control program known as 33/50, implying an interim goal of reducing emissions of 17 high-priority toxic chemicals by 33% between 1988 and 1992, with an ultimate goal of 50% reduction by 1995. One of the more noteworthy findings revealed in the 1991 TRI was that emissions had declined by 34% between 1988 and 1991, surpassing program objectives. Twelve of the seventeen high-priority toxic chemicals listed under the 33/50 program were organics: benzene, carbon tetrachloride, chloroform, cyanides, dichloromethane, methyl ethyl ketone, methyl isobutyl ketone, tetrachloroethylene, toluene, trichloroethane, trichloroethylene, and xylenes.

The Clean Air Act of 1990 (Public Law 101-549) contains 11 titles that target 3 major forms of pollution: acid rain, smog, and toxic air pollutants. The most important facets of the act relative to nonrenewable, nonfuel organics deal with volatile organic carbon (VOC) emissions from industrial processing, industrial solvents, paints and coatings, together with emissions from coke ovens.

Issues

The issue of sustainable development was near the top of the list on the public and private global agendas during 1992. Environmental concerns continued to be at the forefront of such issues during 1992, highlighted by an Earth Summit sponsored by the United Nations in Rio de Janeiro, where global population, deforestation, global warming, and damage to the ozone layer were major topics of discussion. There was allied concern by those Federal and private sources responsible for managing our Nation's nonrenewable resources—the magnitude of recoverable reserves coupled with the most prudent use of post-consumer material resources in the supply-demand equation.

Many communities throughout the United States were struggling with the issue of how to safely and effectively manage municipal solid waste. Most discovered that there are no quick-fix solutions to the waste management problem and that the only real solution is an integrated waste management approach utilizing four basic methods: (1) source reduction, (2) recycling, (3) waste-to-energy incineration, and (4) landfilling. According to the latest EPA figures, plastics account for 21.1% of the municipal waste stream by volume; paper and paperboard, 31.9%; metals, 11.1%; yard waste, 9.8%; food waste, 3.2%; and all others, 20.7%.

A study conducted for the American Plastics Council by R. W. Beck and Associates revealed that post-consumer plastics recycling increased significantly between 1991 and 1992. The recycling of plastics packaging was up 47% in 1992 to about 430,000 tons. Plastic bottles recycled in all forms increased from 14% to 19%. PET soda bottle recycling amounted to 170,000 tons, or 41% of total production between 1991 and 1992. Recycled HDPE milk, juice, water and household chemical bottles, and film bags was about 200,000 tons in 1992, up 67%, while colored HDPE bottle recycling rose dramatically to about 60,000 tons. Recycled polypropylene was 100,000 tons, while LDPE, polystyrene, and PVC, in combination, was about 60,000 tons.

In response to an ongoing nationwide survey conducted by the Council, over 6,850 cities and towns confirmed that plastics were being collected for recycling through either curbside, dropoff, or buyback programs during 1992.

The North American Free Trade Agreement (NAFTA) was a topic of debate during the 1992 presidential campaign. Both the public and private sectors were divided over the issue of whether NAFTA would aid and abet, or serve as a deterrent to the U.S. economy. Candidates also debated the issue of imposing new taxes on fossil fuels that would be designed to raise revenues for deficit reduction and for proposed new government programs.

The Uruguay Round of General

Agreement on Tariffs and Trade (GATT), under negotiation since 1986, had still not been resolved at yearend. The United States and European Community (EC) ended the year in a stand off over agricultural subsidy issues, while the Cairn group of nations observed from the sidelines.

Ethylene and Derivatives

Although the HDPE market was in an overcapacity situation in 1992, LDPE and LLDPE were in short supply. Only small expansions in capacity are planned for the near-term for LDPE and LLDPE, and no new capacity came on-stream in 1992. Producers of these materials were looking to increase prices and expand production.

Most of the U.S. producers were working on process and catalyst technology to improve yields and production efficiencies, but at the same time, the polyethylene market continued to change. Traditionally, the United States exported only 10% to 15% of its polyethylene production. The remaining material was destined for the domestic market. The exported material was sold at reduced prices so that U.S. producers could maintain high operating rates. Asia, Europe, and South America were expanding their resin capacities; consequently, the export market for U.S. polyethylene was expected to decrease over the next few years.

Occidental Chemical Corp. (OxyChem) planned to discontinue HDPE production at its 118,000-ton-per-year Orange, TX, plant by yearend. Oversupply and industry projections for a continued supply-demand imbalance led to the decision. The company has 658,000 tons per year of HDPE capacity elsewhere in Texas.

Propylene and Derivatives

U.S. production of polypropylene in 1992 increased slightly from that of the previous year, but there was a significant drop in the export market for polypropylene. As with polyethylene, significant increases in capacity within the past few years in Asian countries have mitigated the export market for material produced in the United States and Europe.

According to industry analysts, polypropylene is expected to have strong growth throughout the rest of the decade, despite the current period of overcapacity. Operating rates are expected to fall to about 80% because of planned increases in world capacity before starting to rise in 1994. Growth in U.S. demand is expected to average 5.8% per year, and exports are expected to continue to drop significantly. Growth in western Europe is expected to average 7.6% per year. Overbuilding in recent years has overtaken healthy growth rates, and the market suffered from overcapacity. Capacity additions of 320,000 tons per year in Europe in 1992 were set to raise the European total to 5.3 million tons per year, with demand estimated at 4.2 million tons.

Amoco Chemical began production at a new 136,000-ton-per-year polypropylene plant in Chocolate Bayou, TX. This plant brings Amoco's total North American polypropylene capacity to 953,000 tons per year, making the firm the second largest North American producer after HIMONT, Inc. and the third largest producer in the world after Shell Chemical. This was the only new U.S. capacity installed in 1992.

Vinyl Chloride and Derivatives

PVC production in the United States increased by almost 9% from that in 1991. Growth in this market is generated by both a recovering economy and substitution of PVC for traditional materials in windows and injection-molding compounds. Exports for PVC declined as plants in the Asia-Pacific region supplied some of the U.S.'s traditional export markets.

World vinyl chloride monomer demand is expected to increase at an average rate of 3.6% per year through 2000, to reach 27.5 million tons, according to industry analysts. Growth is almost entirely attributable to the growth in PVC markets. U.S. growth in demand will average only about 2% because of the threat of future regulations affecting the use of disposable packaging that would end up in landfills.

Styrene and Derivatives

Demand for styrenics is projected to grow at an average annual rate of 3.7% per year through 2000, but a surge of capacity additions will result in low operating rates. Interpolymer competition between polystyrene and polypropylene and high-heat polystyrene and acrylonitrile butadiene styrene, and styrenics and engineering resins will cause problems. Environmental issues also were causing the displacement of polystyrene on disposable packaging.

Chevron Chemical announced plans for a new $250 million benzene plant at its Pascagoula, MS, refinery. The plant, to be completed in 1994, was constructed to supply feedstock to the downstream styrene market. Westlake Styrene completed its ethylbenzene/styrene plant at Lake Charles, LA, with a capacity of 160,000 tons per year of styrene.

Novacor Chemicals announced that it would close its 54,400-ton-per-year Leomister, MA, polystyrene plant by August 31 to improve the competitiveness of its styrene/polystyrene business. With recent closures at Cambridge, Ontario, and Copley, OH, Novacor reduced its North American polystyrene capacity by 35% to 356,000 tons per year.

Industry analysts estimated that acrylonitrile butadiene styrene (ABS) demand in North America will increase at an average rate of 4% per year through 1996, to reach a total demand of 1.45 million tons per year. The growth is a result of automotive and construction rebounds from 1991 lows. By yearend 1992, total North American ABS capacity was 950,000 tons per year. Monsanto had 34%, GE Plastics had 47%, and Dow Chemical had 19% of the total.

Monsanto completed an 36,000-ton-per-year expansion of its ABS capacity in Addyston, OH. The expansion will raise Monsanto's worldwide capacity to 600,000 tons per year.

Polyethylene Terephthalate (PET)

PET bottle resin supply was tight during 1992. As a result of the tight supply, several companies announced capacity increases. Goodyear planned to expand its PET capacity by 35% or 90,700 tons per year by the first quarter of 1994. Eastman Chemical planned process improvements to increase capacity by 10% from 408,000 tons per year to 454,000 tons per year. In the United States, total PET capacity was 962,000 tons per year and is broken out by company as follows: Eastman Chemical, 51%; Goodyear, 26%; Hoechst Celanese, 14%; and ICI Americas, 9%.

Bottle-grade PET demand was expected to remain strong in the North American market, but prices will remain stable until early 1993. Demand is expected to grow at an average annual rate of 7% to 8% through 2000, with a dramatic increase in capacity between 1992 and 1995. The additional capacity will reduce operating rates, but will allow PET to be used in applications such as bottles, jars, and custom containers because of increased supply.

Toray Plastics America, a subsidiary of Japan's Toray Industries, planned to more than double its production of PET film to 20,000 tons per year at a cost of $100 million. The expanded facilities in North Kingstown, RI, were expected to begin production in March 1994 and will give the Toray group as a whole, 108,000 tons of annual capacity, making it the world's largest producer of PET film for audio and videotapes.

Tejin and Du Pont reached an agreement to jointly develop polyethylene napthalate (PEN) films, an analog of PET. Tejin is currently the only commercial producer of PEN films, with a plant in Japan. PEN films are stronger than PET films and are expected to see significant growth in the next few years. They already are used in Japan for audio and videotapes, and Du Pont hopes to market PEN for thin-film capacitors and for insulating film used in motors, traditional PET markets.

John Brown was awarded a contract by Goodyear for the design, engineering, and procurement of a 90,000-ton-per-year PET plant in Point Pleasant, WV. The project, to begin construction in September, will increase PET capacity at the site to 295,000 tons per year.

Hoechst Celanese planned to increase its PET capacity by 56,700 tons per year in Mexico in response to the country's increasing growth in the PET market. This is a part of Hoechst's plan to increase total North American capacity by nearly 227,000 tons per year by 1995.

Other Organics

Industry analysts projected growth for ethylene glycol to increase by an average of 4.3% per year through 1997. In the United States and Europe, demand will be driven by PET bottle and engineering resin demand. In Asia and the Pacific, demand growth will be directly related to polyester fibers growth.

Maleic anhydride demand in the United States is expected to increase by 5% per year, to reach 211,000 tons per year by 1996. Recovering demand for unsaturated polyester resins, accounting for more than 50% of maleic anhydride demand, plus increasing demand for copolymers such as styrene-maleic-anhydride will account for the projected growth.

Demand for tert-butylamine in the United States is projected to grow at an average rate of 7% per year. The material is used primarily in the production of sulfonamide-type vulcanization accelerators for rubber. The increased growth rate is expected to occur because of growing concern about the use of morpholine-based products for environmental reasons.

New Clean Air Act regulations for reformulated gasoline prompted increased interest in methyl tert-butyl ether (MTBE) production. In November, Chevron started up a 2,100-barrel-per-day MTBE plant at its Pascagoula, MS, refinery, and in December, Enron Petrochemicals started up a 15,000-barrel-per-day MTBE plant in LaPorte, TX. The company will sell 75% of the output under long-term contract. Jacobs Engineering was awarded a contract to build a 2,050-barrel-per-day MTBE unit for Chevron in Richmond, CA. Completion was scheduled for February 1993.

Shell Oil planned to construct an MTBE plant at its Wood River, IL, refinery. This is in addition to units already announced at Deer Park, TX, and Norco, CA. The Illinois facility is scheduled for completion in 1994. Combined capacity of the three units is 15,000 barrels per day.

The MTBE market was soft during the latter part of 1992 because of stockpiling in advance of new regulations for reformulated gasoline effective November 1.

Hüls America planned to construct a multipurpose nylon polymer facility at Theodore, AL, to produce nylon-12 and copolyamide specialties. World demand for nylon-12 is estimated to be 40,000 tons per year. It is expected to be increasingly in demand for use in pneumatic tubes for industrial robots and tubes and hoses for automobiles.

Mixed xylenes demand was expected to grow by 4.3% per year through 1997, according to industry sources. Capacity additions to para-xylene will reduce operating rates from 85% in 1989 to 79%. Ortho-xylenes capacity utilization was expected to increase from a 1991 level of 70% to 76% by 1997.

Texaco planned to cease production of cyclohexane, and its departure from the market was expected to leave the United States without sufficient domestic supplies. As a result of the closure, Du Pont was investigating the restart of a mothballed facility at Corpus Christi, TX, and BASF was investigating the construction of a new U.S. facility. Texaco's closure will reduce U.S. capacity to about 360 million gallons per year, with demand estimated at 400 million gallons per year, including product shipped to Canada. Demand was expected to increase gradually as the nylon fiber and resin markets improve.

Because of strong demand increase projections, acrylic acid producers were planning capacity increases. New capacity was expected to be required as soon as 1995 in the United States and by

1997 in Europe. Europe and the Far East have been in an overcapacity situation. BASF officials estimated worldwide growth at 5% to 6% per year and as great as 10% per year in some Asian markets. *(See tables 8-17 and figure 10.)*

World Review

Europe.—In polyethylene, recent capacity additions in Europe have led to a significant oversupply situation for all three major product lines. In 1991, about 570,000 tons per year of HDPE capacity came on-stream, and 320,000 tons per year came on-stream in 1992. Introduction of the new capacity represents a 7% to 8% increase in total European capacity, and the market has had only a 4% growth rate.

In May, Compagnie Industrielle des Polyethylenes de Normandie began production at its 220,000-ton-per-year LLDPE plant in France. The startup came at a time when polyethylene markets were depressed because of overcapacity and economic recession. In October, because of the slump in Europe's polyethylene market, the company temporarily closed its new LLDPE plant to correct "inventory imbalances." In addition, Dow Europe plans to close 55,000 tons per year of LLDPE capacity in Spain for at least 1 year and then reevaluate the market.

Shell Chemical commissioned a new ethylene pipeline to feed downstream units in England. The company planned to have a 100,000-ton-per-year LDPE plant on-stream by yearend and to close 40,000 tons per year of existing capacity, leaving the company with a total of 170,000 tons per year of LDPE capacity.

In November, closures of four LLDPE plants in Europe allowed producers to increase prices, but the restart of one plant moderated the price increases.

For polypropylene, overcapacity was depressing prices, despite a growth rate of about 10%. Some capacity has closed in Europe during the year, but closed capacity has not compensated for scheduled plant startups. Since 1987, European polypropylene capacity additions have increased capacity by 40%.

Overcapacity in Europe's polypro-polypropylene industry was cited as one of the reasons for the closure of Neste Chemicals' 70,000-ton-per-year facility in Portugal. European polypropylene growth is projected at 7% through 1998. The current overcapacity is expected to be absorbed by 1996.

Neste Corp. has been authorized to construct a $150 million polypropylene plant in Porvoo, Finland, to be completed by 1994. The plant also will produce LLDPE and HDPE. The company may close one of the existing LDPE lines at the plant when the new capacity comes on-stream, because it is already balanced in ethylene.

Hoechst AG announced that it would close its 135,000-ton-per-year polypropylene plant at Kelsterbach, Germany, by gradually phasing out production by the end of the year. The company recently opened a 140,000-ton-per-year polypropylene plant in Knapsack, Germany, and the Kelsterbach plant was opened in the early 1970's and used some of Hoechst's oldest technology.

OMV plans to mothball 70,000 tons of annual polypropylene capacity in Austria in June, citing low prices. The closure is for an indefinite period of time.

BASF is investing $32 million in an expanded polypropylene plant in Germany to be complete by 1994. Expanded polypropylene is used primarily for packaging and impact absorbing applications in the automotive industry.

Elf Atochem plans to close its 110,000-ton-per-year polystyrene plant in France in 1992, because the polystyrene market is at overcapacity and restructuring is necessary. According to industry analysts, polystyrene demand in western Europe was 7% less than the 1990 peak, and significant capacity additions were due on-stream by early 1994. The increased capacity plus competition from imports from the Mideast and Asia would continue the overcapacity situation unless some capacity was closed.

In June, a fire at Dow Chemical's new 450,000-ton-per-year styrene plant in the Netherlands closed the plant for an indefinite period. This problem, along with unscheduled closures in North America and western Europe, drove styrene prices up significantly.

Eastman Chemical plans to double PET capacity at its United Kingdom facility to 100,000 tons per year by early 1993. After the expansion, the company will be tied for the largest European producer with EniChem (Milan, Italy). European PET consumption is projected to increase from 465,000 tons in 1992 to 630,000 tons by 1995 and to 950,000 tons by 2001. Production is expected to increase as well: from 335,000 tons in 1992 to 560,000 tons in 1995 and 890,000 by 2001.

Melamine demand in Europe, which has dropped significantly in the past 2 years, has resulted in severe overcapacity in that sector. One new 50,000-ton-per-year plant in the Netherlands completed in 1991 was never started up. In the past, eastern Europe was an important destination for melamine imports from western countries, but this region has practically stopped buying because of a shortage in foreign exchange, although the melamine demand still exists. The weak U.S. dollar led to an influx of U.S. imports from an already oversupplied U.S. market, and product is arriving from Saudi Arabia. Melamine producers are projecting a flat demand in Europe for 1992 and average annual growth rates of 1% through 1995.

Central America and South America.—ABB Lummus Crest was awarded a contract to build a 150,000-ton-per-year LLDPE plant in Venezuela. The plant was scheduled for completion in the first quarter of 1994.

Brazil was set for a restructuring of its chemical industry after privatization. Polyethylene capacity was more than 1 million tons per year, with domestic demand estimated at less than 600,000 tons per year. Two new polyethylene plants were added during the year, with a total capacity of 240,000 tons per year. Two units were closed for one quarter because of operating difficulties. For polypropylene, capacity was at 650,000 tons per year, and demand was estimated

at 300,000 tons per year. In Argentina, restructuring is also occurring after privatization, but the country was expensive for capital investment.

Increases in polypropylene in South America from 1990 to the end of 1992 would allow the area to become a net exporter of polypropylene. Additional capacity in Argentina, Brazil, and Mexico, coupled with existing capacity in these countries and Venezuela and Colombia, would bring total capacity to 908,000 tons per year. Latin American consumption was estimated to be about 600,000 tons annually.

Braspol Polimeros inaugurated its 150,000-ton-per-year polypropylene plant in Brazil. This brings total Brazilian polypropylene capacity to 700,000 tons per year, with domestic demand estimated at 384,000 tons per year. Consequently, a large portion of the new unit's output must be destined for the export market.

Former U.S.S.R.—**Belarus.**—Eastman Chemicals and Pepsico International formed a joint venture with two Belarus companies to produce polyethylene terephthalate and PET bottles at Mogliev. PET resins were expected to be produced beginning in September. One-half of the output will be used to produce bottles for use in the former U.S.S.R., and the remaining PET resin was destined for the western European market.

Kazakhstan.—The French company Litwin reportedly signed a contract with Shevchenkovski Zavod Plastmass to build a 370,000-ton-per-year styrene plant in Kazakhstan. The existing plant also will be modernized.

Russia.—Major Russian chemical producers have joined to form a new company, A/O Neftek-Techno. This brought together some of the country's largest chemical producers, with a goal to coordinate plans to improve earnings and profitability. For example, rather than selling excess propylene in western markets, the material will be converted to polypropylene before being sold to add value.

Tecnimont signed a contract to supply a 100,000-ton-per-year polypropylene complex for the Kapotnia Refinery in Moscow.

Ukraine.—The Chlorvinyl enterprise at Kalush, Ukraine, announced that it signed a $200 million contract with Linde (Germany) and Union Carbide (United States) for the construction of a 100,000-ton-per-year LLDPE and an 80,000-ton-per-year polypropylene plant. The plants could be completed as early as 1995. Uhde will expand capacity of vinyl chloride monomer and polyvinyl chloride in Ukraine. The monomer plant will be expanded from 250,000 tons per year to 370,000 tons per year.

Asia and the Pacific Basin.—This region accounted for about one-third of world chemicals demand, with the potential to increase to 40% of the total by 2000. The area's first major impact on the world chemical market was as a textile supplier, so chemical fibers were the first to undergo expansion. As a result, Taiwan and the Republic of Korea have larger polyester fiber production capacities than western Europe—each produces about 1.2 million tons per year of polyester filament yarn and staple fiber. This area has been primarily a market for Japan, which accounts for about two-thirds of the region's GNP. Large multinational companies have been increasing their investment in the region; however, impending overcapacity has led to a slowdown in investments. China, Indonesia, and Taiwan have some room for growth. Other countries in the region are faced with overcapacity. Between 1990 and 1992, ethylene production capacity in Asia (China, Indonesia, Japan, the Republic of Korea, Malaysia, Singapore, Taiwan, and Thailand) grew from 10.6 million tons to 13.3 million tons, and in 1995 capacity is projected to reach 16.0 million tons. Polymeric resin production capacity growth in China from 1991 to 1995 is projected to grow by the following quantities: LDPE, 1.26 million tons; LLDPE, 330,000 tons; HDPE, 300,000 tons; polystyrene, 301,000 tons; polypropylene, 980,000 tons; and PVC, 480,000 tons.

Regional growth in the Far East led several companies to announce expansion plans for PVC. Tosoh Corp. (Japan) plans to expand production in Indonesia and Malaysia, while Thai Plastic & Chemicals also plans to increase its capacity in Thailand. Postwar reconstruction programs in Cambodia and Vietnam were cited as reasons for increased PVC demand.

Amoco Chemical Corp. and a local conglomerate formed a joint venture to build a 350,000-ton-per-year purified terephthalic acid plant in West Java. Completion is slated for 1995. Amoco also formed a joint venture with several Japanese firms and completed a feasibility study for a 250,000-ton-per-year purified terephthalic acid plant in the Republic of Korea. The new capacity, to be completed by mid-1995, will bring the country's total capacity to nearly 900,000 tons per year, all to be used in the domestic market.

ICI commissioned its 350,000-ton-per-year purified terephthalic acid plant in Taiwan to serve the Asia/Pacific market, which accounts for about 60% of total world demand. The Far East market has been oversupplied following several startups in the past few years, and analysts do not believe this market will be able to absorb the additional capacity until 1993. Between 1993 and 1995 at least six new purified terephthalic acid plants were planned in the region, increasing capacity by about 1.5 million tons per year.

China.—The Chinese Government approved construction of a 140,000-ton-per-year ethylene plant at Dongying, Shandong, and discussions began with foreign suppliers for an associated $600 million complex that also will produce 100,000 tons per year of polyethylene, 60,000 tons per year of acrylonitrile, and 30,000 tons per year of acrylic fibers.

The Italian firm Snamprogetti won an order to build a 120,000-ton-per-year LLDPE plant in China. The plant will form part of the Zhongyuan complex at Puyang, Henan. Mitsui Engineering won a $35 million contract to build a 40,000-

ton-per-year polypropylene plant at the Daqing petrochemical complex in Heilongjiang Province.

Chi Mei Industrial plans to build a 300,000-ton-per-year acrylonitrile butadiene styrene (ABS) plant and a 300,000-ton-per-year polystyrene plant in China by mid-1995.

In China, two new styrenics complexes are planned. One in Heilongjiang Province will have annual capacities of 60,000 tons of styrene monomer, 25,000 tons of polystyrene, and 50,000 tons of ABS. At Guangzhou, annual capacities will be 60,000 tons of styrene monomer and 50,000 tons of polystyrene. China also started a new ethylene plant in Liaoning Province, with a capacity of 120,000 tons per year. The country plans to increase ethylene capacity from 1.8 million tons per year in 1990 to 3.7 million tons per year by 1995 and has plans for 12 additional ethylene-based complexes.

Snamprogetti won an order to build a 100,000-ton-per-year styrene monomer unit, and Mitsui Engineering won an order to build a 100,000-ton-per-year ethylene oxide/glycol unit at the Maoming petrochemical complex in China. SNC-Partec was awarded a $55 million contract for a 60,000-ton-per-year styrene plant in Panjin, Liaoning Province, China.

India.—India has had shortfalls in domestic capacity and production to meet petrochemical demand. With the Government's liberalization of the economy, enough new petrochemical capacity was expected to be installed to meet the demand and perhaps provide some material for export. By the end of the decade, ethylene capacity was projected to increase from 230,000 tons per year to more than 2 million tons per year. In 1992, production of LDPE, LLDPE, HDPE, polypropylene, PVC, and polystyrene was estimated to be 471,000 tons, with demand at 755,000 tons. By 1995 production is expected to be 1.1 million tons, with a demand of 1.06 million tons.

Simon-Carves (Manchester, England) was awarded a contract for the basic design and engineering of a 55,000-ton-per-year LDPE plant to be built in India. The plant is due on-stream in 1994.

Reliance Petrochemicals (Bombay, India) formed a joint venture with Mitsubishi Corp. to build a new 250,000-ton-per-year polypropylene plant at the petrochemical complex in Hazira, Gujarat. Startup is scheduled for 1994, to coincide with the complex's 320,000-ton-per-year cracker coming on-stream. Italy-based Tecnimont was awarded a contract to build a 75,000-ton-per-year polypropylene plant for Indian Petrochemical Corp. Ltd. at Baroda, Gujarat. Completion was scheduled for 1995.

ABB Lummus Crest (Bloomfield, NJ) was selected to build a 60,000-ton-per-year styrene monomer/polystyrene complex in India. The company also will provide basic engineering and other services for a 100,000-ton-per-year ethylbenzene/styrene monomer plant. Both plants will be near Nagothane and were scheduled for completion in 1994.

Reliance Industries plans to build a 350,000-ton-per-year purified terephthalic acid plant at Hazira at a cost of $528 million. Also to be constructed are downstream facilities for the production of polyester filament, polyester staple, and PET, totaling 200,000 tons per year. Initial production was scheduled to begin at the end of 1993, and the complex completion date was in 1995.

Indian Petrochemicals Ltd. closed its 48,000-ton-per-year para-xylene plant because of poor demand from purified terephthalic acid and dimethyl terephthalate producers.

Indonesia.—In Indonesia, textile company P.T. Polyfin announced that it would build a complex with a capacity of 63,000 tons per year of polyester fiber to be completed by mid-1994. Total polyester filament capacity in Indonesia was 170,000 tons per year and was scheduled to double by 1993 when capacity expansions announced earlier are brought on-stream. Also, P.T. Pusaka Warna Polypropylene plans to construct the country's first integrated polyethylene/polypropylene plant, scheduled for completion by the fourth quarter of 1994. Annual capacities for the two products will be 200,000 tons for polyethylene and 140,000 tons for polypropylene.

Indonesia has approved construction of the Chandra Asri petrochemical complex at Cilegron, West Java, as long as it is 100% foreign-owned; the project was postponed in 1991. The first stage is a 450,000- to 500,000-ton-per-year ethylene plant, with downstream units to produce polyethylene and polypropylene.

Golden Key Group completed engineering for its $300 million styrenics complex in Serang, West Java. The project is expected to come on-stream in 1994. The complex will include plants for styrene monomer, polystyrene, high-impact polystyrene, ABS, styrene acrylonitrile, styrene butadiene rubber, and styrene butadiene latex.

P.T. Tripolita Indonesia will shortly begin production of polypropylene at its 160,000-ton-per-year plant in Anyer, West Java.

PT Styrene Monomers Indonesia completed its 100,000-ton-per-year styrene plant in West Java. Dow Chemical and the Salim Group were setting up a plant in Indonesia to produce 30,000 tons per year of styrene butadiene latex. The plant was due on-stream early in 1993.

Japan.—Because of the continued slump in the Japanese petrochemical market, several projects have been postponed or downsized. Maruzen Polymer delayed plans to build a 100,000-ton-per-year HDPE plant at Chiba. Asahi postponed the April startup of its 40,000-ton-per-year LLDPE plant in Mizushima by 3 months. Sumitomo and Tosoh postponed the opening of a new 80,000-ton-per-year LLDPE plant from February to May. Nippon Petrochemical postponed the startup of its 50,000-ton-per-year LLDPE plant from March until September. In polypropylene, 150,000 tons per year of capacity will be delayed by at least 6 months. In styrene, a 240,000-ton-per-year unit scheduled to be on-stream in the summer will be delayed until July 1993,

and production at a 100,000-ton-per-year unit will be suspended for 3 months. Nippon Petrochemical postponed commissioning of its 50,000-ton-per-year LLDPE reactor until yearend. Ube Polypropylene postponed startup of its new 80,000-ton-per-year polypropylene plant from October until 1993, citing poor demand and overcapacity. Showa Denko planned to cut back production of ethylene and derivatives through December. Projections from MITI are that ethylene equivalent demand was expected to decrease by 3.5% from that of 1991 because of declines in the automotive, construction, packaging, and electronics sectors.

An 80,000-ton-per-year PVC plant was completed at Sumitomo Chemical's Chiba complex, but startup was delayed by 6 months because of the depressed state of Japan's PVC market.

Idemetsu Petrochemical began limited production at its 80,000-ton-per-year polypropylene plant. The product was destined for Malaysia, and the company does not expect to start full-scale operations until the spring of 1993.

Sumitomo Chemical and Denki Kagaku reached an agreement to build a 250,000-ton-per-year styrene plant at Chiba by 1993. If this project proceeds, the proposed expansion of Nihon Oxirane's Chiba unit from 330,000 tons per year to 450,000 tons per year may be canceled. Also coming on-stream is 300,000 tons per year of styrene capacity in the Republic of Korea that is aimed at the Japanese market.

Nippon Polystyrene will cut production of polystyrene as a result of lower demand for electronic appliances and office equipment. The company will close its 30,000-ton-per-year plant for 1 month.

Asahi Chemical announced that it would close its 80,000-ton-per-year Kawasaki styrene plant for 6 months because of decreasing demand, starting in early April. Mitsui Toatsu delayed completion of its 240,000-ton-per-year styrene plant in Ube City to July 1993, and Mitsubishi Yuka is extending the closure of its Yokkaichi plant until August. The styrene supply situation was worsened by the recent startup of Idemitsu Petrochemical's 200,000-ton-per-year plant at Tokuyama.

Mitsui Toatsu will begin construction of its 240,000-ton-per-year styrene plant, despite the poor market situation. The plant had been postponed earlier because of the poor market conditions. ABB Lummus Crest was providing technology and basic engineering to Chiba Styrene Monomer Ltd. for a new 250,000-ton-per-year styrene monomer complex at Chiba. The $160 million venture was scheduled for completion in mid-1994.

Japanese manufacturers of polystyrene have been working to reduce 1991 high inventory levels, and plant operating rates have decreased below 80%. Total Japanese polystyrene capacity is about 1.4 million tons, and 1991 demand was about 1.05 million tons. Exports for Japanese polystyrene were not growing as expected because of competition from other producers in countries such as the Republic of Korea.

Idemitsu Kosan planned to construct a 100,000-ton-per-year MTBE plant at its Chiba refinery. Completion was scheduled for June 1993. In Japan, MTBE was approved for use in gasoline blending in 1991, which prompted several companies to build production capacity.

In September, Kashima Oil completed the first MTBE plant in Japan, with an annual capacity of 60,000 tons; the plant relies on imported methanol.

Korea, Republic of.—In the Republic of Korea, the trade and industry ministry banned construction of new ethylene plants and some derivatives until 1995, including styrene and caprolactam. Ethylene capacity in the Republic of Korea was at about 20% above domestic demand. Two years before, the deficit was about 20% between capacity and domestic demand. But, to meet upcoming clean air regulations, the Republic of Korea plans to increase its MTBE capacity.

Malaysia.—Titan Himont Polymers recently commissioned a 120,000-ton-per-year polypropylene plant in Pasir Gudang. A 140,000-ton-per-year plant is being constructed at the same site for a third quarter 1993 startup.

Japan's Mitsui Engineering & Shipbuilding reportedly won an order to build Idemitsu's $50 million 60,000-ton-per-year polystyrene plant in Malaysia. This plant is a part of Idemitsu Chemicals' ethyl benzene/styrene monomer, polystyrene, and ABS production facilities.

Taiwan.—After a 6-year delay, Formosa Plastics (Taipei, Taiwan) received tentative approval from Taiwan's Environmental Protection Administration to begin construction of a $3.3 billion petrochemical complex. The complex will include the country's sixth ethylene plant and 24 downstream units, including styrene, MTBE, acrylonitrile, PVC, polyethylene, polycarbonate, and ABS.

Taiwan's Environmental Protection Administration will require polystyrene foam recycling beginning in late September.

ICI formally commissioned a 350,000-ton-per-year purified terephthalic acid plant in Taiwan. This plant will bring the company's global capacity to 872,000 tons per year. Taiwan is the second largest user of purified terephthalic acid, and if predicted growth rates materialize, Taiwan will be the largest user within a few years. ICI estimates demand will grow by an average of 8% per year during the 1990's, with 60% of that growth in Asia and the Far East. At the same time, the other large producer in Taiwan is operating at below 50% of rated capacity, and prices are depressed.

Taiwan faces a significant oversupply of polyester filament. Demand has fallen to about 25,000 tons per month, while production is about 70,000 tons per month. Although exports have fallen, producers have shown no effort to reduce production.

Thailand.—Dow Chemical and Siam Cement received a license to build a 75,000-ton-per-year polystyrene plant at Map Ta Phut, at a cost of about $50 million. Completion is scheduled for mid-1995. Several other projects are already under way at Map Ta Phut—a

25,000-ton-per-year polyols plant, a 20,000-ton-per-year styrene butadiene latex plant, and a 200,000-ton-per-year styrene plant.

Mideast Region.—**Iran.**—Iran reportedly gave permission for 10 new private-sector chemical projects. These include one project to produce 30,000 tons per year of aniline and a project for 25,000 tons per year of isocyanates, 24,000 tons per year of acetic acid, and 10,000 tons per year of monochloroacetic acid. Also included are a project for 10,000 tons per year of melamine; a 70,000-ton-per-year PVC plant; a 15,000-ton-per-year ABS and styrene acrylonitrile resins complex; a plant for 40,000 tons per year of dioctyl phthalate and 10,000 tons per year of petroleum resins; and two 10,000-ton-per-year plants for petroleum resins.

A new 1 million-ton-per-year MTBE plant is planned to be constructed in Iran by the third quarter of 1994. State-owned National Petrochemical Co. and an Irani businessman Abdul Wahab Galandri signed a letter of intent for the $300 million venture to be constructed in Bandar Imam. About 15% to 20% of the output from the plant is expected to be sold in the domestic market, with the rest to be exported to North America, western Europe, and Japan.

Kuwait.—Petrochemical Industries Co. reportedly revived plans to construct a petrochemical complex at Shuaiba that had been shelved since the war with Iraq. Along with an overseas investor, the company plans to build a 600,000-ton-per-year ethylene plant and include facilities to produce polyethylene, polypropylene, ethylene oxide, and glycol.

Saudi Arabia.—Dow Europe formed a joint venture with a Saudi Arabian firm to manufacture and market styrene butadiene latex in Saudi Arabia. The first 30,000-ton-per-year unit is due on-stream at the end of 1994, and a doubling of capacity is planned.

United Arab Emirates.—The Abu Dhabi National Oil Co. announced plans to begin petrochemical manufacture. The first stage of the project will include an ethylene and polyethylene complex with an annual capacity of 300,000 to 500,000 tons. No timetable was given for construction. *(See tables 18, 19, and 20.)*

OUTLOOK

The United States continued as the leading producer of polymeric resin materials, with nearly 36% of global production, followed by Japan and Germany. Steady growth has been experienced in U.S. synthetic organic chemicals and downstream products over the past 25 years. Since 1967, the production of polymeric resins has increased at a compound annual rate of 6.3% and sales and captive use by 7.1%. Since 1977, however, growth has been somewhat lower, averaging about 5%. The recessionary period and sluggish economic situation since 1987 have resulted in even lower growth rates, approximating 3.5% for production and 3.9% for sales and captive use. Production and sales volume in 1992 rebounded to between 6% and 7%, even though overall profitability did not change markedly. Still, the total increase in production and sales and captive use during the past 12 years has been remarkable, approximating 78% and 83%, respectively.

The value of industry shipments for resin materials and products and miscellaneous polymeric products was $92.5 billion (1987 dollars) in 1992, according to the ITA. ITA estimates for 1993 indicate a growth rate in industry shipments of about 3%, valued at $95.2 billion (1987 dollars), ranking the monetary value of the U.S. plastics and resins industry as the fourth largest in the country, eclipsed only by motor vehicles and car bodies, petroleum refining, and automotive parts and accessories. High-performance characteristics and production economics have resulted in price pressures that have driven significant substitution patterns of polymers for traditional materials such as wood, glass, and metal.

U.S. exports of the large commodity polymers, including polypropylene, PVC, PET, and polystyrene, more than doubled during the 1980's and reached 3.3 million tons by 1990. Even so, the U.S. trade surplus has remained at about 2 million tons because imports increased about eightfold to 1.1 million tons by 1990. This trend is likely to continue as Saudi Arabia, other Mideastern countries, and the Far East continue to develop petrochemicals businesses, and Canada, Japan, Germany, the United Kingdom, and other EC countries continue to seek markets in the United States. The United States is also a major net exporter of petrochemicals—methanol, ethylene, propylene, butadiene, benzene, toluene, and xylene—approximating $15 billion in 1992.

Although the United States should continue to be a strong competitor in the global petrochemicals and resin business, long-term market share seems destined to decline in face of increasing pressures from foreign competition. Countries in the Far East, now heavily dependent on U.S. products, are building their own domestic supplies of primary petrochemicals. Of 28 new ethylene producers set to start up in the 1990's, for example, 18 are in the Far East. Also, about 46% of the 4.6 million tons of new styrene capacity to be added to global production by 1995 is in the Far East. Significant new global capacity will increase competition, reduce U.S. market access, and most probably depress margins and profitability.

Other factors that will affect the long-term outlook for U.S. petrochemicals and downstream businesses include the environmental movement and drive to recycle more plastics materials, and full implementation of the Clean Air Act in 1995. Industry analysts believe that up to 12% of U.S. HDPE may be recycled by 2000. Although the precise percentage is uncertain, the trend toward more recycling will potentially reduce U.S. competitiveness in the global high-quality virgin resins market. The Clean Air Act will require reductions in the benzene and butane content of gasoline. This, in turn,

could bring more of these feedstocks into the organic chemicals sector, potentially creating an imbalance in supply-demand for other important chemical feedstocks such as propylene, isobutane, and aromatics.

Future developments in the energy-rich former U.S.S.R. and currently depressed central European nations also will pose problems and opportunities for the U.S. petrochemicals industry, together with the outcome of NAFTA and GATT trade negotiations.

Paints and coatings are classified under three main categories: architectural, mainly used for interior/exterior applications in commercial and residential installations; original equipment manufacture, used as final coatings for a variety of durable goods; and special-purpose or specialty coatings for numerous and highly specific uses in the maintenance, marine, transportation, and electronics markets. There have been many changes in the marketplace during recent years, including industry restructuring, a gradual expansion of specialized end user markets, and much stricter environmental regulations. Environmental concerns continue to pressure producers to develop more environmentally friendly products that minimize the use of organic solvents.

A gradual turnover to aqueous-based systems is under way, especially for architectural coatings, which comprise about one-third of industry production. Long term, the industry is expected to place more emphasis on performance characteristics. High-density formulations, already a high-growth market, are expected to expand. The use of high-diffusion wetting agents shows promise. High U.S. growth rates also are expected for solventless powder coatings. The prospects for radiation-curing, however, remain mixed, owing partially to unfavorable consumer acceptance.

Turning to the outlook for synthetic rubber, industry shipments were about $4 billion (1987 dollars) in 1992, with an expected increase of about 4% in 1993, mostly related to automotive industry products. Most synthetic rubber (SR) or elastomers fall into two distinct groups: commodity or general purpose, and specialty elastomers. Typical general purpose elastomers include styrene butadiene latex, polychloropropylene, nitrile, ethylene-propylenediene monomer (EPDM), carboxylated styrene, butadiene, and polybutadiene.

Commodity SR accounts for the bulk of SR production and is used in the production of tires and fabricated rubber products. Fast growing, but still minor compared with SR, are the specialty elastomers, including the thermoplastic elastomers and olefins (TPE's and TPO's), which tend to be used where resistance to extreme temperature and chemical and mechanical stress is required. Material substitution is growing, especially in automotive usage, at the expense of traditional materials. Environmental concerns also may gain in prominence as firms are pressured to switch to less toxic chemical processes.

Industry consolidation has significantly changed the face of the tire industry. The bulk of the industry is now held by a few European and Japanese multinationals. U.S. tire shipments were valued at about $12 billion in 1992 (1987 dollars), according to ITA statistics, of which about 20% to 30% is estimated to be synthetic rubber. Consolidation has left few American firms unaffiliated with a major multinational concern. U.S. tire exports have grown rapidly during the past 3 years, while imports have declined. Export growth can be attributed to the combined effects of global restructuring and the depreciation of the dollar. Canada remains our largest trading partner in both imports and exports. Long-term growth prospects in the U.S. tire market are likely to come from niche markets such as recreational tires and high-performance varieties.

Fabricated rubber products outside of tires that may include both synthetic and natural rubber include: rubberized fabrics; vulcanized rubber clothing; health supplies for medical, druggist, and pharmaceutical use; and rubber goods made from reclaimed and recycled materials. Other articles of commerce include rubber and synthetic elastomeric footwear, hose and belting, gaskets, packing and sealing devices, and molded, extruded, and lathe-cut mechanical rubber goods. Fabricated rubber products were valued at more than $6 billion (1987 dollars) in 1992.

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TABLE 1
SALIENT U.S. ORGANIC MATERIALS STATISTICS

(Million metric tons, unless otherwise specified)

	1988	1989	1990	1991	1992
Petrochemical industries:					
Production, total feedstocks:[1]	56.06	55.66	57.75	r67.79	65.91
Production, resins[2]	31.89	31.61	33.04	r33.22	35.12
Production, others[3]	24.17	24.05	24.70	r34.57	30.79
Imports for consumption[4]	9.63	9.18	10.11	r9.79	8.68
Exports[4]	1.99	2.19	2.17	r1.48	1.49
Consumption, apparent primary	63.61	63.17	64.92	r74.90	73.78
Price, dollars per metric ton[5]	$91.84	$113.75	$134.36	r$116.38	$113.29
Stocks, yearend[4]	4.51	3.99	4.74	r5.94	5.26
Lubricants, miscellaneous products, waxes:					
Production	12.99	12.78	12.51	12.10	11.05
Imports for consumption	.73	.74	.74	.58	.73
Exports	1.46	1.15	1.19	1.04	.97
Consumption, apparent primary	12.35	12.35	12.29	11.65	10.72
Price, dollars per metric ton[5]	$91.30	$117.30	$148.90	r$127.30	$120.79
Stocks, yearend	2.39	2.41	2.18	2.17	2.26
Petroleum coke and coal:					
Production	12.07	11.47	13.05	r12.93	13.83
Imports for consumption[6]	.03	.02	.04	.04	.04
Exports[6]	4.44	4.21	4.58	r4.68	4.62
Consumption, apparent primary	7.62	7.26	8.53	r8.17	9.26
Price, dollars per metric ton[5]	$63.52	$78.47	$98.95	r$82.85	$79.65
Stocks, yearend[6]	.41	.43	.41	r.53	.52
Asphalt and road oil:					
Production	26.72	25.52	25.02	r25.85	25.25
Imports for consumption	1.90	1.85	1.91	1.67	1.64
Exports	.06	.19	.17	.19	.27
Consumption, apparent primary	28.22	27.23	27.06	r26.73	27.39
Price, dollars per metric ton[5]	$87.60	$110.40	$139.10	r$115.23	$110.64
Stocks, yearend	3.44	3.39	3.09	3.69	2.92

rRevised.

[1]Total feedstocks are composed of liquefied petroleum gases, petrochemical feedstocks, special naphthas, and dry natural gas as defined in table 2.6 of the Annual Energy Review 1992.

[2]Resins are composed of feedstocks for the production of plastics, synthetic fibers, and synthetic rubber.

[3]Others are composed of those feedstocks used in the production of pesticides, coatings, solvents, and other petrochemicals.

[4]Dry natural gas is not included.

[5]Price is based on the British thermal unit value of fossil fuels as close to the point of production as possible as given in table 3.1 of the Annual Energy Review 1992.

[6]Coal is not included.

Sources: Chemical & Engineering News, Annual Energy Review 1992, Petroleum Supply Annual 1992, and Modern Plastics.

TABLE 2
CONSUMPTION OF MAJOR FEEDSTOCKS FOR PLASTICS, 1990

Feedstock	Consumed in plastics	
	Thousand metric tons	Percent of total
Benzene	4,173	68
Butadiene	102	11
Ethylene	12,020	75
Methane	1,225	(1)
Naphthalene	136	65
Propylene	5,489	64
Toluene	318	11
Xylene	635	22

[1]Less than 0.5%.

Source: Rauch Associates, Inc.

TABLE 3
PLASTICS FABRICATION, BY PROCESS AND TYPE OF PROCESSOR

Process	Total[1] (number of plants)	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	3
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.
[1]Plants engaged in one or more primary processes.

Source: Rauch Associates, Inc.

TABLE 4
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[r]	10,053	35.8	2,105	7.5	2,472	8.8	28,077
1992	11,040	36.7	2,317	7.7	2,696	9.0	30,068

[r]Revised.

Source: Modern Plastics.

TABLE 5
PETROCHEMICAL FEEDSTOCKS (CONTRACT PRICES)

(Cents per pound)

	First quarter	Second quarter	Third quarter	Fourth quarter
Acrylonitrile	26.0	26.0	26.0	27.0
Benzene	14.0	16.5	15.0	12.0
Butadiene	14.0	15.0	19.0	20.0
Ethylene	19.0	18.5	20.5	23.0
Propylene	14.0	14.0	15.0	14.5
Styrene	26.0	24.5	24.0	23.0
Vinyl chloride	14.0	16.0	17.0	17.0

Source: Modern Plastics.

TABLE 6
U.S. PLASTICS, FIBERS, AND RUBBER WORK FORCE CHARACTERISTICS

	1990	1991	1992
Industrial employment (thousands):	181.0	r178.0	173.0
Women employed	41.4	r41.3	40.3
Men employed	139.6	r136.2	133.0
Production workers (thousands)	116.0	110.0	104.1
Average workweek (hours)	42.5	42.6	43.8
Average hourly earnings (dollars):			
Plastics, fibers, and rubber	$13.44	r$14.79	$15.37
All manufacturing	$10.84	$11.18	$11.46

rRevised.

Sources: Chemical & Engineering News and U.S. Bureau of Labor Statistics.

TABLE 7
RELEASES AND TRANSFERS FOR THE TOP 50 CHEMICALS IN 1991

(Percent of all TRI chemicals)

	Total releases[1]	Total transfers[2]	Percent of total transfers recycled
First-level derivatives:			
Benzene	0.5	0.2	5.5
Ethylene	1.1	([3])	—
Propylene	.7	([3])	—
Toluene	5.9	3.3	19.4
Xylene	3.4	3.3	30.6
Other organics	48.2	23.7	30.0
Inorganics	36.1	58.8	79.0
Total[4]	96.0	89.3	61.8
Total for all TRI chemicals (metric tons)	1,535,822	1,753,280	1,067,823

[1]Releases include fugitive or nonpoint air emissions, stack or point air emissions, surface water discharges, underground injection, and releases to land.
[2]Transfers include transfers to publically owned treatment works, transfers to treatment, transfers to disposal, transfers to energy recovery, transfers to recycling, and other offsite transfers.
[3]Less than 1/2 unit.
[4]Total represents the percentage for all TRI chemicals.

Source: 1991 Toxics Release Inventory, Environmental Protection Agency.

TABLE 8
PLASTIC PRICES

(Cents per pound)

	First quarter	Second quarter	Third quarter	Fourth quarter
HDPE, injection molding	30-32	30-32	35-37	35-37
HDPE, recycled, natural	33-36	30-36	30-37	30-37
LDPE, injection molding	32-34	36-38	40-42	40-42
Phenolics	68-75	68-75	68-75	68-75
PET, recycled, clear	43-52	43-54	45-54	45-54
Polypropylene, homopolymer, injection	34-35	34-35	36-38	33-35
Polypropylene, recycled	24-27	24-27	24-27	24-27
Polystyrene, crystal	42-43	44-45	45-47	45-47
PVC, suspension resin	26-27	28-30	28-30	28-30
PVC, recycled	12-18	10-13	10-13	10-13

Sources: Plastics News.

TABLE 9

U.S. PRODUCTION CAPACITY, SELECTED RESINS

(Thousand metric tons)

Resin	1988	1989	1990	1991	1992
Polyethylene:					
High-density (HDPE):					
Capacity	3,869	4,119	4,333	4,902	5,406
Utilization rate (percent)	98.5	89.2	87.3	85.2	82.3
Low-density (LDPE):					
Capacity	5,207	3,524	3,562	3,556	3,563
Utilization rate (percent)	90.6	84.6	92.4	92.4	92.6
Linear low density (LLDPE):					
Capacity	NA	1,891	2,289	2,350	2,498
Utilization rate (percent)	NA	74.8	77.1	83.9	84.3
Polypropylene:					
Capacity	3,622	4,021	4,118	4,314	4,522
Utilization rate (percent)	91.1	81.6	91.5	87.6	84.5
Polystyrene:					
Capacity	2,587	2,740	2,544	2,671	2,551
Utilization rate (percent)	91.0	84.5	89.5	84.1	90.6
PVC:					
Capacity	4,040	4,213	4,257	4,390	4,664
Utilization rate (percent)	93.8	91.3	96.9	94.7	97.2

NA Not available; included in LDPE.

Source: The Society of the Plastics Industry, Inc.

TABLE 10
U.S. PRODUCTION OF SELECTED THERMOPLASTICS AND THERMOSETS

(Thousand metric tons)

	1991	1992
Thermoplastic resins:		
LDPE	r5,254	5,441
HDPE	r4,179	4,451
Polypropylene	r3,778	3,819
Polystyrene	r2,247	2,290
Styrene-acrylonitrile	49	52
Acrylonitrile-butadiene-styrene	r1,037	1,182
Polyamide, nylon type	261	303
PVC	r4,157	4,530
Other vinyl resins	86	90
Thermoplastic polyester	r959	1,095
Other thermoplastics	1,189	NA
Total	r23,196	23,253
Thermoset resins:		
Epoxy	r225	207
Melamine	89	105
Phenolic	1,206	1,326
Polyester	488	533
Urea	673	704
Polyurethane	r1,427	1,510
Total	r4,108	4,385

rRevised. NA Not available.

Sources: Chemical & Engineering News and Modern Plastics.

TABLE 11
U.S. SYNTHETIC FIBERS PRODUCTION

(Thousand metric tons)

	1988	1989	1990	1991	1992
Noncellulosic fibers:					
Acrylic	267	247	230	206	199
Nylon	1,212	1,244	1,208	1,152	1,158
Olefin	721	744	827	847	904
Polyester	1,671	1,632	1,451	1,548	1,622
Cellulosic fibers	279	263	229	220	225
Total	4,150	4,130	3,945	3,973	4,109

Source: Chemical & Engineering News.

TABLE 12
U.S. PLASTIC RESIN SALES

(Thousand metric tons)

	1988	1989	1990	1991	1992
ABS	580	561	527	510	583
Acrylic	316	335	315	r284	284
Alkyd	145	147	145	143	145
Cellulosics	41	41	36	r36	37
Epoxy	212	219	210	r222	213
EVA	503	475	497	506	NA
HDPE	3,667	3,707	4,009	r4,239	4,733
LDPE	2,962	2,975	2,770	2,827	5,582
LLDPE	1,500	1,763	2,160	2,175	NA
Nylon	260	263	263	252	270
Other styrenics	499	535	566	r533	589
Other vinyls	431	408	[1]87	r [1]81	80
PBT/PCT/PET	927	951	1,060	r1,153	1,244
Phenolic	1,385	1,282	1,333	r1,208	1,341
Polyacetal	63	65	65	64	66
Polycarbonate	267	283	281	273	300
Polyester, unsaturated	623	598	557	490	541
Polyphenylene alloys	78	89	90	88	93
Polyurethane	1,467	1,462	1,492	r1,427	1,510
PP	3,215	3,313	3,737	r3,777	3,856
PS	2,280	2,327	2,290	r2,220	2,357
PVC	3,759	3,849	4,080	r4,180	4,560
SAN	66	49	61	r52	51
Thermoplastic elastomers	223	246	265	r279	297
Urea/melamine	687	626	759	r752	788
Others	131	141	150	156	162
Total[2]	26,156	26,712	27,805	r27,651	29,683

rRevised. NA Not available; included in LDPE.
[1]Includes only polyvinyl butyral, polyvinyl formal, and polyvinylidene.
[2]Data may not add to totals shown because of independent rounding.

Source: Modern Plastics.

TABLE 13
U.S. CONSUMPTION OF SELECTED RESINS

(Thousand metric tons)

Resin	Consumption	
	1991r	1992
LDPE	4,798	5,176
HDPE	3,972	4,388
PVC	3,551	4,067
PP	3,122	3,455
PS	2,087	2,209
ABS	478	578

rRevised.

Source: Modern Plastics, Jan. 1993.

TABLE 14
DISTRIBUTION OF RESIN CONSUMPTION IN SELECTED END USES

(Thousand metric tons)

	Appliances	Building and construction	Electrical and electronic	Transportation	Furniture	Toys	Housewares	Packaging
ABS	106	63	50	149	3	16	—	3
Acrylic	5	96	—	32	—	—	—	—
Cellulosics	1	2	1	—	—	1	1	2
Epoxy	4	21	23	—	—	—	—	17
EVA	—	—	—	—	—	—	103	37
HDPE	—	—	67	—	—	91	209	2,240
LDPE	—	—	177	—	—	83	—	2,430
Nylon	—	—	41	67	—	—	—	—
PET	—	—	—	—	—	—	—	684
Phenolics	13	1,002	42	10	43	—	16	5
Polyacetal	6	—	2	16	—	—	—	—
Polycarbonate	24	55	17	27	—	—	—	10
Polyester	44	163	48	25	3	—	—	—
Polyurethane	—	—	—	—	283	—	—	—
PP	85	13	15	13	53	31	134	770
PS	123	186	215	—	37	93	117	782
PVC	64	2,646	223	10	39	18	88	250
SAN	5	14	2	—	—	—	10	6
Urea/melamine	—	638	24	—	—	—	—	1
Others	128	891	35	774	26	48	38	265
Total	608	5,790	982	1,123	487	381	716	7,502

Source: Modern Plastics.

TABLE 15
DOMESTIC SHIPMENTS OF STAPLE FIBERS, BY MARKET

(Thousand metric tons)

Fiber	Market	1988	1989	1990	1991	1992
Rayon:	Shipments to nonwovens	55	44	33	32	32
	All others	120	109	100	84	86
	Total domestics[1]	175	153	132	116	118
Polyester:	Shipments to nonwovens	111	123	108	108	111
	All others	938	902	805	858	888
	Total domestics[1]	1,049	1,026	914	965	999
Olefin:	Shipments to nonwovens	82	88	106	123	117
	All others	74	76	70	75	83
	Total domestics[1]	156	165	176	199	200
	Grand total[1]	1,380	1,344	1,222	1,280	1,317

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

Source: Nonwovens Industry, June 1993.

TABLE 16
U.S. SYNTHETIC RUBBER SHIPMENTS

(Thousand metric tons)

	1988	1989	1990	1991	1992
Ethylene-propylene	224	225	208	192	206
Nitrile	75	72	69	71	74
Polybutadiene	430	427	431	416	463
Polychloroprene	82	79	79	70	72
Styrene-butadiene rubber	829	827	791	727	796
Other[1]	355	295	329	298	315
Total	1,995	1,925	1,907	1,774	1,926

[1]Includes butyl-styrene-butadiene latex, nitrile latex, polyisoprene, and other synthetic elastomers.

Source: Chemical & Engineering News.

TABLE 17
U.S. IMPORT AND EXPORT TRADE SUMMARY OF SELECTED RESINS

(Thousand metric tons)

	1991[r]	1992
LDPE:[1]		
Exports	796	728
Imports	394	429
Net exports	402	299
HDPE:		
Exports	477	585
Imports	210	240
Net exports	267	345
PP:		
Exports	701	463
Imports	47	61
Net exports	654	402
PVC:		
Exports	677	600
Imports	49	107
Net exports	628	493
PS:		
Exports	133	148
Imports	28	57
Net exports	105	91
ABS:		
Exports	80	86
Imports	48	81
Net exports	32	5

[r]Revised.
[1]Included 5 LLDPE and EVA.

NOTE.—Net exports = exports minus imports. All categories are independently rounded.

Source: Modern Plastics, Jan. 1993.

TABLE 18
WORLD SALES OF PLASTIC RESINS

(Thousand metric tons)

	1991	1992
Australia	948	NA
Belarus	717	629
Bulgaria	r142	NA
Canada:		
ABS	r48	39
HDPE	r434	601
LDPE	r1,157	1,023
PP	r218	201
PS	r126	153
PVC	r240	264
Total[1]	r2,223	2,281
China	2,640	3,142
Czechoslovakia	944	NA
France:		
PE	1,199	1,349
PP	812	902
PS	527	507
PVC	1,048	1,095
Total[1]	3,586	3,853
Germany:		
PE	r1,363	1,452
PP	r531	590
PVC	r1,176	1,141
Total[1]	r3,070	3,183
Hungary	r604	686
Italy:		
PE	r948	925
PS	r310	280
PVC	r620	616
Total[1]	r1,878	1,821
Japan:		
PE	2,982	2,980
Phenolic resins	383	356
PP	1,963	2,038
PS	2,121	2,005
PVC	2,055	1,981
Total[1]	9,504	9,360
Korea, Republic of		
PE	1,164	1,755
PP	772	1,226
PS	758	754
PVC	621	732
Total[1]	3,315	4,467

See footnotes at end of table.

TABLE 18—Continued
WORLD SALES OF PLASTIC RESINS

(Thousand metric tons)

	1991	1992
Mexico:		
HDPE	200	199
LDPE	339	340
PP	39	110
PS	99	99
PVC	373	380
Total[1]	1,050	1,128
Poland	593	644
Romania	349	267
Russia	2,963	NA
Taiwan:		
ABS	472	569
PE	334	360
PS	476	522
PVC	978	1,043
Total[1]	2,260	2,494
Ukraine	746	555
United Kingdom:		
PE	376	314
PP	315	327
PVC	322	293
Total[1]	1,013	934
United States	r27,651	29,683
Grand total[2]	r66,196	65,127

rRevised. NA Not available.
[1]Country subtotals are for resins shown only.
[2]Total is for countries and resins listed only.

Sources: Modern Plastics and Chemical & Engineering News.

TABLE 19
SYNTHETIC FIBERS PRODUCTION, SELECTED COUNTRIES

(Thousand metric tons)

	1989	1990	1991	1992
Austria	172	173	157	169
Belarus	450	453	443	385
Benelux countries[1]	291	311	326	321
Bulgaria	71	r58	26	NA
China	1,466	1,655	r1,909	2,083
Czechoslovakia	208	200	137	142
Finland	68	69	r58	67
France	180	156	118	122
Germany	1,015	1,019	r980	982
Hungary	36	30	r31	25
Ireland	94	93	r95	109
Italy	676	694	r708	725
Korea, Republic of[2]	654	730	780	778
Poland	238	149	106	111
Portugal	65	64	64	74
Romania	273	209	144	112
Russia	731	673	529	472
Spain	309	301	283	292
Switzerland	120	118	r108	112
Taiwan	1,193	1,290	1,457	1,598
Turkey	302	252	NA	NA
Ukraine	191	179	136	NA
United Kingdom	340	350	332	318
United States	4,130	3,945	3,973	4,109
Yugoslavia	159	148	101	NA
Total[3]	r13,273	r13,171	r13,001	13,106

rRevised. NA Not available.
[1]Belgium, the Netherlands, and Luxembourg.
[2]Polyester fibers only.
[3]Total is for countries listed only.

Source: Chemical & Engineering News.

TABLE 20
SYNTHETIC RUBBER PRODUCTION, SELECTED COUNTRIES

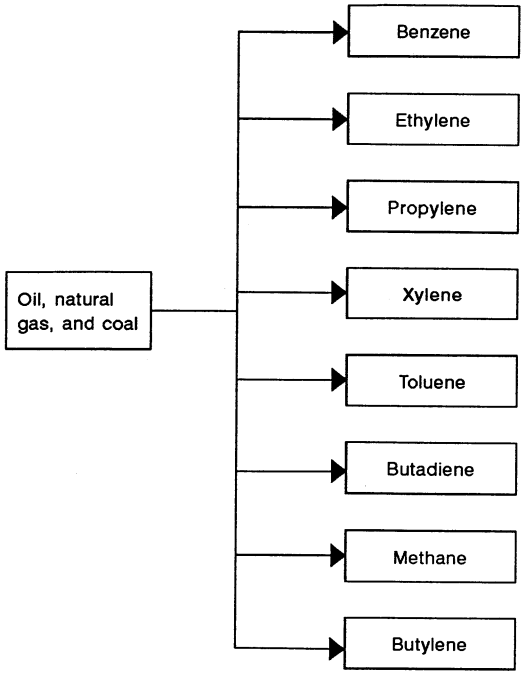
(Thousand metric tons)

Country	1991	1992
China	335	366
Czechoslovakia	45	64
France	470	501
Germany	r509	490
Japan	1,368	1,388
Poland	80	89
Romania	55	36
Russia	2,012	1,620
United Kingdom	r251	253
United States (shipments)	1,907	1,926

rRevised.

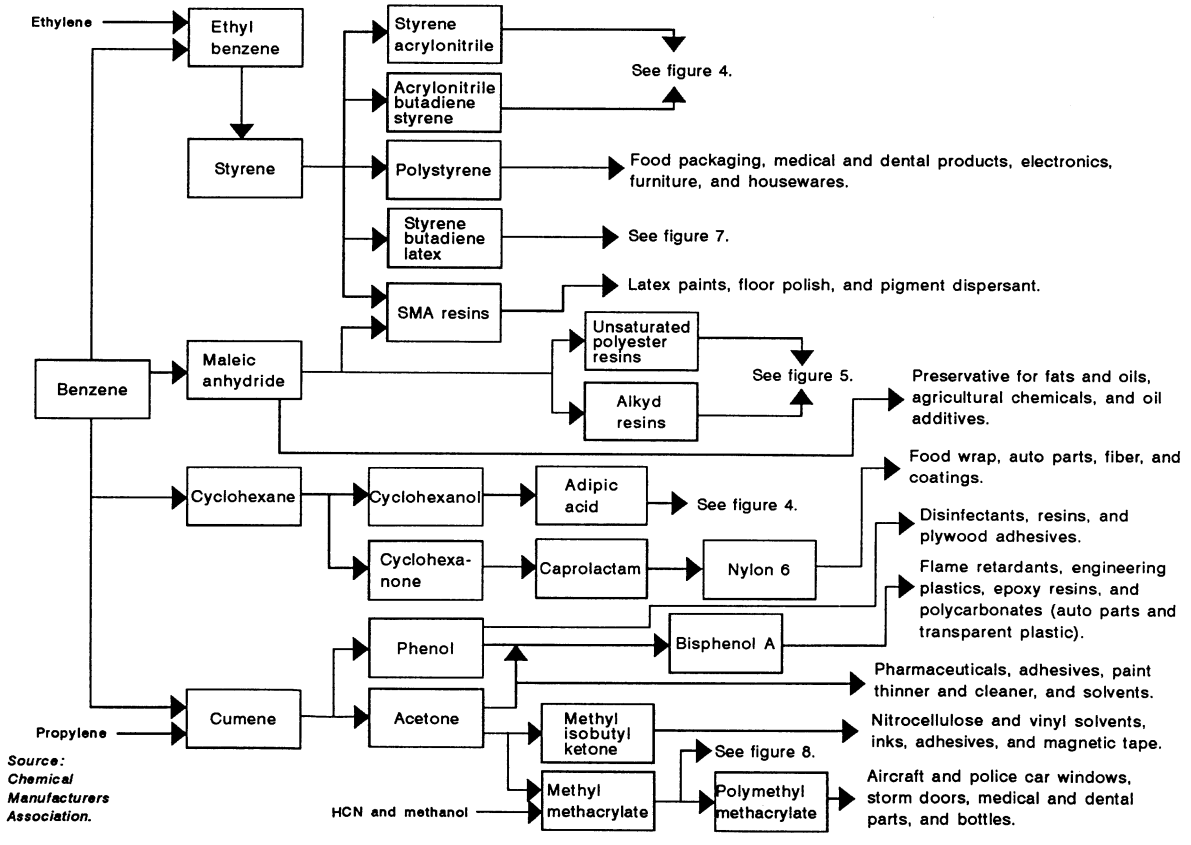
Source: Chemical & Engineering News.

FIGURE 1
FIRST-LEVEL DERIVATIVE ORGANIC CHEMICALS



Source: Chemical Manufacturers Association.

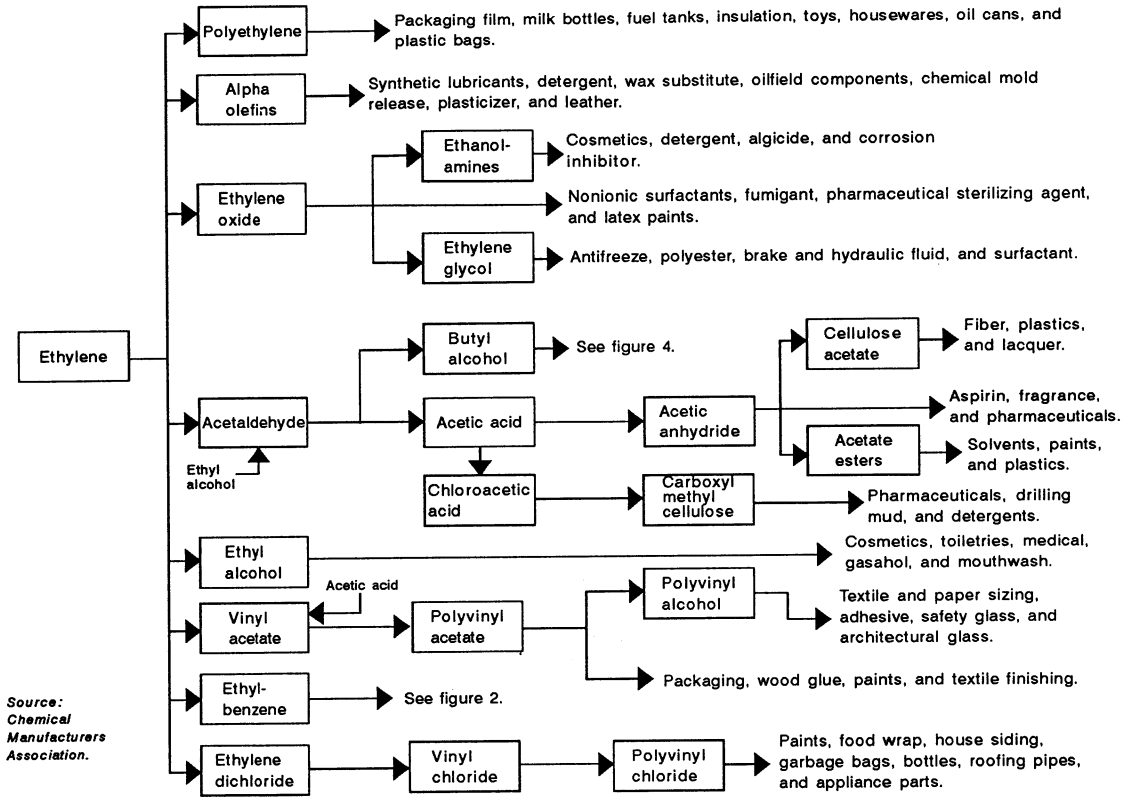
FIGURE 2
BENZENE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

FIGURE 3

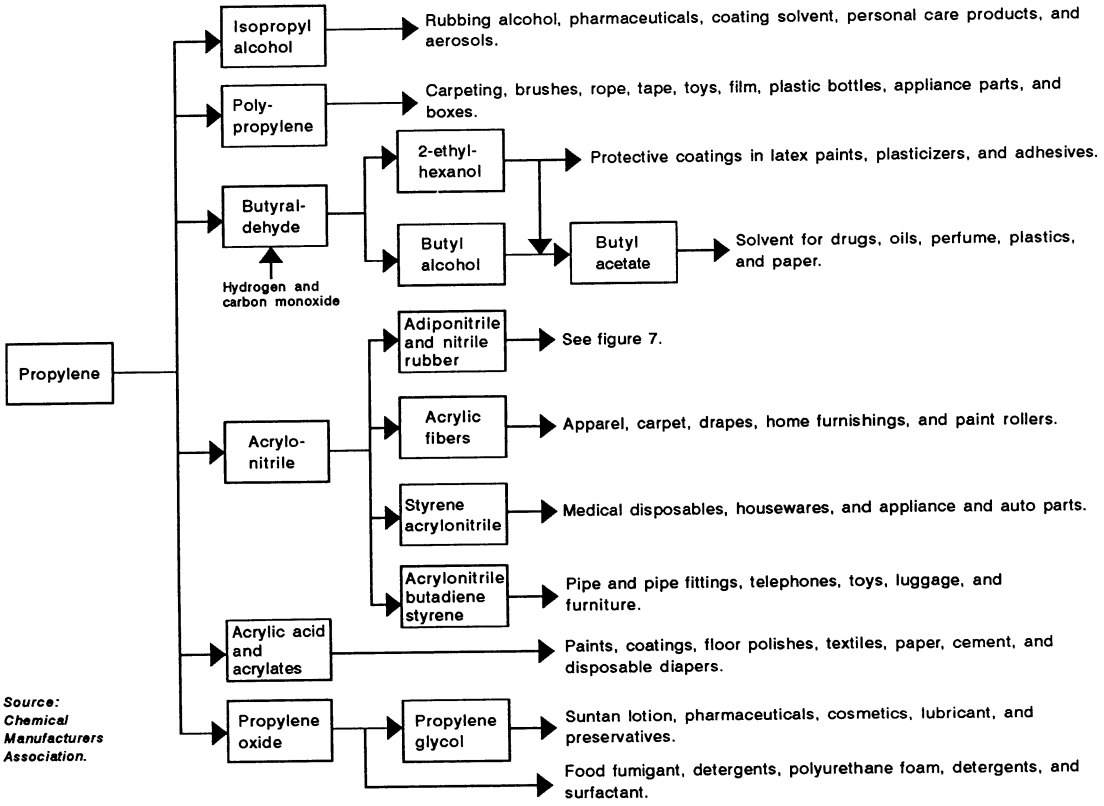
ETHYLENE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

FIGURE 4

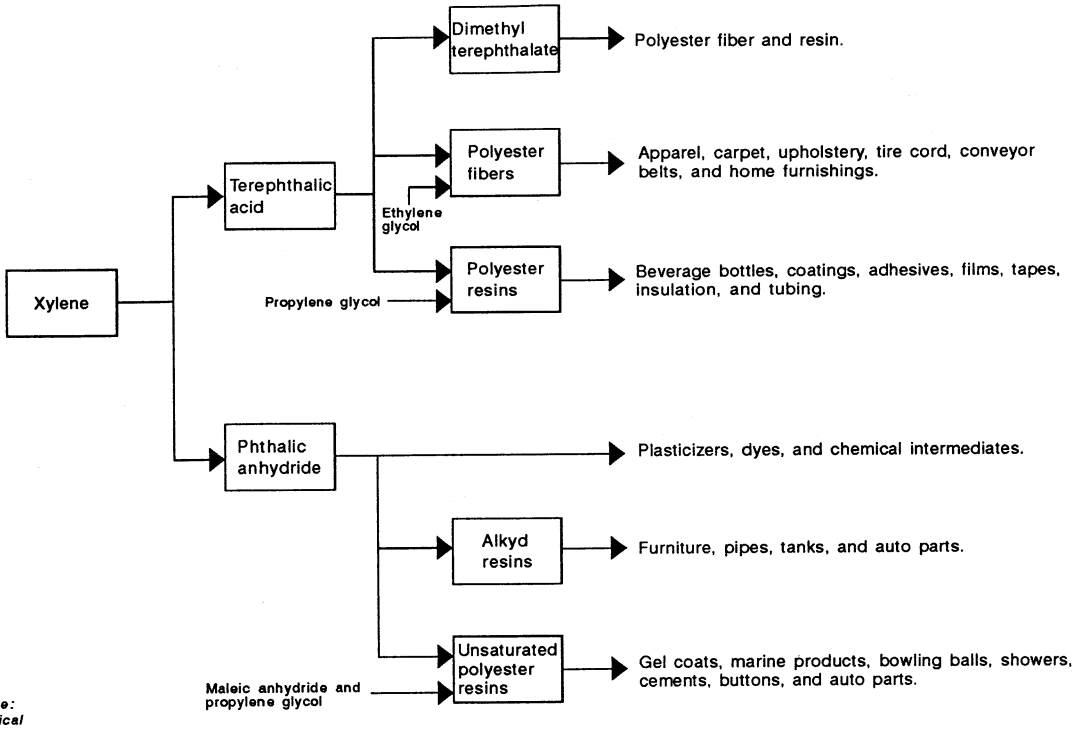
PROPYLENE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

FIGURE 5

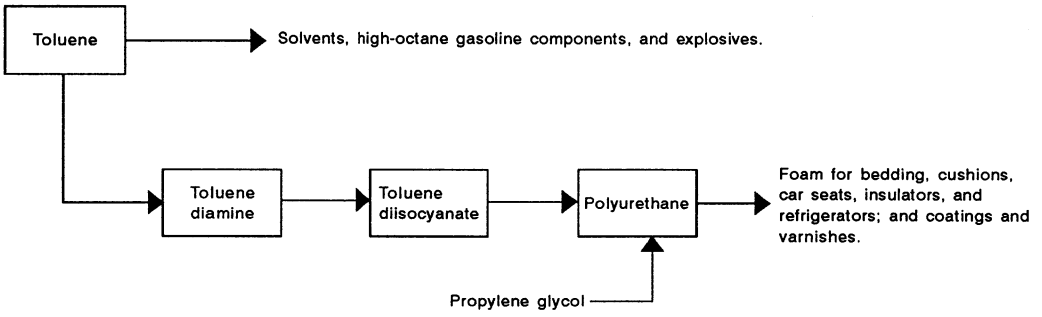
XYLENE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

FIGURE 6

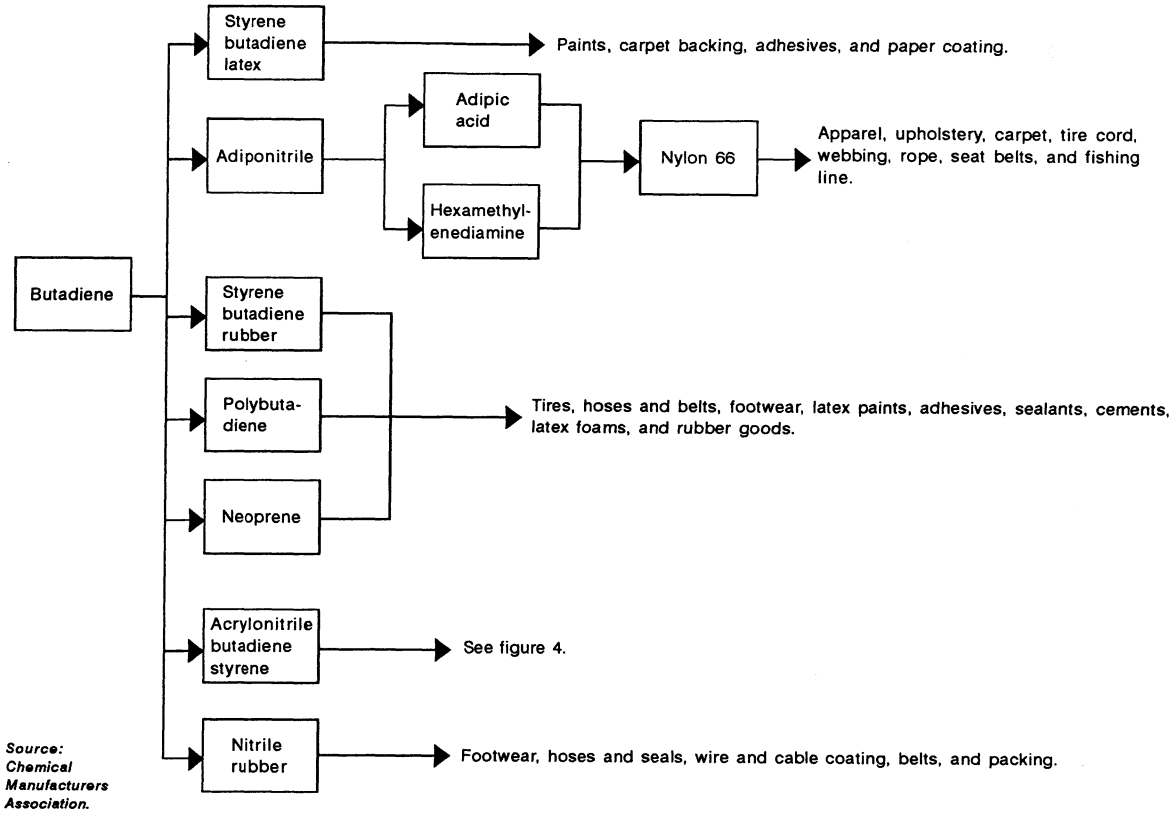
TOLUENE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

FIGURE 7

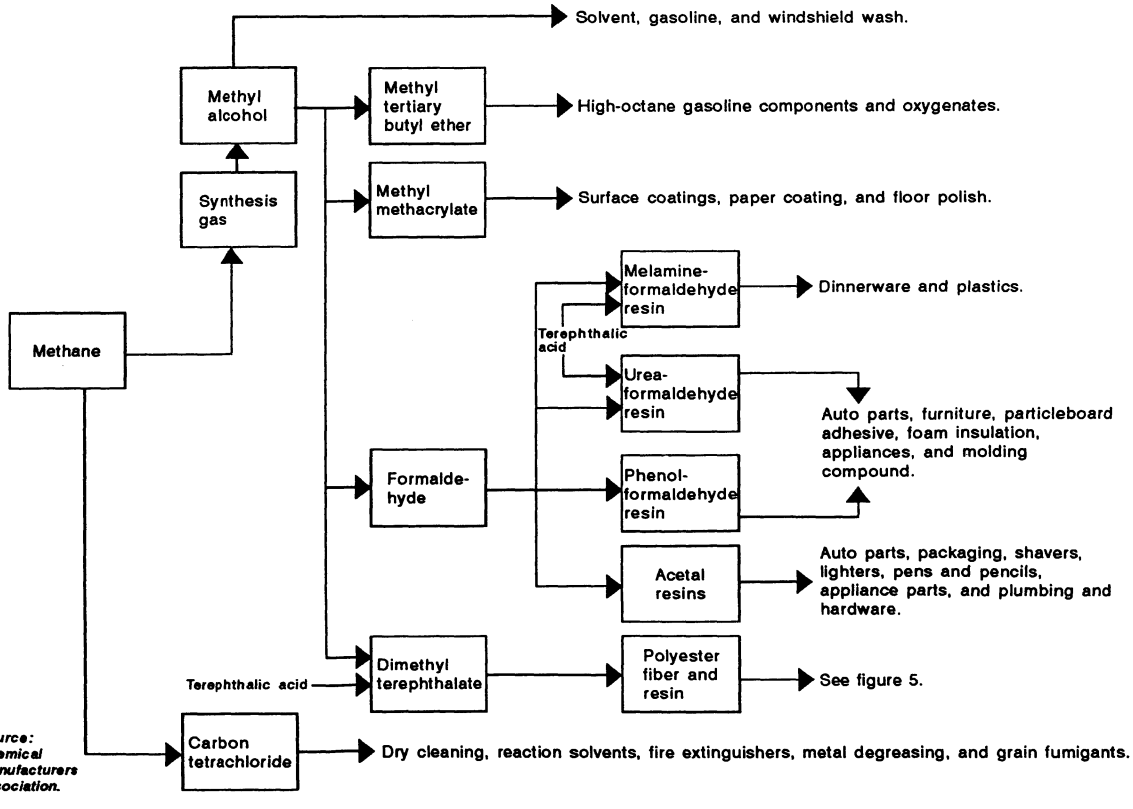
BUTADIENE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

FIGURE 8

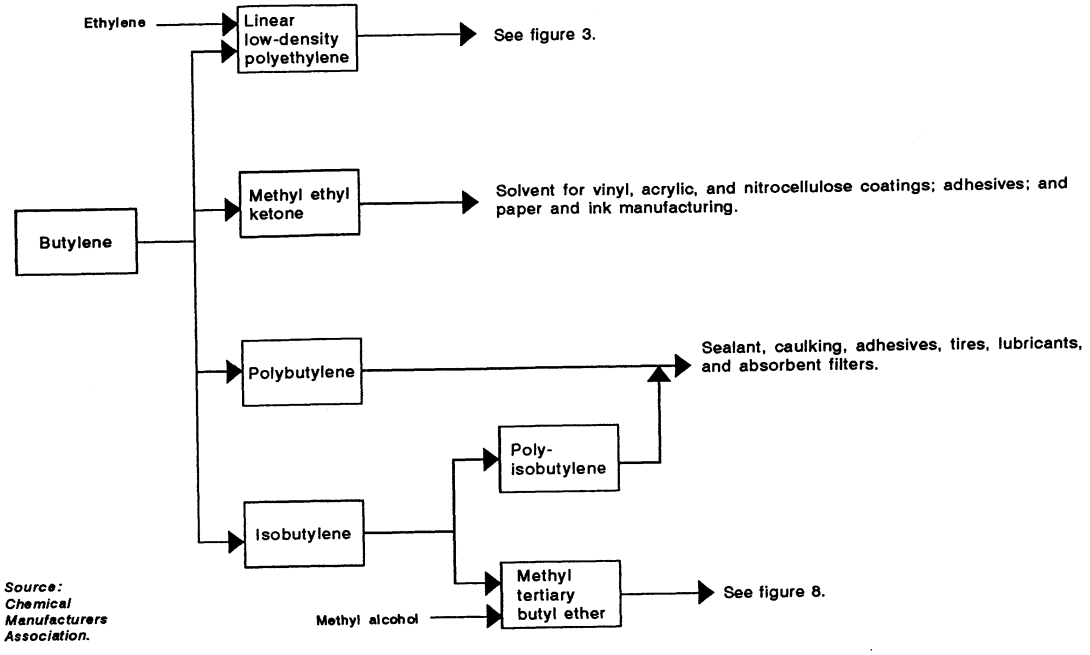
METHANE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

FIGURE 9

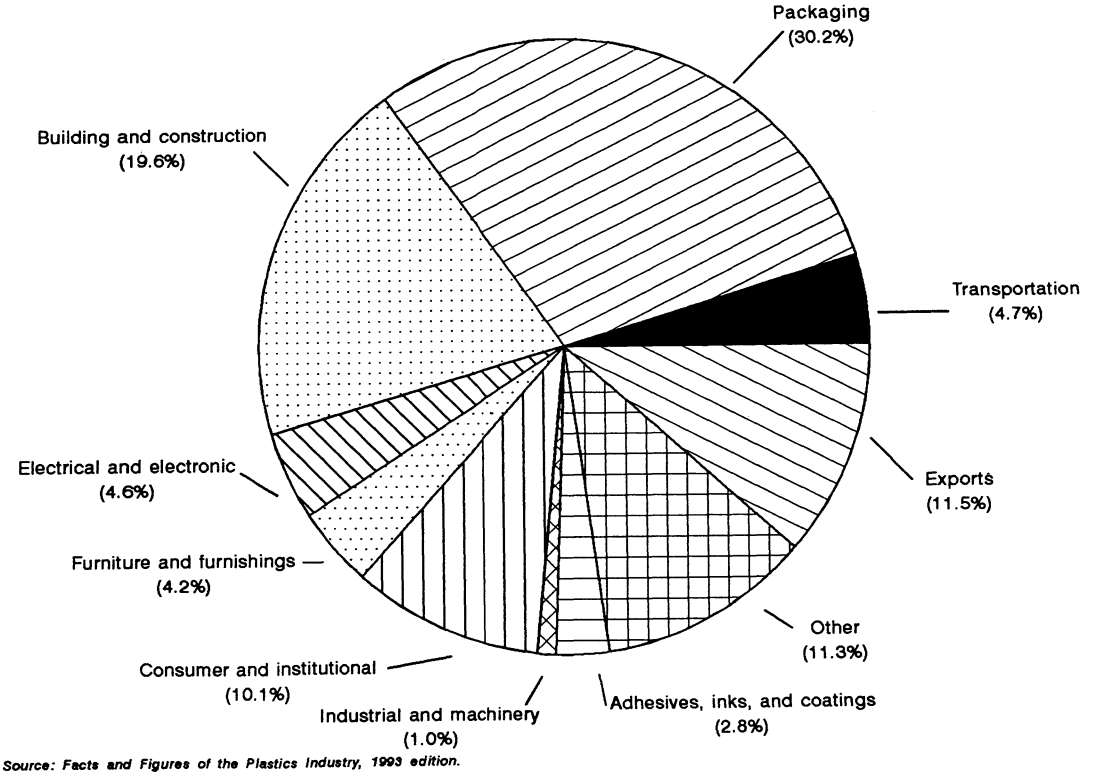
BUTYLENE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

FIGURE 10

DISTRIBUTION OF RESINS IN MAJOR MARKETS IN 1992



Source: Facts and Figures of the Plastics Industry, 1993 edition. Society of the Plastics Industry, Inc.

PEAT

By Raymond L. Cantrell

Mr. Cantrell, a physical scientist with 29 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. The international data table was prepared by Audrey Wilkes, international data coordinator.

More than 90% of Earth's 1.1 billion acres of natural organic peat and peatland resources remain untouched, forming the basis for a continuous biological procreation mechanism for biomass. It is estimated that carbon stock in peat is approximately 330 billion short tons, representing about 13% of the total carbon resources on Earth.

Significant quantities of peat are consumed by the global horticultural and agricultural sectors 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 1992, the U.S. peat industry continued to be disrupted by a weakened domestic economy, regulatory constraints, the large-scale recycling of yard wastes and other natural organic materials, and record imports of Canadian sphagnum peat, peat mixtures, and other articles of peat. For the first time, Canadian peat imports surpassed U.S. domestic production and equalled domestic sales tonnage, f.o.b. U.S. plant.

Several entrepreneurial domestic peat firms capitalized on the abundance of recycled yard and animal wastes by selling blends of composted natural organic materials and peat. The utility of U.S. sphagnum peat in specialty value added applications also continued to generate new demand in the areas of oil sorption products and wastewater effluent treatment. Peat-based oil sorbents were accepted as environmentally friendly substitutes for clay sorbents in industrial and emergency cleanup applications in selected northeastern States and cities where clay has been banned from landfill disposal because of bulk, undesirable disposal economics, and potential health risks associated with clay dust containing crystalline silica. Minnesota's new sphagnum peat operations optimized capacity utilization and experienced improved competitiveness and profitability.

The Bureau's annual survey of domestic peat producers in the 48 contiguous United States reflected a 5% decline in production accompanied by the closure of 6 U.S. peat operations in the States of Florida, Michigan, Minnesota, Montana, New Jersey, and Wisconsin. An idle bog in North Dakota was reactivated during the year. Sales volume fell 7% to 0.7 million short tons, dropping the total value of producer sales to $16.7 million, f.o.b. plant, a decline of $1 million or 6% below the prior year. Idled and discontinued operations continued to liquidate stocks.

Alaskan peat production in the Fairbanks vicinity was estimated at 70,000 yards by personnel of the State Division of Geological and Geophysical Surveys, Fairbanks, AK. The Alaskan peat carried a value of about $400,000, or $5.71 per yard, representing a decrease of 5% in unit value compared to 1991. Peat production from the Anchorage area was not available for publication.

Canadian peat shipped predominately from the Provinces of Quebec and New Brunswick in eastern Canada and Alberta, Manitoba, and Saskatchewan in western Canada accounted for a record 50% of the total U.S. peat supply. Canadian import volume was a record 702,229 short tons and was valued at $110.6 million, equating to a new record price of $157 per ton at U.S. Customs. Another $19 million of Canadian finished peat products was declared at U.S. Customs.

The total U.S. peat supply was valued at $127 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 is estimated to be well in excess of $1 billion.

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 peat that are in compliance with Public Law 100-418, will begin to report bottom line totals in both metric units (metric tons, kilograms) and U.S. customary units (short tons, pounds). Volume measurements (cubic yards, cubic feet) will continue to be reported in U.S. units only. Comments on the Bureau's plan to gradually convert U.S. peat data to the metric system are welcomed and may be addressed to the author. *(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 97 peat operations surveyed in 1992, 71 were reported to be active, 21 were idle, and 5 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 and Geophysical Surveys, Fairbanks, AK. In 1992, operations in the Fairbanks area reported active production.

BACKGROUND

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 land mass, of which the United States ranks third in importance, eclipsed only by the large deposits found in the former U.S.S.R. and Canada.

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 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 saphric 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. Peat reserves are also found in about 10 Western States, of which active harvesting is known to occur in Colorado, Montana, North Dakota, and Washington. At current mining rates, the U.S. permitted reserve base estimate of 16 million tons could theoretically be depleted within the coming 20 years.

Large peat resources are protected by Federal and State agencies in a vast area known as the Great Dismal Swamp near the southeastern coast of Virginia, extending south into northeastern North Carolina. Vast peat resources are also found in the sensitive wetlands areas of North Carolina's Pamlimarle Peninsula, Pamlico River Basin, and along the South Carolina coast. Peat resources are also found along the east coast and southern regions of Georgia and along the U.S. Gulf Coast from Alabama to Texas.

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 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. This posture could change given that the Secretary of the Interior is currently formulating a proposed plan to conduct an extensive biological survey across the United States.

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

U.S. peat prices, without adjustment for inflation, have increased at an average annual rate of 5% per year over the past 22 years (1970-92). Prices expressed in terms of constant 1992 dollars, however, have declined at an average annual rate of about 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.

ANNUAL REVIEW

Legislation and Government Programs

The Environmental Protection Agency (EPA) issued final rules for Hazardous Waste Management; Liquids in Landfill, 40 CFR Parts 260, 264, 265, and 271. The rule was published in the Federal Register on November 18, 1992, and was to become effective on May 18, 1993. EPA's ruling addressed the final of three congressional requirements developed under the 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act (RCRA)—"landfill disposal of containerized liquids mixed with sorbents."

This rule satisfies the statutory requirement that EPA issue a rule prohibiting the disposal of liquids in "hazardous waste landfills" that have been sorbed in materials that biodegrade or that release liquids when compressed, as might occur during routine landfill operations, and is intended to ensure the stability of materials in "hazardous waste landfills."

The Assistant Surgeon General, U.S. Public Health Service, clarified several points relative to EPA's seemingly complicated ruling. It was emphasized that the rule prohibits only the "direct" landfilling in "hazardous waste" landfills of liquids that have been sorbed into "biodegradable" sorbents. Thus, the rule does not in any way prohibit or restrict the use of sorbents (organic or otherwise) to address wastes or products going to a nonhazardous waste landfill (e.g., municipal or nonhazardous waste industrial landfill). Furthermore, it does not affect the use of sorbents with hazardous waste that is not landfilled; for example, that is burned for energy recovery, incinerated, recycled, or treated through bioremediation or land treatment.

EPA, in its rulemaking, did not conduct tests on the degradation of organic sorbents in an anaerobic landfill environment. Also, EPA did not test and made no judgment on the efficacy of different sorbents, including organic sorbents, in spill situations. Factors like absorption and retention—important considerations in the performance of sorbents in responding to spills—lay outside the scope of the rulemaking.

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 Pamlimarle 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.

The Fish and Wildlife Service combined these lands with its adjacent 10,000-acre Pungo National Wildlife Refuge to form Pocosin Lakes National Wildlife Refuge. The development includes 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 Pamlimarle 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 1992 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 1992, 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 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.

Since 1987, U.S. domestic peat sales have declined 25%, apparent domestic consumption has fallen by 13%, and 21 U.S. peat operations have been closed. During the same period, imports of Canadian peat have increased 37%, and the U.S. import reliance has skyrocketed from 33% of total domestic consumption in 1987 to a record 52% in 1992.

About 55% of the decline in domestic peat production and sales was in the leading States of Florida and Michigan, but equally disturbing was the fact that about one-third of the loss was attributable to five States in mid-America (Iowa, Illinois, Indiana, Ohio, and Pennsylvania). Production in New Jersey has fallen 45% during the same period, while operations in California, Georgia, and Maryland have ceased altogether. Small operations in Maryland, New Jersey, and New York, for example, have been shut down for an indefinite period by various regulatory agencies.

In total, about 35 U.S. peat operations have been idled or have gone out of business since 1987. 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

Peat was harvested and processed by 71 operations in 20 States, excluding Alaska. Florida and Michigan produced about 64% of the U.S. total, followed by Minnesota with 6%. 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. Geographically, about 40% of the total U.S. peat output by weight was from four southeastern States; 35% from the Great Lakes region; the Midwest and Northeast, 10% each; and 5% from the Western States. The States of California, Georgia, and Maryland did not report production in 1992.

On a weight basis, reed-sedge peat was 60% of total U.S. production; humus, 23%; hypnum moss, 8%; sphagnum moss, 5%; and other forms, 4%. On a volume basis, the product distribution may be altered dependent upon variations in peat bulk density, from sphagnum moss at the low end of the scale, having a density of about 500 pounds per ton, to humus, having a bulk density of more than 1,000 pounds per ton. Thus, reed-sedge was 59% of production by volume; humus, 20%; sphagnum moss, 10%; hypnum moss, 9%; and other forms, 2%.

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. *(See tables 2 & 3).*

Domestic Operations.—Minnesota production and sales volume were each up 21% by weight in 1992, given better weather conditions and improved demand for quality sphagnum and reed-sedge peat products. During the year, eight producers were active, 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 $69 per ton, f.o.b. plant, threefold above the U.S. average.

Davidson Peat was harvesting reed-sedge peat from a 35-acre bog in Rice County, MN. Raw peat was extracted with a 4-cubic-yard swinghoe power shovel and stockpiled on-site. Following windrowing to effect drying and weathering, tractor-trailer rigs transported the peat to Davidson's processing plant at Kenyon, MN, near the town of Webster. Davidson sells fine milled bulk peat and peat-sand bulk blends. The firm, operating under county mining permits because peat harvesting permits were not available, was working with local officials to study the feasibility of introducing peat harvesting permits.

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), University of Minnesota 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.

Minnesota Sphagnum, Inc. (MSI) commenced sphagnum harvesting in 1987. The past 5 years has 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.

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.

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 was 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.

Michigan Peat is headquartered in Houston, TX, from which a $15 million annual business is coordinated. The firm 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. Michigan Peat products are marketed under the BACCTO and Garden • magic labels.

Hyponex Corp. harvested and processed reed-sedge peat from facilities in six States extending from New Jersey to Colorado. Hyponex markets peat and peat blends throughout much of the United States. The firm operates from parent headquarters, the O. M. Scott & Sons Co., in Marysville, OH. Scotts is a recognized leader in the lawn and garden fertilizer market.

Hyponex was also operating 12 organic composting process facilities and a like number of additional sites across the country that were open to receive yard trimmings in line with the national thrust by the EPA and municipalities to recycle waste materials that otherwise contribute significantly to landfills overloading. Waste collection firms contracted by various municipalities transfer natural organic yard waste materials such as leaves, grass, and hedge trimmings, which in turn are recycled into marketable compost materials. The composting/recycling approach has proven to be a win-win-win situation for municipalities, taxpayers, and the environment. Consumer demand for Hyponex organic products, such as Compost plus Organic Peat, Rich Dark Top Soil, and all purpose Potting Soil, ensure a steady market for composted yard trimmings. The firm believes that enough demand could be generated for its organic products to allow for recycling virtually all yard trimmings generated by the major metropolitan areas of the United States.

Domestic Projects.—New horticultural peat projects were reported to be under consideration in the States of Georgia, Maine, New Mexico, North Dakota, and possibly in North Carolina. Fisons Horticulture, Inc. verified the transfer of its peat bogs in Minnesota and Iowa to State regulatory agencies.

NorthWoods Organics, a new Duluth, MN, subsidiary of Faulks Brothers Construction Co., Inc. of Waupaca, WI, was developing a new sphagnum peat bog in St. Louis County, MN. NorthWoods Organics will provide technical support and new product development for Faulks Brothers in the area of organic products for commercial landscape and construction applications. The new 150-acre bog and processing facility were targeted for completion by late 1993.

Fuel Peat Projects.—Plans by EcoPeat Co.—a U.S. affiliate of the Finnish firm Outokumpu—to develop 360 megawatts of peat-fueled electrical powerplants in cooperation with south-central Florida utility companies were postponed indefinitely. Central Florida utilities have reportedly opted to build powerplants based on natural gas fossil fuel.

The Down East Peat LP peat-fueled powerplant at Cherryfield, ME, was purchased in early January 1993 under the provisions of a reorganization that involved the formation of Worcester Energy Co., Inc. and Worcester Peat Co., Inc. The energy company acquired the 22.8-megawatt biomass powerplant, ancillary buildings, equipment, and 20 acres of adjoining land. The peat company, in turn, purchased about 900 acres of the adjoining Denbow Heath peat bog. At full capacity, the powerplant will require about 165,000 tons of bone-dry peat annually.

Worcester Energy Co. closed the powerplant in mid-January 1993 pending negotiations of a proposed power contract with Bangor Hydro-Electric Co. in which Bangor was asked to pay $0.02 above the normal $0.03 per kilowatt-hour "avoided" rate. Bangor Hydro was required by law to purchase the plant's power at the avoided rate, the cheapest price that the utility would pay for additional electricity. The new firms projected a good harvest season on the bog and planned to bring the powerplant back on-line in June 1993.[7]

Down East Peat LP of St. Petersburg, FL, originally brought the $51 million peat-fueled powerplant on-stream in June 1989 under the provisions of a 20-year supply agreement with Boston Edison, but the owners were ultimately faced with the prospect of continuing losses and opted to allow the utility to buy its way out of the contract in mid-1992. The plant operated on a combination of woodchips and peat

depending upon the availability of peat. Former Down East Peat officials reported that the project could potentially become one of the more viable sources of power in the country were enough peat acreage available, given that peat can be harvested at a fraction of the cost of wood, oil, or coal. Down East Peat also cited technology problems, high transmission costs, and an oversupply of electricity in the northeast as other factors that had been detrimental to the project's success.

Humate Production.—Humates were mined from the San Juan Basin deposits in northwest New Mexico and sold primarily for use as soil conditioners and drilling mud additives. 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.

Humate and weathered coal occur in the Upper Cretaceous Fruitland, Menefee, and Crevasse Canyon formations in the San Juan Basin. All of these humate deposits—high in humic acid content—represent a facies in poorly drained swamps in nearshore deltaic and fluvial sequences accumulated during marine regression in the Cretaceous. Most humate occurrences consist of carbonaceous claystones rich in organic matter, or weathered coal ("leonardite"), having a high humic acid content.[8]

Humate is commonly associated with both coal and lignite. When associated with lignite, humate is called leonardite, after A. G. Leonard of the North Dakota State Geological Survey. Through use, the term leonardite has been informally expanded to include coal-derived humate. Humic acid-rich deposits also exist in Arkansas, Florida, Louisiana, New York, North Dakota, Michigan, Minnesota, Texas, and Wyoming.

Consumption and Uses

Demand for U.S. peat products in 1992 continued to mirror the relatively flat profile of the past few years, underscored by a general downturn in the U.S. economy and the importation of more Canadian peat and peat products. In 1992, domestic sales tonnage declined 7% from 1991 levels, while imported material rose by more than 11% and captured a record 50% of the total U.S. peat market.

Packaged peat commanded 56% of the domestic sales volume by weight in 1992 and was valued at a 59% premium relative to bulk forms, according to the U.S. Bureau of Mines annual survey. Approximately 90% of U.S. producer sales was for general soil improvement, horticultural use, and agricultural 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, for mushroom cultivation, oil absorption and wastewater filtration, and for use in hygienic products. Minor quantities of peat were used as fuel for electric power generation.

One major challenge facing U.S. mushroom growers, according to the U.S. Department of Agriculture (USDA), arises when other natural organic products are substituted for peat as a growing medium. The storage and disposal of the natural organic peat substitutes can reportedly lead to environmental problems, not just for growers but for their nonfarm neighbors as well. *(See tables 4 and 5).*

Stocks

In 1992, primary producer peat stocks did not vary significantly from prior year levels and stood at about 0.3 million tons at yearend, according to the Bureau's annual survey of domestic peat producers. Producer peat stocks in all forms were about 50% of production, typical of the industry. Reed-sedge peat accounted for about 60% of total stocks by weight. *(See table 6).*

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.

Lindqvist Business Development Corp. of Minnetonka, MN, was evaluating the feasibility of the CARGO 2000, an innovative side dumping trailer developed by BURE VERKSTADS A.B. of Sweden for tractor-trailer or rail transport of peat, woodchips, beet pulp, and other bulk materials. During unloading, the roof, floor, and one side of the trailer are raised hydraulically. The lifting action of the floor and side wall will break up the cargo as it is dumped from the trailer, allowing even frozen cargo to be safely unloaded at rates in excess of 90 cubic yards per minute.

Markets and Prices

Domestic peat prices averaged $23 per ton f.o.b. plant in 1992, relatively unchanged from the prior year. Packaged peat was quoted at a premium $28 per ton compared with $18 for bulk peat; however, packaged forms captured about 56% of the total sales tonnage. Sphagnum moss sold at a premium $81 per ton, about 3 1/2-fold above the national average. *(See table 7).*

Foreign Trade

The United States has shipped minor quantities of peat offshore averaging about 20,000 tons per year over the past 4 years. In 1992, the U.S. peat industry exported 24,000 tons to 22 countries that was valued at $2.1 million f.a.s., or about $85 per ton. Mexico, Saudi Arabia, Canada, the United Arab Emirates, and Argentina, in order of importance, accounted for 86% of the

total.

In 1992, 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 702,000 short tons, roughly 50% of the total U.S. peat supply, and carried a U.S. Customs value of $110.6 million, equating to $158 per ton. The value of Canadian shipments at the U.S. border exceeded total U.S. domestic peat sales, f.o.b. plant, by more than 560%. Another $19 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 10.2% was imposed by Canada on U.S. peat in 1992. The United States exported a minuscule 2,000 tons of peat to Canada in 1992, valued at $164,000 or $82 per ton, according to U.S. Department of Commerce trade statistics. Under terms of the United States-Canadian Free Trade Agreement, the Canadian tariff on U.S. peat was to be removed effective January 1, 1993. A Canadian duty of 3.4% is currently imposed on U.S. "Articles of Peat," down from a maximum of 6.8%. This duty is scheduled to be gradually phased out at a rate of 10% per year over the next 10 years. The U.S. Bureau of Mines could not find a record for U.S. articles of peat export shipments in the U.S. Department of Commerce trade data base.

The United States accounted for roughly 90% of total Canadian export shipments in 1992. About 70% of the total was shipped from central and Atlantic Canada and the remaining 30% from western Canada. Officials of Energy, Mines and Resources Canada in Ottawa, Ontario, reported that Canada's improved performance in the United States was largely attributable to a greater visibility brought about by an intensive national promotional campaign, together with more aggressive marketing by Canadian producers.[9] Canada typically exports between 75% to 80% of its total peat shipments. *(See table 8).*

Energy, Mines and Resources Canada reported that about 75% of all Canadian shipments in 1992—domestic and export—originated from Quebec and New Brunswick in eastern Canada. Alberta, in western Canada, supplied about 10% of the total. The remaining 15% was reported to originate principally from Manitoba and Saskatchewan in western Canada, with minor contributions from the eastern Provinces of Nova Scotia and Newfoundland.

World Review

After peaking at 221 million tons in 1989, global production is estimated to have declined by 58 million tons to current levels, representing a drop of more than 26%. The major decline can be traced to the former U.S.S.R., where U.S. Bureau of Mines production estimates indicate that production has fallen about 57 million tons or 29% during the period cited.

In 1992, global peat production declined to 160 million short tons (10%), principally because of continuing geopolitical events in the former U.S.S.R. The centrally planned economy of the former U.S.S.R. was replaced by 15 independent republics during the year, and the political and socioeconomic reforms of the recent past intensified. Finland rebounded from a poor harvest year in 1991 to near record levels of 6 million tons in 1992. Production in all other countries was believed to be comparable to 1991 levels with the exception of Ireland, which should recover somewhat from a poor harvest year. The total value of world peat production, assuming an average f.o.b. plant value of $30 per ton, was about $5 billion.

Ireland and Finland, in order of importance, accounted for about 63% of the estimated 21 million tons of peat produced outside the former U.S.S.R. in 1992. 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. Germany provided 16% of global production outside the former U.S.S.R.; Sweden, 9%; Canada and the United States, 8%; and other countries, 4%.

Although peat was known to be deposited in the United Kingdom, tropics of Africa, Argentina, Brazil, China, Indonesia, Malaysia, New Zealand, Paraguay, and Uruguay, production data were not available. *(See table 9).*

Industry Structure.—The former U.S.S.R. was estimated to account for about 87% of global peat production in 1992, followed by Ireland and Finland, 4% each; Germany, 2%; Sweden, 1%; the United States and Canada, 1%; and all other countries, 1%.

Canada.—Energy, Mines and Resources, Ottawa, Ontario, reported that the total area of peatlands in Canada is estimated at 111 million hectares (275 million acres) covering approximately 12% of the country's surface. Canada produces sphagnum peat for the most part typically from May to September, primarily in the eastern and southeastern parts of the Province of Quebec, in the eastern and northeastern parts of the Province of New Brunswick, and in the western Provinces near Edmonton, Alberta; Carrot River, Saskatchewan; and Giroux and Elma, Manitoba. Some peat production is also found in the Provinces of Nova Scotia, Prince Edward Island, and Newfoundland. Canada's massive peat resources can probably be harvested for centuries.

Production from about 77 operations declined about 13% in 1992 owing principally to bad weather in Quebec. Shipments—predominately for export—rose, indicative of inventory liquidation from the prior year. Production increased 58% in Nova Scotia, 20% in Manitoba, and 3% in New Brunswick. Production was down 49% in Newfoundland, 16% in Saskatchewan,

7% in Alberta, and 40% in Quebec. Production figures are confidential for the Provinces of Manitoba, Nova Scotia, and Saskatchewan.

Two new operations were opened or under development in New Brunswick in 1992 near Shediac and Acadieville, respectively. Tourbières Premier Enterprises Ltd., a subsidiary of the important Canadian peat producer Premier CDN, was opening the bog at Acadieville. A new bog was also opened and harvested in New Brunswick by Berger Mix Inc. at Bay-au-Vent, and plans were developed by Le Groupe Qualite' Lamèque Ltèe to put a plant in place in 1993 that will produce peat-based mixes. Fafard et Frères Ltd. increased its activity at Sainte-Marguerite, Quebec, to respond to a growing demand for Johnson and Johnson Inc's. new sanitary napkins. Peat was harvested in blocks and, as such, was unaffected by the bad weather conditions that prevailed in Quebec during the summer and fall of 1992.

The United States and Japan were Canada's principal export targets, in respective order of importance. A 1990 study supported by the Canadian Embassy in France indicates that substantial quantities of peat could be sold to France and eventually to other European countries if producers took full advantage of backhauling to reduce freight costs.[10]

The Newfoundland and Labrador Peat Association, in cooperation with many other Canadian agencies, was to hold an international peat conference—Newfoundland Peat Opportunities—in the fall of 1993. The conference was to examine the current situation in Newfoundland and around the world, identify barriers to development, and formulate a plan of action aimed at appropriate development of the province's peat resources. The island of Newfoundland is blessed with more than 1 million hectares (2.5 million acres) of peatlands. These deposits represent a largely untapped natural resource offering significant business development opportunities. The resources of Labrador, while yet to be quantified, are likely to offer far greater potential.

Finland.—In 1992, Finland's peat production totaled 21.5 million cubic meters (28.2 million cubic yards) representing an increase of 115% compared to 1991, when production declined significantly owing to inclement weather. This production was very near to the alltime production record established in 1986. Milled fuel peat production was 18.5 million cubic meters, 86% of the total, and sod fuel peat 1.4 million cubic meters, or 6.5%, bringing total fuel peat to 92.5% of total production. Horticultural peat was 1.6 million cubic meters, or 7.5% of total production.[11]

Peat production in Finland was very small in 1970, but grew to about 3 million cubic meters by 1975 and to a record of about 22 million cubic meters by 1986.[12] The potential for utilization of fuel peat in Finland is currently about 30% above actual use and is projected to potentially more than double during the next 10 to 15 years.[13]

Former U.S.S.R.—The peat resources in the former U.S.S.R. are commonly referred to as the largest in the world, and more than 90% are found in Russia. The total area of peatland in the former U.S.S.R. is about 80 million hectares, and the quantity is 200 to 250 billion metric tons at 40% moisture. The western Siberian plain is a vast peatland covering about 30 million hectares with a resource base in excess of 100 billion metric tons. The world's largest deposits lie here with Vasyugaskoe alone having an area of 5 million hectares containing about 10 billion metric tons of peat. The resource has been extensively exploited for fuel use for more than 50 years.[14]

Production was confined to the Baltic Republics, the Moscow-Gor'kiy area, Belarus, and the Ukraine, although peat was known to be deposited throughout much of the country. Peat was burned in thermal powerplants in the European Republics and was also used to fire industrial boilers and large heating plants.

The use of peat in the former U.S.S.R. was reportedly declining because of insufficient reserves in the primary consuming areas around Moscow and St. Petersburg 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.[15]

Changes have caused extensive restructuring in the various new republics that, in turn, have created a number of alterations in the membership structure of the International Peat Society (IPS). In June 1992, the IPS Council meeting in Uppsala, Sweden, resulted in the approval of membership applications from the Russian National Committee and the Belorussian Peat Society. The Ukrainian company "Ukrtorf" (Ukrainian Peat) was accepted as a collective member of the IPS. Earlier, in a meeting at The Hague, The Netherlands, the IPS Council approved Estonia's application. Latvian Peat and the Lithuanian Peat Society from Lithuania were also approved as collective members.

The entry of major producing regions from the former U.S.S.R. was warmly greeted by the IPS Council. Estonia has already reported detailed peat information, and expectations were that comprehensive information would soon be available from IPS members in other areas of the former U.S.S.R.

Estonian officials reported that in 1992 a total of 6.1 million cubic meters of peat was produced, of which 4.0 million cubic meters (66%) was horticultural peat and 2.1 million cubic meters (34%) was peat fuel. Estonia exported 111,000 metric tons of peat, representing a volume of about 555,000 cubic meters. Peat was harvested from an area of 14,000 hectares. Estonian peat resources were reported to cover about 1 million hectares.[16]

In the Ukraine, annual agricultural peat use dropped sharply between 1991 and 1992, from 18 million annual metric tons to just less than 5 million annual tons. Fuel use has remained level at about 2 million tons of dried peat, about 50% of which was used to produce briquettes in about 20 factories.

In Belarus, fuel peat production was reported to be about 2 million tons,

almost all in the form of briquettes. Lithuania has only three small briquette plants with a total annual capacity of 20,000 tons.[17]

Ireland.—In the fiscal year ending March 25, 1992, Ireland's Bord na Móna peat production fell owing to inclement weather conditions, but, most importantly, the sales volume was up and profitability reached an alltime high. These positive results were a reflection of the success of a major reorganization effected in 1988.[18]

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.

A reorganization in 1988 established four core business divisions. The largest of the new divisions is the Peat Energy Division, which is responsible for milled peat operations, with sales accounting for about 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. Gains in productivity have reached a point where milled peat costs are becoming more competitive in terms of world energy prices. The Division decided to conduct a prefeasibility study for a new 125-megawatt peat-fired power station that could take advantage of recent advances in technology.

The Solid Fuels Division is responsible for the production and sales of "briquettes and machine turf." The outlook for solid fuels 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. In the recent fiscal year, the Division registered a significant improvement through the development of a capacity rationalization program that will ultimately result in the closure of the Lullymore Briquette Factory in County Kildare in 1992-93.

The Horticultural Products Division 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 Dutch 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. Shamrock Horticulture, a wholly owned subsidiary, was processing peat at a new plant in Liverpool. A new composting plant was successfully commissioned at Liverpool during the year in response to a growing trend in consumer preference for blended products (fertilizer and other).

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, 3,400 hectares of boglands will be protected in accordance with Government policy.

Netherlands.—In the 11th and 12th centuries fuel peat cutting in the bogs was practiced throughout the country, and by the 15th and 16th centuries, peat production was also active in the lowmoor deposits. Not only was the landscape radically changed and land reclamation commenced, but also extensive lakes were formed, which today contribute to the beauty of the surrounding countryside. After World War II, demand for fuel peat had been reduced to the small-scale production of activated carbon.

Sphagnum peat moss began to be harvested by 1880, and many mills were founded in the east of the country and in the neighboring German peat areas, where Dutch producers bought bogs. The peat moss industry flourished until the end of World War I, when there were large-scale exports of sphagnum peat moss litter to Belgium, England, France, and many other countries.

Peat production in the Netherlands today is essentially nonexistent. There are still a few state-owned bogs reserved for conservation, and a few thousand hectares of boglands is managed by environmentalists. Demand continues to grow, however, and in addition to traditional black peat imported from Germany, supplies continue to increase from Scandinavian countries, the Baltic States, Ireland, and Russia. Canada may also become a future supply source.[19]

Sweden.—The 9th International Peat Congress, "Peat in Nature and Industry—a Matter of Balance," was held in Uppsala, Sweden, June 22-27, 1992, under the auspices of the Swedish National Committee of the International Peat Society. Approximately 308 representatives from 26 countries attended the Congress, and 141 papers were presented by a global spectrum of noted peat scientists during the Congress proceedings. The Congress proceedings were published in three volumes and may be obtained from International Peat Society headquarters in Jyskä, Finland.[20]

In 1992, Sweden was producing about 1 million cubic meters of horticultural peat and about 3 million cubic meters of fuel-grade peat, annually. Swedish peatlands were reported to cover an area of about 6.3 million hectares (15.6

million acres), or about 15% of the total land area. About 865,000 acres of peatland was available for fuel peat production. The overall area suitable for horticultural peat production has not yet been surveyed.

Sweden currently 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.[21]

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.

Unfortunately, the Government's philosophy regarding Swedish fuel peat and peatland research has changed during the past 3 years. Environmental and ecological concerns have apparently dampened further progress in fuel peat output. So far, fuel peat has been taxed based on sulfur dioxide and nitrogen oxide emissions. The Swedish Peat Producers Association recent promotional activities have again generated moderate optimism by Government agencies.

United Kingdom.—A private consortium of peatland conservationists, called the Commission of Inquiry into Peat and Peatlands, held three public hearings between September 29, 1991, and November 27, 1991, two at the Natural History Museum, London, and another in the Council Chamber, Strathclyde Regional Council in Glasgow, Scotland. The commission was concerned primarily with the conservation of lowland raised bogs, because this was identified as the most immediately and seriously threatened of peatland types in the United Kingdom. The commission also expressed concern for the conservation of blanket bogs, fens, and other British peatlands, but considered this issue to merit separate consideration.

The commission reached several important conclusions and recommendations. Current data suggested that there was 1,421,194 million hectares of "blanket boglands" in England, Wales, and Scotland; 10,060 hectares of "intermediate bog," and 67,058 hectares of "lowland raised bog." The best available scientific evidence suggested that the maximum area of natural, undamaged raised bog remaining in the United Kingdom was less than 6,200 hectares, 10,000 hectares in Great Britain. The predominate reduction resulted from forestation and conversion of peatlands to agricultural use.

It was recommended that Country Conservation Councils: English Nature, the Countryside Council for Wales, Scottish Natural Heritage, and the Department of the Environment (Northern Ireland) should adopt a rigorous policy to protect raised bogs and rehabilitate damaged bogs where necessary. The commission also stressed the use of alternative natural organic composts.[22]

Current Research

Peat research continued at a rapid pace during 1992, and many projects were reaching commercial fruition. Commercial ventures were established to produce and market peat-based oil sorbent 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, management control of urban stormwater, elimination of offensive odors, and as a superior bulking agent in the composting of natural organic waste products.

The NRRI, at Duluth continued to provide technical assistance to Mat Inc., a Floodwood, MN, peat firm that produced peat sorbents for D M S & D Associates, Inc. of Ocean, NJ, and Fisher Steven Inc. NRRI researchers reported that additional sorbent products were in the development stage, including peat-based socks, booms, and wood fiber pads. Mat Inc. was already receiving orders for the new products although NRRI had just begun to identify tooling requirements for production.

According to a recent NRRI study, sorbents manufactured from the higher density, more decomposed Minnesota peats carry an optimal unit value that gives Minnesota product more than a twofold competitive transportation cost advantage over Canadian sorbents. NRRI researchers also reported that properly dried and processed Minnesota sphagnum peat performs as well or better than Canadian peat and surpasses clay, paper, sawdust, and corn. All peats tested were reported to exceed clay-type sorbents.[23]

During 1992, a 2-year commercial-scale turkey litter waste management project was initiated between NRRI, the Agriculture Utilization Research Institute (AURI), and Langmo Farms of Litchfield, MN, in association with Minnesota Technology, Inc. and Howe Chemical. Best waste management practices must be developed given that Minnesota is the second largest turkey producer in the United States with about 46 million birds generating about 1 million tons of manure annually, in concert with new environmental regulations formulated by the Minnesota Pollution Control Agency (PCA) placing limitations on manure application rates.

Traditionally, farmers have tilled turkey droppings into wood shavings litter that remain in the barn with the birds throughout the year. Heavy applications of turkey manure to agricultural lands can lead to an excessive buildup of fertilizer nutrients that may lead to serious water quality problems. A novel feature of the landmark research was to incorporate turkey-friendly and environmentally sound sphagnum peat, oat, and sunflower hulls with the traditional wood shavings litter. Peat is used in the litter to maintain low ammonia and odor levels and to control micro-organisms that can cause disease in the birds. Additionally,

sphagnum peat is low in dust—beneficial to the birds' health—and provides a low pH and high nitrogen content; ideal conditions for producing high-quality compost for horticultural applications.

In addition to high waste litter production levels and avoidance of PCA violations, the project should provide a new commercial horticultural substrate product outlet for turkey farmers. Howe Chemical planned to collect 1,000 tons of composted turkey litter produced during the project to manufacture and test market an organic-based, premium-grade lawn and garden fertilizer and a low-grade organic agricultural fertilizer. Howe planned to be at the test market stage by late 1993.[24]

Michigan Peat Co. of Houston, TX, developed a unique compacted peat that served as a natural potting soil additive, providing improved aeration and drainage. Michigan peat representatives said that its particle size could be tailored to individual needs, while maintaining integrity and resistance to breakdown during watering cycles.

D M S & D Associates, Inc. developed and test marketed a unique hydrophobic sphagnum peat moss product having superior hydrocarbon sorption properties. The firm reported that 1 pound of the product would effectively sorb 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 importance.

In addition to its unique hydrocarbon sorbent 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 micro-organisms 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.

State transportation agencies in the northeastern United States, where clay sorbents have been banned, found that peat sorbents represent an environmentally friendly and economically viable clay substitute. In one northeastern State where clay has been banned since 1990, it was found that the use of peat sorbents was advantageous to employee health, represented indirect cost savings via disposal and less bulk, avoided landfills, and could be consumed in industrial fuel applications.

Several domestic and foreign parties continued to be interested 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.[25] 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.[26]

STS Consultants, Ltd., Minneapolis, MN, continued to develop a unique peat wetlands treatment approach to acidic mine drainage abatement. 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 was 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.[27]

The Department of Environmental Programs, Metropolitan Washington Council of Governments, was developing peat-sand filter systems for stormwater management in the Anacostia River Basin. The River Terrace Peat-Sand Filter Project, situated on a 155-acre drainage area in the District of Columbia, was under contract for completion by late 1993. Engineering was underway for the Hollywood Branch Peat-Sand Filter Project in Montgomery County, MD, scheduled for construction beginning in the fall of 1994.[28]

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.[29]

Johnson & Johnson (J&J) successfully marketed 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. The product was developed by the company's Montreal-based Canadian unit.[30]

MULTITEK of Prentice, WI, introduced a modular system designed to separate and pulverize peat and other natural materials to desirable marketable consistency at rates up to 150 tons per hour. The unique tumbler screen rotates the material while 32 hammers pulverize

to produce unequalled productivity. The system is totally portable and is hydraulically powered, permitting variable adjustment to peak performance speeds. This machine was reported to outperform a typical vibrator screen system. A portable unit was available that could be towed at highway speeds with a 1-ton truck. In addition to peat, the system can handle top soil, sand and gravel, compost, grade rock, composted manure, clay, woodchips, bark, coal, and composted sewage sludge.

Enviro Industrial Technology Corp. (E.I.T.C.) of Alberta, Canada, developed a novel line of peat harvesting and wetlands transport equipment. The products currently developed include a Field Profiler, Root Picker, Spoon and Rotary Harrow, Chain Miller, Ditcher, Vacuum Harvester, and Transport Wagons. E.I.T.C.'s equipment was designed to meet the rigorous durability demands associated with high production rates and low maintenance costs expected by the North American peat industry.

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.[31]

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.[32]

Peat also showed promise as a biodegradable medium in disposable diapers and in food packaging.

OUTLOOK

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 an 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 millon tons in 1987.

Between 1987 and 1992, 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 50% in 1992.

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.[33]

In December 1992, USDA officials were cautiously optimistic about near-term 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, dependent upon the fate of the U.S. economy. Mr. Doyle C. Johnson, an agricultural economist with USDA, in speaking before the Annual Agricultural Outlook Conference in Washington, DC, stated: "As the economy slowly improves, consumer demand for flowers and plants will accelerate. The 1993 Greenhouse/Nursery industry outlook for consumer expenditures and producer receipts is for a gradual, renewed expansion at a more moderate rate than the rapid expansion of the 1980's. For 1993, the Gross Domestic Product is forecast to grow 3.1% which projects to an 8% growth in retail Greenhouse/ Nursery product sales to nearly $44 billion ($170 per capita)."

The U.S. Bureau of Mines forecast for horticultural peat during the next 5 years is based on a gradual 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 2% to levels approaching 0.8 million tons by 1997.

Total apparent domestic consumption for horticultural purposes is forecast to grow at an average annual rate of about 4% per year to about 1.6 million tons by 1997. Canadian imports are forecast to rise from a current 50% of the U.S. supply to about 55% by 1997. Per capita consumption is forecast to approximate 12.5 pounds by 1997 and 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. However, 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 future 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 in recent years. 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.[34] 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.[35]

The global outlook for peat supply-demand is shown in table 10. Last year's outlook for balanced supply-demand conditions, long-range, has been clouded by the continuing downturn in former U.S.S.R. production. If the projected downturn only impacts the internal supply-demand situation, then the rest of the world should still anticipate reasonably balanced conditions during the next 5 years. If the former 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 10).*

The U.S. Bureau of Mines basic forecast methodology has been modified to include the assumption that peat production in the former U.S.S.R. will not return to 1990 levels in the foreseeable future. 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 1992 and 1997, 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

		1988	1989	1990	1991	1992
United States:						
Number of active operations		88	80	82	76	71
Production	thousand short tons	844	761	763	697	660
Sales by producers	do.	908	775	795	r775	719
Bulk	do.	457	384	397	r384	317
Packaged	do.	451	391	398	391	402
Value of sales	thousands	$20,320	$17,703	$19,200	r$17,773	$16,747
Average per short ton		$22.37	$22.84	$24.16	r$22.94	$23.30
Average per short ton, bulk		$18.14	$18.98	$17.76	r$18.35	$17.52
Average per short ton, packaged or baled		$26.67	$26.63	$30.53	$27.45	$27.86
Exports	thousand short tons	NA	33	13	14	24
Imports for consumption	do.	590	530	599	632	704
Consumption, apparent[1]	do.	1,468	r1,303	r1,358	r1,379	1,351
Stocks, December 31: Producers'	do.	447	402	393	329	340
World: Production	do.	r215,839	r220,864	r197,989	r182,150	e163,088

eEstimated. pPreliminary. rRevised. NA Not available.

[1]Apparent consumption equals U.S. primary production plus imports minus exports plus adjustments for industry stock changes.

TABLE 2
RELATIVE SIZE OF PEAT OPERATIONS IN THE UNITED STATES

Size in short tons per year	Active operations		Production (thousand short tons)	
	1991	1992	1991	1992
25,000 and over	9	7	355	325
15,000 to 24,999	10	9	183	169
10,000 to 14,999	4	6	49	67
5,000 to 9,999	7	8	46	59
2,000 to 4,999	14	8	45	21
1,000 to 1,999	7	9	8	11
Under 1,000	25	24	10	8
Total[1]	76	71	697	660
Total metric tons	XX	XX	632	599

XX Not applicable.

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

TABLE 3

U.S. PEAT PRODUCTION AND SALES BY PRODUCERS IN 1992, BY STATE

State	Active operations	Production	Sales		
		Quantity (thousand short tons)	Quantity (thousand short tons)	Value[1] (thousands)	Percent packaged
Colorado	4	W	W	$333	62
Florida	9	238	211	3,158	18
Illinois	4	W	W	W	96
Indiana	5	W	27	512	60
Iowa	2	W	W	W	96
Maine	2	W	W	W	—
Massachusetts	1	W	W	W	100
Michigan	11	187	199	5,894	78
Minnesota	8	39	40	2,764	42
Montana	1	W	W	W	—
New Jersey	2	W	W	W	97
New York	2	W	W	W	—
North Carolina	1	W	W	108	100
North Dakota	1	W	W	W	16
Ohio	3	W	W	W	—
Pennsylvania	7	16	16	250	34
South Carolina	1	W	W	W	85
Washington	3	W	W	W	—
West Virginia	1	W	W	W	—
Wisconsin	3	W	62	553	94
Total[2] or average	71	660	719	16,747	56
Total metric tons	XX	599	652	XX	XX

W Withheld to avoid disclosing company proprietary data; included in "Total or average." XX Not applicable.

[1]Values are f.o.b. producing plant.

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

TABLE 4

U.S. PEAT SALES BY PRODUCERS IN 1992, BY TYPE AND USE

Use	Sphagnum moss			Hypnum moss			Reed-sedge		
	Quantity		Value (thousands)	Quantity		Value (thousands)	Quantity		Value (thousands)
	Weight (short tons)	Volume[1] (cubic yards)		Weight (short tons)	Volume (cubic yards)		Weight (short tons)	Volume (cubic yards)	
Earthworm culture medium	533	1,060	$11	—	—	—	1,604	3,008	$95
General soil improvement	34,773	147,278	3,226	6,998	17,195	$466	255,613	538,384	6,405
Golf courses	800	2,000	12	1,000	2,000	18	9,389	21,243	219
Ingredient for potting soils	—	—	—	2,090	4,180	85	114,246	221,458	1,595
Mixed fertilizers	—	—	—	—	—	—	15,000	30,000	285
Mushroom beds	—	—	—	—	—	—	1,250	2,318	23
Nurseries	6,527	30,023	454	1,162	4,525	41	29,724	60,529	557
Packing flowers, plants, shrubs, etc.	1,276	6,074	211	25	50	1	180	300	2
Seed inoculant	—	—	—	—	—	—	22,000	44,359	191
Vegetable growing	—	—	—	700	1,400	11	199	400	7
Other	6,650	21,600	178	—	—	—	50,000	102,564	420
Total[2]	50,559	208,035	4,092	11,975	29,350	621	499,205	1,024,563	9,799
Total metric tons	45,866	XX	XX	10,864	XX	XX	452,871	XX	XX

Use	Humus			Other			Total[2]		
	Quantity		Value (thousands)	Quantity		Value (thousands)	Quantity		Value (thousands)
	Weight (short tons)	Volume (cubic yards)		Weight (short tons)	Volume (cubic yards)		Weight (short tons)	Volume (cubic yards)	
Earthworm culture medium	824	1,574	$10	—	—	—	2,961	5,642	$115
General soil improvement	38,851	70,701	502	—	—	—	336,235	772,928	10,600
Golf courses	4,140	7,292	173	—	—	—	15,329	32,535	422
Ingredient for potting soils	66,497	121,385	980	—	—	—	182,833	347,023	2,659
Mixed fertilizers	600	1,000	20	—	—	—	15,600	31,000	305
Mushroom beds	—	—	—	—	—	—	1,250	2,318	23
Nurseries	2,686	5,172	65	—	—	—	40,099	100,249	1,117
Packing flowers, plants, shrubs, etc.	800	1,500	10	—	—	—	2,281	7,924	223
Seed inoculant	—	—	—	—	—	—	22,000	44,359	191
Vegetable growing	428	856	11	—	—	—	1,327	2,656	29
Other	18,000	30,000	180	24,176	24,176	$284	98,826	178,340	1,063
Total[2]	132,826	238,850	1,950	24,176	24,176	284	718,741	1,524,974	16,747
Total metric tons	120,498	XX	XX	21,932	XX	XX	652,031	XX	XX

XX Not applicable.

[1]Volume of nearly all sphagnum moss was measured after compaction and packaging.

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

TABLE 5
AVERAGE DENSITY OF DOMESTIC PEAT SOLD IN 1992

(Pounds per cubic yard)

	Sphagnum moss	Hypnum moss	Reed-sedge	Humus	Other
Bulk	633	803	1,009	1,086	2,000
Packaged	444	824	954	1,159	—
Bulk and packaged	486	816	974	1,112	2,000

TABLE 6
U.S. PEAT PRODUCTION AND PRODUCERS' YEAREND STOCKS IN 1992, BY KIND

Kind	Active operations	Production (short tons)	Percent of production	Yearend stocks (short tons)
Sphagnum moss	15	32,781	5.0	38,525
Hypnum moss	8	52,866	8.0	40,300
Reed-sedge	33	396,769	60.1	207,036
Humus	21	153,121	23.2	53,981
Other	2	24,692	3.7	—
Total	[1]71	660,229	100.0	339,842
Total metric tons	XX	598,950	XX	308,300

XX Not applicable.
[1]Data do not add to total shown because some plants produce multiple kinds of peat.

TABLE 7
PRICES[1] FOR PEAT IN 1992

(Dollars per unit)

	Sphagnum moss	Hypnum moss	Reed-sedge	Humus	Other	Average
Domestic:						
Bulk:						
Per short ton	27.45	24.00	17.31	17.31	11.75	17.52
Per cubic yard	8.69	9.64	8.74	8.74	11.75	9.08
Packaged or baled:						
Per short ton	102.48	68.62	21.05	9.77	—	27.86
Per cubic yard	22.77	28.27	10.04	5.66	—	12.26
Average:						
Per short ton	80.94	51.89	19.63	14.68	11.75	23.30
Per cubic yard	19.67	21.17	9.56	8.17	11.75	10.98
Imported, total, per short ton[2]	157.31	XX	XX	XX	XX	157.31

XX Not applicable.
[1]Prices are f.o.b. plant.
[2]Average customs value.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF PEAT MOSS, BY COUNTRY[1]

Country	1991		1992	
	Quantity (short tons)	Value[2] (thousands)	Quantity (short tons)	Value[2] (thousands)
Canada	630,903	$95,684	702,229	$110,588
Denmark	6	5	—	—
Ireland	421	35	1,022	63
United Kingdom	419	152	—	—
Other[3]	96	257	763	98
Total[4]	631,845	96,132	704,013	110,749
Total metric tons	573,200	XX	638,670	XX

XX Not applicable.

[1]Poultry and fertilizer grade.

[2]Customs value.

[3]Includes Australia, Cameroon, Finland, France, Germany, Hong Kong, Japan, the Netherlands, Sweden, Switzerland, the U.S.S.R. (dissolved in Dec. 1991), and Vatican City.

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

Source: Bureau of the Census.

TABLE 9

PEAT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1988	1989	1990	1991	1992e
Argentina: Agricultural use	3	3	e3	e3	3
Australia e	3 4 11	12	12	12	12
Burundi	19	16	13	r11	11
Canada: Agricultural use	811	895	789	840	945
Denmark: Agricultural use (sales)	55	e55	121	e110	110
Finland:					
Agricultural use	358	497	r e360	r243	4391
Fuel	4,133	5,060	r e4,960	r2,544	4 5,625
France: Agricultural use e	220	220	220	220	220
Germany: Western states:					
Agricultural use	r2,941	r3,126	r3,288	r3,170	3,200
Fuel	r255	256	262	r e250	230
Hungary: Agricultural use e	77	77	70	70	70
Ireland:					
Agricultural use	332	293	253	e274	330
Fuel	4,473	8,557	7,088	5,255	6,830
Israel: Agricultural use e	r—	r—	r—	r—	—
Netherlands e	330	330	330	e330	330
Norway: e					
Agricultural use	33	33	33	33	33
Fuel	1	1	1	1	1
Poland: Fuel and agricultural use e	220	220	220	220	220
Spain e	4 83	83	77	77	77
Sweden: e					
Agricultural use	250	4 250	280	4 290	290
Fuel	1,100	4 1,600	1,500	1,500	1,500
U.S.S.R.: 5					
Agricultural use e	180,000	180,000	165,000	155,000	132,000
Fuel	19,290	18,519	12,346	e11,000	10,000
United States:					
Agricultural use	844	761	763	r697	4 660
Fuel	—	—	W	W	W
Total	r215,839	r220,864	r197,989	r182,150	163,088
Fuel peat included in total	r29,472	34,213	r26,377	r20,770	24,406

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]Table includes data available through June 21, 1993.

[2]In 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.

[3]Excludes data from some States.

[4]Reported figure.

[5]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

TABLE 10
WORLD PEAT SUPPLY-DEMAND RELATIONSHIPS[1]

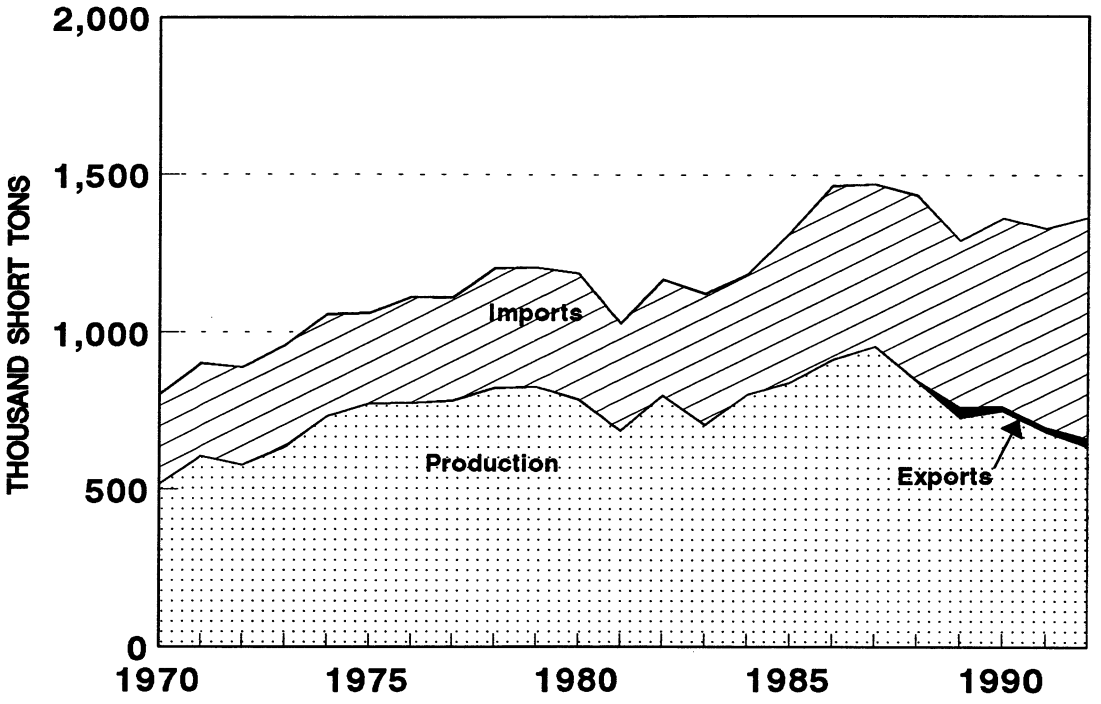
(Million short tons)

	1987	1988	1989	1990	1991	1992[e]	1993[2]	1994[2]	1995[2]	1996[2]	1997[2]
Capacity[3]	218.8	218.8	218.8	219.8	220.0	220.0	220.5	220.8	221.0	221.5	222.0
Demand:											
Agricultural	185.5	r186.3	r186.5	r171.6	r161.4	138.7	140.2	143.6	148.7	154.7	161.5
Fuel	23.0	29.5	34.2	r26.4	r20.8	24.4	24.8	25.4	26.3	27.3	28.5
Total	208.5	r215.8	r220.9	r198.0	r182.2	163.1	165.0	169.0	175.0	182.0	190.0
Operating rate, percent[4]	95	99	101	90	83	74	75	77	79	82	86
Consumption pounds per capita[5]	83.4	84.6	85.0	74.7	67.5	59.3	58.9	59.3	60.3	61.7	63.3
Population, billion[6]	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0

[e]Estimated. [r]Revised.
[1]Calendar years.
[2]Forecast.
[3]Effective production capability.
[4]Total demand as a percent of capacity.
[5]Peat demand expressed in pounds per person.
[6]Statistical Abstract of the United States, 1992; 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



PHOSPHATE ROCK

By David E. Morse

Mr. Morse, a Supervisory Physical Scientist with 16 years of U.S. Bureau of Mines experience, has been the acting phosphate rock specialist since May 1992. Domestic survey data were prepared by Christopher Lindsay, mineral data assistant; and the international data table was prepared by Jeremy Tidwell, international data coordinator.

Domestic and world production of phosphate rock decreased 2% and 4%, respectively, compared with output in 1991. World phosphate rock trade decreased to less than 30 million metric tons from the nearly 34 million tons traded in 1991; U.S. phosphate rock exports decreased from 5.1 million tons to 3.7 million tons primarily because of decreased consumption in Western Europe and the loss of exports to Mexico.

The historic events of recent years that include the restructuring of the former U.S.S.R. and the significant changes in the political and economic structures of countries in Eastern Europe will affect the demand for phosphate fertilizers in this region for several years. 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., the political changes will probably encourage markets rather than state planning organizations and will determine production and trade patterns in the region. *(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 a 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. Eight companies in Florida and one in North Carolina produced 87% of the phosphate rock. The balance of 13% was produced in Idaho, Montana, and Utah. Approximately 85% of the phosphate rock sold or used by U.S. producers was consumed domestically to produce fertilizers and feed supplements; about 8% was exported and the balance was used to produce a variety of industrial chemicals.

Sedimentary apatite has a range of chemical compositions. The general formula for marine carbonate-apatite is $Ca_{10}(PO_4CO_3)_6Fe_{2-3}$. 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 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 with controlled quantities of sulfuric acid to single superphosphate, which contains about 20% P_2O_5, was the major phosphate fertilizer through the 1950's and into the 1960's. High analysis triple superphosphate, which contains more than 40% P_2O_5, is manufactured by acidulating phosphate rock with phosphoric acid. Ammonium phosphates, which contain 46% to 54% P_2O_5, are produced by reacting phosphoric acid with anhydrous ammonia. The ammonium phosphates and triple superphosphate have become the preferred fertilizers for domestic consumption and international trade. The intermediate chemical for these preferred fertilizers, phosphoric acid, is produced by acidulating phosphate rock with sulfuric acid. Phosphoric acid itself may be used as a fertilizer and is traded internationally; importers of phosphoric acid may manufacture fertilizers from the acid or use it to produce other phosphate chemicals.

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

State and local jurisdictions in Florida studied regulations to control the disposal of phosphogypsum and process wastewater. Final rules from the Florida Environmental Regulation Commission were expected early in 1993. 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.

The U.S. Environmental Protection Agency (EPA) announced the establishment of the Dialogue Committee on Phosphoric Acid Production Wastes in the November 24th issue of the Federal Register. The committee included the EPA, various State agencies, industry representatives, the Fertilizer Institute, and public interest groups. The committee was to address any existing or potential risks to human health or the environment from the producing of phosphoric acid wastes by identifying technically and economically feasible changes to the current production process.[1]

The EPA promulgated a final rule that announced the Administrator's final decision on reconsideration of 40 CFR part 61, subpart R, National Emission Standards for Radon Emissions From Phosphogypsum Stacks.[2]

In October, the President signed a bill (HR 5679) into law (Public Law 102-389) that had a provision that prevented the EPA from expending funds to promulgate, implement, or enforce subtitle C or subtitle D regulations under the Resources Conservation and Recovery Act for phosphoric acid production waste in fiscal year 1993.

Issues

Phosphate rock mining involves the movement of huge volumes of soil and other materials in overburden and large quantities of material in the matrix. Operating mines cover large areas of land surface and are unsightly while active operations are being conducted. 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 world agriculture to raise food production. The increase in the food needs is met by increasing total farmed acreages and increasing productivity with fertilizers.

Production

Production of marketable phosphate rock in the United States decreased 2.4% in 1992 to about 47 million tons. Production during the first three quarters of 1992 was about the same as it had been in 1991; production in the fourth quarter, however, was more than 1 million tons less than in the fourth quarter of 1991.

Florida and North Carolina.— Phosphate rock was produced in central Florida by Agrico Chemical Co., a division of Freeport-McMoRan Resource Partners L.P.; Cargill Fertilizer, Inc.; IMC Fertilizer Inc. (IMCF); Mobil Mining and Minerals Corp.; Nu-Gulf Industries Inc., owned by Wingate Creek Acquisition Corp.; Seminole Fertilizer Corp., owned by Tosco Corp.; and U.S. Agri-Chemicals Corp., owned by Sinochem (USA) Inc. Mobil closed its Fort Meade mine and announced plans to develop its South Fort Meade property with production expected in 1995. Nu-Gulf suspended operations and began a temporary layoff in early September; mining operations were not restarted during 1992. 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. (TG), a division of Texasgulf Inc., a subsidiary of Elf Aquitaine Inc., produced phosphate rock from the Aurora Mine in eastern North Carolina. TG employed bucket wheel excavating systems 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. FMC began mining at its Dry Valley facility, but did not ship material to its Pocatello plant; dry valley material will replace shale from the Gay Mine, which was expected to be depleted during 1993. 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. In April, FS Industries, a limited liability company, formed by Simplot and Farmland Industries, purchased Chevron Resources Co.'s phosphate operations, which included a phosphate rock mine near Vernal, UT, slurry pipeline, and a Rock Springs, WY, fertilizer facility. *(See tables 2 and 3.)*

Consumption and Uses

The demand pattern for phosphate rock was similar to that of 1991. In 1992, approximately 93% of the U.S. primary demand was used to manufacture wet-process phosphoric acid; about 93% of the wet-process acid or approximately 87% of total phosphate rock demand was used to manufacture fertilizers. The remaining 13% was for other applications. Both domestic and foreign markets were supplied by the industry. Of the total demand, 33% was consumed domestically as fertilizer and 55% was converted to fertilizer and exported. About 11% of the total demand was consumed as phosphorus chemicals domestically, and 1% was exported in chemical products.

Nearly 93% of the phosphate rock sold or used by U.S. producers was for the manufacture of wet-process phosphoric acid, single superphosphate, and triple superphosphate; the balance was used to produce elemental phosphorus. Most of the phosphate rock imported was used to produce wet-process phosphoric acid. *(See tables 4 and 5.)*

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 winter. 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 1991 were 10.2 million tons. In 1992, phosphate rock ending stocks were 12.6 million tons, which indicates an increase of more than 2 million tons; nearly 50% of the increase was because of inventory adjustments by producers reported to the U.S. Bureau of Mines, indicating that inventories at the end of 1991 were actually more than 11.3 million tons. *(See table 6.)*

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 $23.20 per ton in 1990; the price decreased slightly in 1991 and by an additional 53 cents in 1992. *(See tables 7, 8, and 9.)*

Foreign Trade

Exports of phosphate rock from Florida and North Carolina declined from 14 million tons in 1979 to 3.6 million tons in 1992. Imports of phosphate rock into the United States increased by about 180% in 1992 compared with 1991. Nearly all of the imported phosphate rock was supplied by Morocco and came into ports on the Gulf of Mexico.

Although phosphate rock exports continued to decline, exports of monoammonium phosphate, triple superphosphate, and phosphoric acid increased. Exports of diammonium phosphate, however, decreased sharply to nearly 8.3 million tons from the record-high level of 9.7 million tons reached in 1991. Of the high analysis fertilizers, diammonium phosphate, monoammonium phosphate, and triple superphosphate, produced by the U.S. industry in 1992, 56%, 41%, and 57%, respectively, were exported. *(See tables 10, 11, 12, 13, 14, 15, 16, and 17.)*

World Review

World phosphate rock production was less in 1992 compared with the peak year of 1989. Production from major producing countries has either remained constant or has declined. It was estimated that world fertilizer consumption declined by 4% in 1992. This was principally caused by reduced consumption in Eastern Europe and the former U.S.S.R. The declining consumption of phosphate fertilizers in Central, Eastern, and Western Europe was the principal reason for a decline in phosphate rock production and trade in 1992. In Western Europe, during 1991 and 1992, phosphate rock imports decreased an estimated 2.5 million tons, which reflected the closure or idling of 11 phosphoric acid plants with an annual capacity of about 1.3 million tons P_2O_5. The acid plants were closed or idled for environmental and/or economic reasons.

Kazakhstan.—Phosphate rock production was centered at Kara Tau, northwest of Dzhambul. Output was significantly below the production in 1990 when about 12 million tons was produced.

Russia.—Production was centered in igneous apatite deposits at Khibny and Kovodor on the Kola peninsula; phosphate rock was also produced from sedimentary phosphate deposits at Kimovsk, Lopatinsk, Voskresenik, and Yegoryevsk south of Moscow. Production from the Kola peninsula was well below the 1990 output of approximately 20 million tons; production from other areas and total consumption was considerably lower than during the previous year.

The U.S. Bureau of Mines estimates of world phosphate rock reserves and the reserve base are shown in table 19. Included are reserves and reserve base estimates with costs of less than $40 and $100 per ton, respectively. *(See tables 18, 19, and 20.)*

OUTLOOK

World production and consumption has declined steadily since 1989, primarily as a result of the political and social restructuring of the economies of Eastern Europe and the former U.S.S.R. In addition, imports into Western Europe have mirrored the closure of numerous phosphoric acid plants. China has increased production substantially during the same period, while consumption by developing nations has been stagnant or only increased slightly. North American consumption of phosphate fertilizers has shown a downward trend in recent years as farmers adopted more efficient application practices. The fertilizer industries of Brazil and Mexico have been restructured because of Government actions, and India reduced fertilizer subsidies to its farmers. Overall, significant dislocations, worldwide, have contributed to the decline in phosphate consumption and trade.

A further decline in world consumption and trade during 1993 is probable. After 1993, a modest increase in 1994 is forecast. World consumption will probably not return to the levels attained in 1988-89 until late in the 1990's. The continuing growth in world population will require increased use of fertilizer for food production. The long-term growth in phosphate rock production should average about 1.3% annually beginning in 1997.

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[1]Green Markets. V. 16, No. 48, p. 7.
[2]Federal Register. V. 57, No. 107, June 3, 1992, pp. 23305-23321.

OTHER SOURCES OF INFORMATION

Chemical Marketing Reporter, weekly.
Chemical Week, weekly.
European Chemical News (London), monthly.
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)

	1988	1989	1990	1991	1992
United States:					
Mine production (crude ore)	162,299	170,268	151,277	154,485	154,936
Marketable production	45,389	49,817	46,343	48,096	46,965
P_2O_5 content	13,833	15,116	14,172	14,510	14,063
Value[1]	$887,809	$1,084,022	$1,075,093	$1,109,094	$1,058,393
Average per metric ton[2]	$19.56	$21.76	$23.20	$23.06	$22.53
Sold or used by producers[3]	48,441	49,280	49,754	44,707	45,113
P_2O_5 content	14,760	14,935	15,098	13,467	13,529
Value[1]	$947,721	$1,072,454	$1,154,422	$1,030,913	$1,016,271
Average per metric ton[2 4]	$19.56	$21.76	$23.20	$23.06	$22.53
Exports[5]	8,092	7,842	6,238	5,082	3,723
P_2O_5 content	2,608	2,522	2,019	1,643	1,200
Value[1]	$206,984	$227,272	$191,233	r$162,624	$120,216
Average per metric ton[2]	$25.58	$28.98	$30.66	$32.00	$32.29
Imports for consumption	676	705	451	552	1,530
C.i.f. value	$26,310	$29,878	$21,905	$28,001	$56,159
Average per metric ton[6]	$38.92	$42.44	$48.57	$50.73	$36.71
Consumption[7]	r41,025	42,143	43,967	40,177	42,920
Stocks, December 31: Producers	9,323	11,027	8,912	10,168	12,612
World: Production	r164,875	r165,748	r161,528	r149,665	e143,753

eEstimated. rRevised.
[1]The total value is based on a weighted value.
[2]Computer-calculated average value based on the weighted sold or used values.
[3]Includes domestic sales and exports.
[4]Weighted average of sold or used values.
[5]Exports reported to the U.S. Bureau of Mines by companies.
[6]Average unit value obtained from unrounded data.
[7]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
			Beneficiated			
	Rock	P_2O_5 content	Rock	P_2O_5 content	Value[1]	
1991	154,485	21,370	48,096	14,510	1,109,094	10,168
1992:						
January-June:						
Florida and North Carolina	76,523	r9,280	20,913	6,314	r490,628	r8,985
Idaho, Montana, Tennessee, Utah	4,008	r1,000	2,911	r816	r52,659	r2,125
Total	80,531	r10,280	23,824	r7,130	r543,287	r11,110
July-December:						
Florida and North Carolina	69,711	9,033	19,916	6,032	461,055	10,543
Idaho, Montana, Tennessee, Utah	4,694	1,172	3,225	901	54,051	2,069
Total	74,405	10,205	23,141	6,933	515,106	12,612
Grand total	154,936	20,485	46,965	14,063	1,058,393	XX

rRevised. XX Not applicable.
[1]Computer-calculated value based on the weighted sold or used value.

TABLE 3

PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY GRADE AND REGION

(Thousand metric tons and thousand dollars)

Grade (percent BPL[3] content)	Florida and North Carolina			Tennessee[1] and Western States[2]			Total		
	Rock	P_2O_5 content	Value[2 4]	Rock	P_2O_5 content	Value[2 4]	Rock	P_2O_5 content	Value[2 4]
January-June 1991	18,791	5,710	435,038	1,789	496	31,115	20,580	6,206	466,153
July-December 1991	20,757	6,314	501,775	3,370	947	62,985	24,127	7,261	564,760
January-June 1992:									
74 or more[5]	—	—	—	—	—	—	—	—	—
72 to less than 74	1,187	396	38,312	—	—	—	1,187	396	38,312
70 to less than 72	963	312	29,183	431	142	15,600	1,394	454	44,783
66 to less than 70	13,104	4,004	r281,170	506	156	11,569	13,610	4,160	r292,739
60 to less than 66	5,076	1,439	128,565	1,056	293	15,863	6,132	1,732	144,428
Below 60	—	—	—	769	192	6,936	769	192	6,936
Total	20,330	6,151	r477,230	2,762	783	49,968	23,092	6,934	r527,198
July-December 1992:									
74 or more[5]	—	—	—	—	—	—	—	—	—
72 to less than 74	1,101	367	35,171	—	—	—	1,101	367	35,171
70 to less than 72	539	174	14,820	411	135	15,390	950	309	30,210
66 to less than 70	10,601	3,256	216,668	558	174	11,841	11,159	3,430	228,509
60 to less than 66	6,508	1,879	167,545	1,206	330	17,169	7,714	2,209	184,714
Below 60	—	—	—	1,097	279	10,469	1,097	279	10,469
Total	18,749	5,676	434,204	3,272	918	54,869	22,021	[6]6,595	489,073

rRevised.
[1]1991 only, no production or sales in 1992.
[2]Includes Idaho, Montana, and Utah.
[3]1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.
[4]F.o.b. mine.
[5]No reported sold or used for 1992.
[6]Data do not add to total shown because of independent rounding.

TABLE 4

PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons)

Use	1991 total		1992					
			January-June		July-December		Total	
	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content
Domestic:[1]								
Wet-process phosphoric acid	r35,895	r10,807	19,412	5,828	18,378	5,521	37,790	11,349
Normal superphosphate	47	r14	14	5	9	3	23	8
Triple superphosphate	395	131	217	71	284	93	501	164
Direct applications	—	—	(2)	(2)	(2)	(2)	(2)	(2)
Elemental phosphorus	r3,288	r872	1,369	359	1,707	449	3,076	808
Ferrophosphorus	—	—	—	—	—	—	—	—
Total	39,625	11,824	21,012	6,263	20,378	6,066	41,390	12,329
Exports[3]	5,082	1,643	2,080	671	1,643	529	3,723	1,200
Grand total	r44,707	13,467	23,092	6,934	22,021	6,595	45,113	13,529

rRevised.
[1]Includes rock converted to products and exported.
[2]Less than 1/2 unit.
[3]Exports reported to the U.S. Bureau of Mines by companies.

TABLE 5
PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE AND REGION

(Thousand metric tons)

Use	Florida and North Carolina		Tennessee[1] and Western States[2]		Total	
	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content
1991:	39,548	12,024	5,159	1,443	44,707	13,467
1992:						
January-June:						
Domestic:[3]						
Agricultural	18,320	5,501	1,092	327	19,412	5,828
Industrial	—	—	1,600	435	1,600	435
Subtotal	18,320	5,501	2,692	762	21,012	6,263
Exports[4]	2,012	650	68	21	2,080	671
Total	20,332	6,151	2,760	783	23,092	6,934
July-December:						
Domestic:[3]						
Agricultural	16,860	5,066	1,518	455	18,378	5,521
Industrial	292	97	1,708	448	2,000	545
Subtotal	17,152	5,163	3,226	903	20,378	6,066
Exports[4]	1,595	514	48	15	1,643	529
Total	18,747	5,677	3,274	918	22,021	6,595
Grand total	39,079	11,828	6,034	1,701	45,113	13,529

[1]1991 only, no production or sales in 1992.
[2]Includes Idaho, Montana, and Utah.
[3]Includes rock converted to products and exported.
[4]Exports reported to the U.S. Bureau of Mines by companies.

TABLE 6
MARKETABLE PHOSPHATE ROCK YEAREND STOCKS[1]

(Million metric tons)

Year	Quantity
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
1992	12.6

[1]Includes inventory adjustments.

TABLE 7
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)	1991			1992		
	Domestic	Export	Average	Domestic	Export	Average
74 or more	22.27	38.39	34.25	—	—	—
72 to less than 74	28.19	33.66	31.22	29.57	34.13	32.13
70 to less than 72	31.20	31.29	31.28	25.03	30.14	29.28
66 to less than 70	21.69	30.17	22.18	20.55	30.60	21.00
60 to less than 66	24.86	—	24.86	25.56	—	25.56
Weighted average	22.67	31.69	23.69	22.47	31.69	23.32

[1]1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458 % P_2O_5.

TABLE 8

PRICE OR VALUE OF TENNESSEE[1] AND WESTERN STATES[2] PHOSPHATE ROCK, BY GRADE

(Dollars per metric ton, f.o.b. mine)

Grade (percent BPL[3] content)	1991			1992		
	Domestic	Export	Average	Domestic	Export	Average
70 to less than 72	37.22	—	37.27	36.82	—	36.82
66 to less than 70	20.67	42.67	22.75	18.49	50.76	22.02
60 to less than 66	11.91	—	11.91	14.60	—	14.60
Less than 60	12.54	—	12.54	9.33	—	9.33
Weighted average	17.65	42.67	18.24	16.72	50.76	17.38

[1]1991 only, no production or sales in 1992.
[2]Includes Idaho, Montana, and Utah.
[3]1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458 % P_2O_5.

TABLE 9

PRICE OR VALUE OF U.S PHOSPHATE ROCK, BY GRADE

(Dollars per metric ton, f.o.b. mine)

Grade (percent BPL[1] content)	1991			1992		
	Domestic	Export	Average	Domestic	Export	Average
74 or more	22.27	38.39	34.25	—	—	—
72 to less than 74	28.19	33.66	31.22	29.57	34.13	32.13
70 to less than 72	35.86	31.24	32.95	34.11	30.14	31.99
66 to less than 70	21.63	31.18	22.21	20.46	32.57	21.04
60 to less than 66	22.51	—	22.51	23.77	—	23.77
Less than 60	12.54	—	12.54	9.33	—	9.33
Weighted average	21.95	32.00	23.06	21.65	32.29	22.53

[1]1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458 % P_2O_5.

TABLE 10

U.S. EXPORTS OF GROUND PHOSPHATE ROCK, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 2510.20.0000)

Country	1991		1992	
	Quantity	Value[1]	Quantity	Value
Canada	151		128	
France	—		122	
India	1		21	
Mexico	1	NA	2	NA
New Zealand	20		—	
Romania	40		—	
Other	6		15	
Total	219	13,078	288	NA

NA Not available.
[1]All values f.a.s.

Source: Bureau of the Census.

TABLE 11

U.S. EXPORTS OF UNGROUND PHOSPHATE ROCK, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 2510.10.0000)

Country	1991		1992	
	Quantity	Value[1]	Quantity	Value
Australia	96		118	
Austria	117		—	
Belgium	199		(2)	
Brazil	3		4	
Canada	171		153	
France	644		236	
Germany	322		312	
India	615		450	
Italy	66	NA	24	NA
Japan	643		603	
Korea, Republic of	982		1,147	
Mexico	689		5	
Netherlands	643		346	
New Zealand	103		161	
Romania	22		32	
Sweden	103		—	
Other	112		98	
Total	5,530	246,755	3,689	NA

NA Not available.
[1]All values f.a.s.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 12

U.S. EXPORTS OF SUPERPHOSPHATES, MORE THAN 40% P_2O_5, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 3103.10.0020)

Country	1991		1992	
	Quantity	Value[1]	Quantity	Value
Argentina	12		27	
Australia	159		227	
Bangladesh	281		108	
Brazil	172		186	
Canada	19		11	
Chile	157		175	
Colombia	8		10	
Costa Rica	28		2	
Dominican Republic	r3		10	
Equador	6	NA	15	NA
Indonesia	—		182	
Japan	37		52	
Mexico	—		4	
Peru	8		4	
South Africa, Republic of	—		6	
Spain	4		4	
United Kingdom	—		25	
Uruguay	7		29	
Venezuela	—		18	
Other	r13		19	
Total	[2]911	120,809	1,114	NA

rRevised. NA Not available.

[1]All values f.a.s.

[2]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13

U.S. EXPORTS OF DIAMMONIUM PHOSPHATES, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 3105.30.0000)

Country	1991		1992	
	Quantity	Value[1]	Quantity	Value
Albania	—		10	
Argentina	112		191	
Australia	345		286	
Bangladesh	—		17	
Belgium	301		35	
Brazil	30		41	
Canada	232		175	
Chile	49		69	
China	5,014		3,582	
Colombia	117		98	
Costa Rica	19		7	
Côte d'Ivoire	—		34	
Dominican Republic	51		49	
Ecuador	24		44	
El Salvador	13		16	
France	49		61	
Germany	61		94	
Guatemala	17		21	
Honduras	—		15	
India	1,541		1,187	
Iran	—		281	
Ireland	41		16	
Italy	32	NA	26	NA
Japan	442		431	
Jordan	—		27	
Kenya	44		31	
Korea, Republic of	—		54	
Mexico	(2)		58	
Netherlands	10		30	
New Zealand	46		55	
Nigeria	10		—	
Pakistan	611		713	
Panama	12		17	
Peru	19		14	
Phillippines	16		33	
Portugal	22		—	
Saudi Arabia	53		—	
Spain	37		42	
Taiwan	—		55	
Thailand	61		111	
Turkey	208		74	
United Kingdom	10		25	
Uruguay	22		66	

See footnotes at end of table.

TABLE 13—Continued

U.S. EXPORTS OF DIAMMONIUM PHOSPHATES, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 3105.30.0000)

Country	1991		1992	
	Quantity	Value[1]	Quantity	Value
Venezuela	—		45	
Yugoslavia	18	NA	—	NA
Other	r49		36	
Total	r9,738	1,707,088	8,272	NA

rRevised. NA Not available.
[1]All values f.a.s.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 14

U.S. EXPORTS OF MONOAMMONIUM PHOSPHATES, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 3105.40.0000)

Country	1991		1992	
	Quantity	Value[1]	Quantity	Value
Argentina	14		5	
Australia	144		216	
Brazil	79		8	
Canada	211		298	
Chile	25		33	
China	17		5	
Colombia	50		40	
Costa Rica	7		26	
Dominican Republic	2		1	
Ecuador	3		—	
Guatemala	18	NA	37	NA
Italy	19		—	
Japan	109		157	
Mexico	9		22	
Peru	(2)		(2)	
Saudi Arabia	30		—	
Spain	(2)		—	
Thailand	11		17	
Venezuela	(2)		(2)	
Other	22		24	
Total	770	140,838	889	NA

NA Not available.
[1]All values f.a.s.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 15

U.S. EXPORTS OF PHOSPHORIC ACID, LESS THAN 65% P_2O_5, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 2809.20.0010)

Country	1991		1992	
	Quantity	Value[1]	Quantity	Value
Australia	14		60	
Canada	10		6	
Colombia	2		8	
India	246	NA	279	NA
Indonesia	45		69	
Japan	(2)		—	
Venezuela	57		56	
Other	66		124	
Total	440	76,342	602	NA

NA Not available.
[1]All values f.a.s.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 16

U.S. EXPORTS OF ELEMENTAL PHOSPHORUS, BY COUNTRY

(HTS No. 2804.70.0000)

Country	1991		1992	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Brazil	529	$1,115	507	$1,060
Canada	1,425	1,944	1,726	2,571
Japan	9,676	17,365	9,334	16,988
Korea, Republic of	104	569	134	596
Mexico	4,384	6,991	5,314	8,329
Netherlands	6	41	21	137
Taiwan	121	154	38	48
Other	773	2,242	806	3,055
Total	17,018	30,421	17,880	32,784

[1]All values f.a.s.

Source: Bureau of the Census.

TABLE 17

U.S. IMPORTS FOR CONSUMPTION OF PHOSPHATE ROCK AND PHOSPHATIC MATERIALS

(Thousand metric tons and thousand dollars)

Phosphatic materials	HTS No.[1]	1991		1992	
		Quantity	Value[2]	Quantity	Value[2]
Natural calcium[3] phosphates unground	2510.10.0000	550	27,657	1,528	55,986
Natural calcium[3] phosphates ground	2510.20.0000	2	344	2	173
Dicalcium phosphate	2835.25.0000	2	2,620	2	2,746
Phosphorus	2804.70.0000	9	17,152	4	10,330
Normal superphosphate	3103.10.0010	1	140	(4)	71
Triple superphosphate	3103.10.0020	(4)	3	(4)	5
Diammonium phosphate	3105.30.0000	7	2,129	22	4,907
Fertilizer containing nitrates and phosphates	3105.51.0000	2	364	1	150
Phosphoric acid	2809.20.0010	1	211	1	214

[1]Harmonized tariff schedule of the United States.
[2]Declared c.i.f. values.
[3]Excludes reported imports from Canada and Israel.
[4]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 18

WORLD PHOSPHATE ROCK ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1992, RATED CAPACITY[1]

(Million metric tons per year)

Country	Capacity
North America:	
Mexico	1.0
United States	52.0
Total	53.0
South America	10.0
Europe:	
Russia	20.0
Other	1.0
Total	21.0
Africa:	
Algeria	2.3
Morocco[2]	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	23.0
Israel	4.0
Jordan	8.0
Kazakhstan	8.0
North Korea	1.0
Vietnam	1.0
Other	1.0
Total	46.0
Oceania:	
Australia	1.0
Nauru	2.0
Total	3.0
World total	188.5

[1]Includes capacities of operating plants as well as plants on standby basis.
[2]Includes former Western Sahara.

TABLE 19

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
Russia	8	—	1,000
Total	10	30	1,100
Africa:			
Algeria	1	240	240
Egypt	5	—	760
Morocco[3]	11	5,900	21,440
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
Kazakhstan	3	—	100
Syria	2	190	190
Other	6	30	330
Total	25	530	1,500
Oceania:			
Australia	5	90	590
Nauru	1	5	5
Total	6	95	595
World total	195	11,255	34,045

[1]Phosphate 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. 1992, f.o.b. mine.
[2]Reserve base at a cost less than $100 per ton. Costs are as defined in footnote 1.
[3]Includes former Western Sahara.

TABLE 20

PHOSPHATE ROCK, BASIC SLAG, AND GUANO: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Commodity and country[2]	Gross weight					P_2O_5 Content				
	1988	1989	1990	1991	1992e	1988	1989	1990	1991	1992e
Phosphate rock:										
Algeria	1,332	r1,124	1,128	1,090	3,r1,136	e404	e371	e333	e322	334
Australia	13	8	16	e4	4	2	1	e3	e1	1
Brazil	4,672	3,655	2,968	r3,280	3,300	1,653	r727	r615	r650	700
Burkina Faso e	3	3	3	3	3	1	1	1	1	1
Chile	9	14	14	13	14	e1	e1	e1	e1	1
China e	17,000	r20,000	r21,550	22,000	23,000	5,470	6,000	r6,400	6,500	6,800
Colombia	35	31	37	r32	32	e9	e8	e8	e8	8
Egypt	1,146	1,347	1,143	r1,652	1,600	e293	e337	r e286	r e413	400
Finland	584	580	546	r472	450	215	214	201	r e170	160
India	739	704	r674	r563	600	246	235	e220	e195	200
Indonesia	1	11	2	r6	8	(4)	4	1	2	3
Iraq e 5	1,270	1,140	900	400	900	r381	r342	270	120	270
Israel	3,479	3,922	3,516	e3,370	3,r3,595	e1,092	e1,231	e1,104	e1,070	1,125
Jordan	6,611	6,900	r6,082	r4,433	3,4,296	e2,182	e2,277	r e2,007	r e1,458	1,410
Kazakhstan[6]	—	—	—	—	7,000	—	—	—	—	1,800
Korea, North e	500	500	500	r550	550	160	160	160	r175	175
Mali e	10	10	10	10	10	2	2	2	2	2
Mexico[7]	835	655	623	r596	500	251	197	e174	e180	170
Morocco[8]	25,015	18,067	21,396	17,900	3,19,184	e8,061	e5,781	e6,906	e5,700	6,100
Nauru	r1,541	1,181	926	530	3,747	e593	e455	e355	e200	285
Pakistan e	35	40	42	r19	20	11	13	r13	r6	6
Peru	13	r15	r47	r18	20	r e4	e4	e6	e6	6
Philippines	8	4	3	r21	20	e2	e2	e1	r e5	5
Russia[6]	—	—	—	—	14,000	—	—	—	—	4,800
Senegal[9]	2,326	2,273	2,147	r1,741	2,300	831	823	777	r e630	830
South Africa, Republic of	2,850	2,963	3,165	3,050	3,3,051	1,079	1,111	1,190	r1,150	1,150
Sri Lanka	23	24	33	r20	20	e7	e8	e11	r6	6
Sweden	142	71	r—	—	—	52	26	r—	—	—
Syria	r2,186	2,256	1,633	r1,359	3,1,266	715	e690	e511	e425	395
Tanzania	4	r5	25	r22	22	r e1	r e1	r e8	e7	7
Thailand	8	7	10	r6	6	e2	2	e3	r2	2
Togo	3,464	3,355	2,314	2,965	3,2,083	e1,257	r1,270	840	1,076	754
Tunisia	6,103	6,610	r6,258	r6,400	6,400	1,813	r e1,963	r e1,858	r e1,900	1,900
Turkey	74	85	87	e90	90	23	26	27	e28	28
Uganda	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
U.S.S.R. e 10	r37,000	r37,500	r36,800	r28,400	—	r12,000	r12,200	r11,800	r9,250	—
United States	45389	49,817	46,343	48,096	3,46,965	13,833	15,116	14,172	14,501	3,14,063
Venezuela	—	237	165	r162	166	—	57	34	e34	35
Vietnam e	330	500	3,274	275	275	115	175	96	96	95
Zimbabwe, concentrate	125	134	148	r117	120	44	47	52	r41	42
Total	r164,875	r165,748	r161,528	r149,665	143,753	r52,805	r51,878	r50,446	r46,331	44,069
Basic (Thomas converter) slag:										
Argentina e	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
Belgium e	r—	r—	r—	r—	—	r—	r—	r—	r—	—
Egypt e	8	8	8	8	8	2	2	2	2	2

See footnotes at end of table.

TABLE 20—Continued

PHOSPHATE ROCK, BASIC SLAG, AND GUANO: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Commodity and country[2]	Gross weight					P_2O_5 Content				
	1988	1989	1990	1991	1992e	1988	1989	1990	1991	1992e
Basic (Thomas converter) slag—Continued:										
France	775	701	r488	r538	500	140	126	r88	r97	90
Germany	r104	r122	r128	r127	125	r15	r18	19	r19	18
Luxembourg	664	r672	r603	e600	550	120	122	r109	e108	100
Total	r1,551	r1,503	r1,227	r1,273	1,183	r277	r268	r218	r226	210
Guano:										
Chile	4	3	2	r1	1	e(4)	e(4)	e(4)	e(4)	(4)
Philippines	1	48	1	r e12	10	e(4)	16	e(4)	r e4	3
Seychelles Islands[8]	5	r—	r—	r—	—	2	r—	r—	r—	—
Total	10	51	r3	r13	11	2	16	r(4)	r4	3

eEstimated. rRevised.

[1]Table includes data available through May 10, 1993. 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.

[2]In addition to the countries listed, Belgium 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.

[3]Reported figure.

[4]Less than 1/2 unit.

[5]Beneficiated.

[6]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[7]Includes only output used to manufacture fertilizers.

[8]Production from Western Sahara area is included.

[9]Does not include aluminum phosphate production, gross weight as follows in thousand metric tons: 1988—119; 1989—140 (estimated); 1990—127 (estimated); 1991—92 (estimated, revised); and 1992—70 (estimated).

[10]Dissolved in Dec. 1991.

PLATINUM-GROUP METALS

By J. Roger Loebenstein

Mr. Loebenstein, a physical scientist with 18 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for platinum-group metals for 12 years. Domestic survey data were prepared by Evangeline Hemphill, statistical assistant; and international data tables were prepared by H. 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 Russian sales of platinum declined to 23 metric tons in 1992, down from the alltime high of 34 tons sold in 1991. Almaz, the Russian PGM marketing agency, had sole responsibility for export sales of PGM after sharing it for 2 years with the Soviet Bank for Foreign Economic Affairs, Vneshekonombank.

Demand for platinum, palladium, and rhodium by the U.S. automobile industry increased in 1992, but total demand for all end uses was not much different than the 1991 level.

DOMESTIC DATA COVERAGE

Domestic production data for PGM are developed by the U.S. Bureau of Mines (USBM) from a voluntary survey of U.S. refiners. Of the 18 refiners to which a survey request was sent, 12 responded. These respondents represent 67% of the total refined metal production shown in tables 1 and 2. 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, Russia, the PGM are produced as byproducts of nickel and copper mining.[1] In the Republic of South Africa, 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. 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 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.

In the United States, only Multi-Metco processed any substantial quantities of autocatalyst PGM. The other major processors 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 spectroscopy.[3] The flow of PGM through their metallurgical, catalytic, and chemical applications is discussed in USBM IC 9303. This study 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), the Commodity Exchange (COMEX), the Tokyo Commodity Exchange for Industry (TOCOM), and to a lesser extent on the MidAmerica Exchange, through the Chicago Board of Trade (CBOT). Platinum and palladium futures contracts, specifying 99.95% metal content, were traded on the NYMEX in units of 50 and 100 troy ounces, respectively. The TOCOM contract unit is 500 grams, the quality specifications are 99.9% purity, and prices are quoted in Japanese yen per gram. 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.

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 USBM publication entitled, "Metal Prices in the United States Through 1991."[5]

ANNUAL REVIEW

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 1992, as shown in table 1. No purchases of rhodium or ruthenium were made, even though there are stockpile goals for these two metals.

Issues

The USBM received many inquiries in 1992 about osmium 187 isotope. Most of the callers asked about markets for this material, which reportedly was sourced from Russia with asking prices varying from $50,000 per gram to more than $100,000 per gram. There are no known commercial markets for osmium 187. Scientific applications may consume perhaps only a few grams per year.

Osmium (atomic number 76) has seven naturally occurring isotopes, all of which are stable. They are osmium 184, 186, 187, 188, 189, 190, and 192. Osmium 187 is produced in nature when radioactive rhenium 187 decays to form stable osmium 187 by emission of a beta particle. Rhenium is most strongly concentrated in molybdenite (MoS_2). Geologists have used the rhenium-osmium isotope ratio method to determine the age of iron meteorites that cannot be dated directly by other methods.

An article entitled "Osmium-187: An Intriguing Isotope" appeared on page 3 of the December 1992 issue of Elements, published by Concord Trading Corporation, Denver, CO. The first line of the article reads: "In what seems to be the latest scam emerging from the former Soviet Union, osmium-187 is being peddled in the international metals market as a rare, mysterious and very expensive material." The article continues "Legal authorities clearly are disturbed by the upswing in Os-187 activity, mostly because they fear that innocent people are being used to ferry material that is not actually Os-187, but instead is a radioactive substitute. This coincides with other fears about the black market trade of radioactive and other valuable substances that has grown out of Eastern Europe since the fall of the U.S.S.R."

Production

The Stillwater Mine, Nye, MT, southwest of Billings, 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, mainly palladium and platinum, increased somewhat in 1992, as shown in table 1. Small amounts of PGM were recovered by other companies as byproducts of domestic copper refining.

On April 1, the Federal Register published a notice that SMC wished to increase ore production at Nye from the

current 1,000 tons per day to 2,000 tons per day. A final environmental impact statement was expected to be released at a later date.

Catalytic Converter Refining (CCR) of Northlake, IL, a major collector of scrapped catalytic converters, announced the closing of its plant in July. CCR was operated by Sloan Metal Co. and financially backed by Nissan Motor Co. Sloan Metal purchased some of CCR's equipment and reentered the catalytic converter recycling business in November as Sloan Precious Metals Co. Sloan collects converters, removes the outer shells, and ships the catalyst contents to other companies for refining.

Consumption and Uses

Reported sales of PGM by refiners is shown in table 3. For comparison purposes, the calculated apparent consumption for the individual PGM is also shown. Use of platinum, palladium, and rhodium in the automotive industry recovered from one of its worst years in 1991.

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 1992 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 addition to emission catalysts, platinum was used in automobile oxygen sensors and in spark plugs. Platinum plugs provide cleaner combustion and last much longer than conventional plugs. Although Ford has been using platinum plugs for some time, Nissan and General Motors plan to use start using platinum spark plugs in some 1993 models. Conventional platinum-tipped plugs are believed to contain 0.01 to 0.02 gram of platinum each.[6]

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.

In its first quarter 1992 report to stockholders, Engelhard Corp. reported that "Russia's electrochemical consortium, UEIP, is licensing Engelhard technology to manufacture automotive exhaust catalysts. In addition, Engelhard will assist UEIP in the design of Russia's first auto catalyst plant at an existing facility in Ekaterinburg. The plant will have a capacity of up to two million catalyst units per year and is scheduled to be in operation by mid-1994. Engelhard also will be supporting UEIP with an ongoing testing program of the plant's catalysts to ensure that they qualify for use on Russian cars."

In addition, Engelhard is proceeding with plans to build a new auto catalyst manufacturing plant in Nienburg, Germany, after buying out its German venture partner, Kali-Chemie AG. Slated to be fully operational in 1993, the new plant at full capacity is expected to produce more than 6 million auto catalysts annually, up from its current level of 2 million units.

In April, Engelhard Corp. said that its catalysts sharply increase the yield of a refinery byproduct, isobutylene, that is combined with methanol to make methyl tertiary butyl ether, or MTBE. MTBE is an additive used in gasoline to increase its oxygen content, which in turn helps the fuel burn cleaner. There has been some concern in the industry that there is not enough isobutylene to make MTBE sufficient to supply demand to comply with the 1990 Clean Air Act. Under the Act, 41 U.S. cities must use oxygenated gasoline during the winter starting in 1992.

Stocks

In addition to the reported stocks held by refiners, importers, and dealers shown in table 4, end users held sizable quantities of PGM that were not reported to the USBM.

Markets and Prices

Generally, prices for PGM were lower in 1992, with the largest declines in prices for rhodium, iridium, and ruthenium. The average dealer prices for all six PGM are shown in table 1.

In August, the Commodity Futures Trading Commission (CFTC) approved trading of platinum and palladium futures contracts on the COMEX, placing that exchange in direct competition with the NYMEX. The COMEX requires a minimum purity of 99.9%, while the NYMEX requires a purity of 99.95%. In December, the CFTC approved the NYMEX's after-hours electronic trading system known as "Access." The system is designed to allow traders to buy and sell platinum futures contracts after normal trading hours. *(See tables 1, 2, 3, and 4.)*

Foreign Trade

Exports of PGM were up in 1992 because of an increase in exports of scrap to the United Kingdom, as shown in table 5. Imports of osmium shown in table 6 totaled 57 kilograms, all of which came from the Republic of South Africa. It is interesting to note that despite reports of

exports of osmium isotope 187 from Russia, U.S. import statistics do not show any imports of osmium originating from Russia (see Issues section). *(See tables 5 and 6.)*

World Review

Canada.—The main Canadian PGM producers were Canada's primary nickel producers—Inco Ltd. and Falconbridge Ltd. Both companies shipped contained PGM to refining facilities in Europe for final recovery. In addition, Inco recovered PGM from scrapped autocatalysts from both Canadian and United States sources. In a typical year, Inco recovers about 2,800 kilograms of PGM from autocatalysts at its Sudbury plant. Noranada Inc. recovers about 4,700 kilograms of palladium and platinum annually from electronic scrap and telecommunications equipment at its Horne smelter in Quebec.

Russia.—In July, Russia imposed new taxes on companies, including foreign firms and joint ventures, extracting mineral resources within its territory. The taxes were retroactive to June 1 and were set at 10% of extraction costs for PGM. Table 7 shows Russia's production of PGM beginning in 1992 and the former U.S.S.R.'s production ending in 1991.

South Africa, Republic of.—Impala Platinum suspended the Messina project and closed the Crocodile River Mine acquired after the takeover of Barplats in 1991. Impala workers returned to work in March after a work stoppage that reduced Impala's annual platinum production in 1992.

Northam Platinum, owned by Goldfields of South Africa Ltd., began producing PGM in January 1993 from the Merensky reef. Output of the mine is being toll refined by Heraeus in Germany. *(See table 7.)*

Current Research

Researchers at the University of Minnesota discovered that they could produce syngas by running a mixture of methane and oxygen or air over either a platinum or a rhodium catalyst. The reaction takes place 1,000 to 10,000 times faster than in the old steam reforming reaction. This means that much smaller reactors would be needed for a commercial syngas plant. Once syngas is produced, it can be easily converted to methanol or diesel fuel.[7]

Mintek, a research agency of the South African Government, and Western Platinum Ltd., a South African platinum producer, have developed a new series of jewelry alloys that ranges in color from yellow to shades of orange and pink. Platinum is difficult to color because it tends to bleach any coloring addition. The Mintek Annual 1992 report stated that "Test items are being manufactured in collaboration with local and overseas jewelers."

OUTLOOK

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, 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—there are 500 million motor vehicles worldwide. The use of palladium is growing because the wider use of cleaner, lead-free fuels permits its use as a substitute for more expensive platinum. However, platinum will probably continue to remain the dominant metal in catalytic converters for some time in the future.

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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[3]Kallmann, S. A Survey of the Determination of the Platinum Group Elements. Talanta, v. 34, No. 8, 1987, pp. 677-698.

[4]Gabler, R. C., Jr. A Platinum-Group Metals Consumption and Recycling Flow Model. BuMines IC 9303, 1991, 27 pp.

[5]U.S. Bureau of Mines, Branch of Metals and Branch of Industrial Minerals. Metal Prices in the United States Through 1991. 201 pp.

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Metals Week.

TABLE 1

SALIENT PLATINUM-GROUP METALS[1] STATISTICS

(Kilograms)

	1988	1989	1990	1991	1992
United States:					
Mine production:[2]					
Platinum	1,240	1,430	1,810	1,730	1,840
Palladium	3,730	4,850	5,930	6,050	6,470
Value[3] thousand dollars	$35,601	$45,764	$48,911	$37,558	$39,157
Refinery production:					
Primary refined	297	339	64	r216	W
Secondary:					
Nontoll-refined	r4,787	3,933	5,819	r4,806	5,424
Toll-refined	46,403	46,253	65,429	r67,543	56,190
Total refined metal[4]	51,488	50,525	71,312	r72,564	61,614
Stocks, yearend:					
Industry (refined)	35,514	32,543	30,324	24,313	26,946
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[5]	20,301	23,082	20,148	27,401	31,061
Total	28,787	38,301	55,044	39,624	57,829
Imports for consumption:[6]					
Refined[5]	110,947	111,107	120,631	121,741	129,362
Total	124,324	113,278	125,354	125,661	132,006
Consumption (reported sales to industry)	70,998	78,483	77,487	r62,597	66,801
Consumption, apparent[7]	103,302	101,209	117,043	r111,798	109,469
Net import reliance[8] as a percent of apparent consumption	91	90	88	e90	87
Price, dealer, average, per ounce:					
Platinum	$523	$507	$467	$371	$356
Palladium	$123	$144	$114	$87	$87
Iridium	$306	$303	$307	$283	$158
Osmium	$592	$549	$416	$400	$400
Rhodium	$1,218	$1,300	$3,565	$3,739	$2,365
Ruthenium	$61	$62	$61	$55	$29
World: Mine production	r280,282	r281,629	r291,015	r288,338	e280,889

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.

[1]The platinum-group comprises six metals: platinum, palladium, iridium, osmium, rhodium, and ruthenium.

[2]Estimates for the Stillwater Mine are from published sources. A very small quantity of byproduct platinum and palladium produced from gold-copper ores was excluded.

[3]Value based on dealer prices.

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

[5]Excludes ores and scrap.

[6]Quantities for general imports and imports for consumption are identical.

[7]Includes mine production plus nontoll-refined production plus refined imports for consumption minus refined exports plus or minus changes in government and industry stocks.

[8]Refined imports for consumption minus refined exports plus or minus changes in Government and industry stocks.

TABLE 2

PLATINUM-GROUP METALS REFINED IN THE UNITED STATES

(Kilograms)

	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total[1]
PRIMARY METAL							
Nontoll-refined:							
1988	46	248	2	—	(2)	—	297
1989	47	289	2	—	—	2	339
1990	2	62	—	—	—	—	64
1991	r11	r205	—	—	—	—	r216
1992	W	W	—	—	—	—	W
SECONDARY METAL							
Nontoll-refined:							
1988	1,133	3,545	4	—	104	2	r4,787
1989	1,134	2,664	6	—	94	35	3,933
1990	1,928	3,672	7	—	178	34	5,819
1991	r2,200	r2,297	r81	—	215	13	r4,806
1992	2,134	3,001	(3)	—	(4)	(3)	5,424
Toll-refined:							
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	38,475	23,297	130	—	3,094	433	65,429
1991	r39,394	r24,045	128	r4	3,080	r891	r67,543
1992	25,050	27,066	(3)	(3)	(4)	1,194	56,190
1991 TOTALS[1]							
Total primary	r11	r205	—	—	—	—	r216
Total secondary	r41,593	r26,343	209	r4	3,295	r904	r72,348
Total refined metal	r41,604	r26,547	209	r4	3,295	r904	r72,564
1992 TOTALS[1]							
Total primary	W	W	—	—	—	—	W
Total secondary	27,184	30,067	(3)	(3)	3,060	1,194	61,614
Total refined metal	27,184	30,067	(3)	(3)	3,060	1,194	61,614

rRevised. W Withheld to avoid disclosing company proprietary data.

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

[2]Less than 1/2 unit.

[3]Withheld to avoid disclosing company proprietary data; included in "Total."

[4]Withheld to avoid disclosing company proprietary data; included in "Total" and "Total refined metal."

TABLE 3

PLATINUM-GROUP METALS[1] SOLD TO CONSUMING INDUSTRIES IN THE UNITED STATES

(Kilograms)

Year and industry	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total[2]
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:							
Reported	36,055	35,116	448	40	4,187	1,641	77,487
Apparent consumption[3]	49,875	51,464	649	56	r12,314	2,685	117,043
1991:							
Automotive[4]	18,643	2,669	—	—	2,669	—	23,981
Chemical	r861	r1,493	32	—	183	40	r2,610
Dental and medical	r598	r4,755	118	r30	1	14	r5,516
Electrical	r3,910	r12,760	r168	—	67	1,436	r18,339
Glass	127	—	—	—	6	4	138
Jewelry and decorative	r626	r299	r5	—	193	3	r1,126
Petroleum	3,163	171	—	—	—	10	3,344
Miscellaneous	r3,182	r3,600	37	—	660	64	r7,543
Total[2]	r31,112	r25,747	r359	r30	3,778	1,571	r62,597
Apparent consumption[3]	r44,385	r57,521	600	r44	6,964	r2,285	r111,798
1992:							
Automotive[4]	20,503	2,930	—	—	2,930	—	26,363
Chemical	1,716	1,916	44	—	157	181	4,015
Dental and medical	635	5,085	111	40	1	11	5,883
Electrical	2,865	13,318	258	—	73	2,344	18,858
Glass	360	126	—	—	15	8	509
Jewelry and decorative	905	798	25	—	196	27	1,951
Petroleum	1,036	750	—	—	—	42	1,828
Miscellaneous	3,225	3,600	5	2	558	4	7,394
Total[2]	31,245	28,523	444	41	3,930	2,617	66,801
Apparent consumption[3]	45,606	54,485	207	-19	6,873	2,317	109,469

rRevised.

[1]Comprises primary and nontoll-refined secondary metals.

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

[3]Defined as mine production plus nontoll production of secondary metal plus refined imports minus refined exports plus beginning stocks minus ending stocks. In 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.

[4]1988-92 platinum, palladium, and rhodium sales to the automotive industry are estimated based on U.S. light truck sales and U.S. automobile production.

TABLE 4

REFINER, IMPORTER, AND DEALER STOCKS OF REFINED PLATINUM-GROUP METALS[1] IN THE UNITED STATES, DECEMBER 31

(Kilograms)

Year	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total
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
1992	14,187	10,641	W	122	364	W	26,946

W Withheld to avoid disclosing proprietary data; included in "Total."

[1]Includes metal in depositories of the New York Mercantile Exchange (NYMEX); on Dec. 31, 1992; this comprised 4,924 kilograms of platinum and 622 kilograms of palladium.

TABLE 5

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[1]	Value (thousands)
1991	12,860	13,638	592	312	863	11,360	39,624	$461,588
1992:								
Australia	30	17	—	—	—	—	47	431
Belgium	1,889	6,283	5	—	445	3,506	12,128	74,931
Brazil	1	15	—	—	—	—	16	82
Canada	1,538	1,171	179	9	6	618	3,521	50,612
China	9	10	—	2	—	1	22	184
France	222	89	77	1	—	6	396	11,135
Germany	535	614	17	69	34	2,542	3,811	19,727
Hong Kong	47	125	10	1	—	9	193	2,118
Italy	14	587	—	5	—	1,099	1,705	11,554
Japan	2,685	1,258	372	31	4	1,434	5,784	82,534
Korea, Republic of	569	188	15	2	—	—	775	8,423
Netherlands	13	1,566	42	—	—	—	1,621	8,572
Singapore	—	255	—	1	—	—	256	1,954
Sweden	17	47	—	—	—	249	313	1,428
Switzerland	889	1,564	—	—	—	194	2,648	23,846
Taiwan	426	1,346	—	3	—	—	1,774	10,462
United Kingdom	2,341	1,967	77	286	—	16,621	21,290	56,644
Other	878	599	40	9	—	—	1,529	17,379
Total	12,103	17,701	834	419	489	26,279	57,829	382,016

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

Source: Bureau of the Census.

TABLE 6

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)
1991	[2]51,468	60,551	6,570	2,587	520	46	3,889	31	[2]125,661	$1,742,866
1992:										
Australia	1,012	—	—	—	—	—	13	—	1,025	10,492
Belgium	3,073	9,002	259	58	—	—	5	—	12,397	79,894
Canada	1,427	2,343	1	([3])	([3])	—	457	—	4,229	30,855
Columbia	2,741	([3])	—	—	—	—	5	—	2,746	24,877
France	188	108	48	—	—	—	93	-	436	6,717
Germany	3,449	1,146	485	78	21	—	18	—	5,196	86,254
Hong Kong	([3])		—	—	—	—	214	—	214	1,955
Italy	375	125	21	—	—	—	([3])	—	522	6,420
Japan	896	2,104	43	—	—	—	31	—	3,074	19,789
Mexico	—	([3])	—	—	—	—	340	—	340	4,135
Netherlands	([3])	1	173	—	—	—	45	—	219	13,785
Norway	1,110	694	68	—	—	—	—	—	1,872	14,963
Russia[4]	886	16,394	1,394	138	6	—	—	—	18,819	161,294
South Africa, Republic of	34,127	19,504	4,462	2,117	118	57	—	—	60,384	808,327
Switzerland	13	1,013	30	2	2	—	—	—	1,060	6,785
Taiwan	—	132	—	—	—	—	141	—	273	1,604
United Kingdom	7,682	8,483	762	343	60	—	378	—	17,709	190,468
Other	594	44	7	—	—	—	847	—	1,493	15,066
Total[1]	[5]57,573	61,093	7,753	2,736	207	57	2,587	—	[5]132,006	1,483,680

[1]Data may not add to totals shown because of independent rounding.
[2]Of this amount, 1,237 kilograms was in the form of platinum coins.
[3]Less than 1/2 unit.
[4]Formerly part of the U.S.S.R.
[5]Of this amount, 2,544 kilograms was in the form of platinum coins.

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

TABLE 7

PLATINUM-GROUP METALS: WORLD PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1988	1989	1990	1991	1992e
Australia, metal content, from domestic nickel ore:e [3]					
Platinum	106	100	100	100	100
Palladium	411	400	400	400	400
Canada:[4]					
Platinume	5,393	r4,467	r5,044	r4,683	4,755
Palladiume	5,643	r4,676	r5,269	r6,439	4,976
Othere	1,505	r1,246	r1,396	r586	1,327
Total	12,541	r10,389	r11,709	r11,708	5,11,058
Colombia: Placer platinum	815	973	1,316	r1,603	1,600
Ethiopia: Placer platinume [6]	71	2	2	1	1
Finland:e					
Platinum	754	60	60	60	60
Palladium	7106	100	100	100	100
Japan, metal recovered from nickel-copper ores:[8]					
Platinum	647	1,031	1,425	988	620
Palladium	1,170	821	1,047	1,053	960
Russia: Placer platinum and platinum-groups metals recovered from nickel-copper ores:e [9] [10]					
Platinum	—	—	—	—	28,000
Palladium	—	—	—	—	76,000
Other	—	—	—	—	8,500
Serbia and Montenegro:[11] [12]					
Platinum	—	—	—	—	10
Palladium	—	—	—	—	120
South Africa, Republic of: Platinum-group metals from platinum ore:[4] [13]					
Platinume	r80,322	r82,884	r87,813	r88,861	90,000
Palladiume	34,400	35,800	38,300	r38,000	38,000
Other	17,000	15,000	15,800	16,000	17,000
Total	r131,722	r133,684	r141,913	r142,861	145,000
U.S.S.R.: Placer platinum and platinum-group metals recovered from nickel-copper ores:e [10] [14]					
Platinum	32,000	32,000	31,000	30,000	—
Palladium	85,000	85,000	84,000	82,000	—
Other	10,500	10,500	10,000	9,500	—
United States: Platinum-group metals from palladium ores:e [15]					
Platinum	1,240	1,430	1,810	1,730	1,840
Palladium	3,730	4,850	5,930	6,050	6,470
Yugoslavia:[12] [16]					
Platinum	23	23	21	e15	—
Palladium	142	199	130	e120	—

See footnotes at end of table.

TABLE 7—CONTINUED

PLATINUM-GROUP METALS: WORLD PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1988	1989	1990	1991	1992[e]
Zimbabwe:					
Platinum	28	25	21	r19	20
Palladium	46	43	31	e30	30
Grand total[17]	r280,282	r281,629	r291,015	r288,338	280,889
Of which:					
Platinum	r120,629	r122,994	r128,611	r128,060	127,006
Palladium	130,648	r131,889	r135,207	r134,192	127,056
Other	29,005	r26,746	r27,196	r26,086	26,827

[e]Estimated. [r]Revised.

[1]Table includes data available through May 18, 1993. 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.

[2]In addition to the countries listed, China, Indonesia, Papua New Guinea, and the Philippines are believed to produce platinum-group metals, and several other countries also may 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 8).

[3]Partial 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 8).

[4]Unless otherwise indicated, data show estimated proportions of platinum, palladium, and other platinum-group metals within the reported total.

[5]Reported preliminary estimate.

[6]Data are for years ending June 30 of that stated.

[7]Reported figure.

[8]Japanese 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.

[9]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[10]All production in the U.S.S.R. from 1988-91 came from Russia.

[11]Formerly part of Yugoslavia.

[12]All production in Yugoslavia from 1988-91 came from Serbia and Montenegro.

[13]Includes osmiridium produced in gold mines.

[14]Dissolved in Dec. 1991.

[15]Estimates for the Stillwater Mine, from published sources. A very small quantity of byproduct platinum and palladium produced from gold-copper ores was excluded.

[16]Dissolved in Apr. 1992.

[17]Data may not add to totals shown because of independent rounding.

POTASH

By James P. Searls

Mr. Searls, a physical scientist and economist, has been a commodity specialist for 13 years. Domestic survey data were prepared by Kelly Dorney, mineral data assistant; and international data were prepared by Theodore Spittal, international data coordinator.

U.S. potash production in terms of potassium oxide (K_2O) equivalent decreased less than 3% relative to that of 1991, and apparent consumption increased less than 2% from a downward revised 1991 value. The average price, f.o.b. mine, increased more than 5%. Yearend stocks decreased more than 17%.

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 more than 97% of total production shown in table 3.

BACKGROUND

Geology[1]

Potassium is the seventh most abundant element in the Earth's crust and the sixth most abundant element in seawater. It is found in silicate minerals of igneous, metamorphic, and sedimentary rocks and is also a major constituent of many surface and subsurface brines. The large majority—perhaps 90%—of potassium minerals in the Earth's crust is in insoluble silicate forms, such as potassium feldspar, micas, and clays. They are not considered potash resources. The majority of the world's potash resources—soluble forms—are found in subsurface bedded salt deposits, which occasionally are high-grade, large tonnage ore bodies that are amenable to low-cost mining and beneficiation. Because of the relatively high solubility of these potassium minerals, usually potassium chloride or potassium magnesium sulfate, potash from salt deposits is nearly ideal for use as fertilizers. Some potash production is from evaporation of naturally occurring brines, but the vast majority of current domestic and international production is from bedded salt deposits.

Sylvite, langbeinite, carnallite, and kainite are some of the more important potassium minerals. *(See table 1.)* Sylvinite, a mixture of KCl and NaCl, is the highest grade potash ore. Langbeinite, though rarely found, is a natural form of chloride-free potassium sulfate that also contains magnesium sulfate. Carnallite can be considered a potash ore when removal of magnesium chloride is included in the beneficiation process, but it can also be considered a contaminant when mining for sylvinite. Kainite is a relatively minor potash form, containing potassium chloride and magnesium sulfate. Potassium sulfate and potassium nitrate are typically manufactured products. Potassium sulfate is produced from mined minerals through conversion processes in Germany, Italy, and Carlsbad, NM, and from brines in southern California and at the Great Salt Lake in Utah. Natural deposits of potassium nitrate occur only in dilute amounts and only in the arid mountains of Chile.

The majority of potash-bearing bedded salt deposits are believed to have originated from the evaporation of seawater or mixtures of seawater and other brines in (restricted marine) large basins[2] that had a narrow, shallow connection to the sea. The reflux depositional model for evaporite deposition was first described in literature in 1877 by Ochsenius.[3] A shallow bar, or sill, across the mouth of a basin lets in a restricted flow of seawater that evaporates into a salt-precipitating brine. *(See figure 1.)* The density of the brine increases as the brine flows from the entrance to the basin. The most insoluble salts form first and the most soluble salts form at the end of the basin farthest from the sill. The least soluble salts are precipitated nearer the sill, and the most soluble components come out of solution at the far side of the basin. Salt crystals fall out as critical brine densities occur due to evaporation. A recent nongeology publication describes the evaporation of seawater in detail[4] along with the brine densities. The salt calcium carbonate crystallizes first, then hydrated calcium sulfate, followed by calcium sulfate. These precipitates indicate a brine volume reduction of 5 to 1 for hydrated calcium sulfate to start to precipitate, which corresponds to a density of 1.131 grams per liter. At a brine volume reduction of 10 to 1, which is a density of about 1.22, halite starts to precipitate and continues to about 80% of the contained halite when the next type of salts start to crystallize. At brine densities of 1.261 and higher and a volume reduction to 1.57% of the original volume,[5] a mixture of halite, sylvite, and carnallite starts to crystallize. Then kainite, schoenite, (possibly glaserite), and langbeinite crystallize. The remaining brine, now called bittern, is extremely difficult to evaporate owing to its low vapor pressure. (If this bittern were evaporated to dryness, bischofite would be crystallized.)

Provided that the flow volume entering the basin is balanced properly with the width and length of basin, and evaporation occurs as necessary, the brine then sinks to the bottom or is overridden by the lighter brines, and sets up a reflux current of higher density brine back toward the sill (ocean). It is clear that if basins were too short or the flow volume into the basin were too high, only earlier parts of this evaporation cycle would occur before the brine reaches the end of the basin and sinks underneath the incoming brine where no more evaporation could occur. The sill that restricts the inflow of seawater also stops the flow of evaporation-concentrated brines back to the ocean. The result is a sequence of precipitated salts in a flat-lying deposit that is longer than it is wide, and that occurs because of the increasing concentration of the surface brine caused by continuous evaporation from the sill to the far end of the basin. *(See figure 2b.)* The noncontinuous marine sediment zone content (asymmetrical facies distribution) of the Paradox Formation in Utah[6] and the Salado Formation in New Mexico[7] might be explained by such a model. The distributions of the various salts in the Paradox Formation in Utah (Middle Pennsylvanian of the Paleozoic Era or about 380 million years ago) and the Salado Formation (the late Mississippian period through the Pennsylvanian period and into the Permian period, all of the Late Paleozoic period, extending from about 390 million years ago to 280 million years ago) in New Mexico could probably be explained by such a model. Other deposits, such as the Salina Formation of the Silurian Period, about 430 million years ago in Michigan,[8] show a compositional distribution that is closer to a bull's-eye pattern, in which the potash is in a central part of the basin surrounded by successively less soluble salts. *(See figure 2a.)* Sedimentary features in the surrounding ring of carbonates in some evaporite basins suggest exposure to the air.[9] This could have resulted in a basin that underwent evaporative drawdown as was suggested by Hsu[10] for the Mediterranean evaporite of Miocene age (24 million years ago), the Permian Upper Zechstein (Permian Period or 280 million years ago) in Europe, the Silurian Salina evaporite deposit (430 million years ago) in Michigan, and the Devonian evaporites (400 million years ago) in Canada. The brine depth in any ancient evaporite basin could have undergone fluctuations related to sea level, ground water inflow, precipitation, and rainwater runoff so that the depositional environment of saline mineral precipitation could have occurred in deep or shallow water. Depositional and petrographic features found in evaporite deposits show evidence of the entire range of these environments, and, therefore, it is possible that many evaporite deposits that show evidence of being disconnected from free inflow of seawater were derived from mixtures of seawater and atmospheric or other waters (such as brines that traveled underground).

The evaporation of seawater results in the precipitation of alkaline earth carbonate minerals, followed by calcium and magnesium sulfates, and then magnesium and potassium chlorides. The ratio of sodium to potassium in seawater is 27:1, and, in general, minable potash beds are accompanied by thicker halite deposits. Often, the potash ore zone is near the top of halite beds in relatively thin layers because the potash is precipitated from brines of higher salinities occurring near the end of the evaporation sequence. The potash salt precipitated from evaporation of seawater after precipitation of magnesium sulfates is carnallite ($KCl{\cdot}MgCl{\cdot}6H_2O$) rather than sylvite (KCl) owing to the high concentration of magnesium in seawater.

The origin of evaporites believed to be marine deposits that are lacking magnesium sulfate and magnesium chloride minerals is often explained by postdepositional dissolution processes in which the carnallite in the salt was altered to sylvite by reaction with a magnesium-poor brine[11] or atmospheric water.[12] In the sylvinite deposits of Thailand, Congo, and the Elk Point Basin of Canada, there is evidence that the introduction of atmospheric water, or seawater of nearly normal salinity, brought about partial destruction of a precursor deposit of carnallite, leaving behind sylvinite or only barren halite. This process of changing the character of a crystallized deposit in some instances began shortly after the deposition of the carnallite layer ore, and as in the case of the Thailand deposits, may even be taking place today.[13] However, recognition that nonmarine evaporite deposits are not necessarily restricted to small, terrestrial saline lake basins has lead some workers to reassess the importance of mixing brines of seawater origin with brines of other origin and with atmospheric water.[14] Some modern evaporites, such as the Basque Lakes in British Columbia, Canada,[15] and those that occur in the Qaidam Basin of Western China,[16] which are clearly nonmarine in origin, precipitate upon evaporation a suite of minerals very similar to that calculated to precipitate from seawater.

Theoretical and experimental sequences of salts precipitated from brines that were calculated by D'Ans in 1933 bore close resemblance to naturally occurring sequences, and the presence or absence of some of the accessory minerals found in naturally occurring evaporite deposits was explained by temperature changes in the precipitating brines, mixing of brines of different compositions, and reaction of brines with previously precipitated salt. The theoretical sequence of primary precipitates from seawater at 25° C was estimated by Braitsch.[17] *(See table 2.)* The sequence and amounts of minerals calculated with more recent computer simulations of the evaporation of seawater[18] shows a slightly different mineral sequence from that calculated by Braitsch. The computer-generated sequence predicts the occurrence of polyhalite, which was not predicted in the earlier theoretical models, which does occur in many evaporite salts believed to be of marine origin, such as to the south of the Delaware Basin in New Mexico-Texas. *(See table 1.)* For deposits such as the Stassfurt horizon of the Permian Zechstein potash in Germany, the computer-predicted sequence predicts the

mineral assemblage as a primary assemblage not extensively chemically altered by postdepositional processes. The initial brine composition is critical to the sequence of minerals that precipitate upon evaporation, but the mixing of waters during evaporation can also have a profound effect on the resulting precipitates. Computer simulations of evaporation show that it is possible to produce widely varying mineral suites by altering the relative amounts of only one or two of the initial aqueous species.

Microscopic analysis (petrographic and textural relationships) and chemical analysis of fluid inclusions of associated halites in potash evaporites suggest that sylvite has occurred in many instances as a primary mineral.[19] Enrichment of seawater with respect to calcium will result in early depletion of sulfate with gypsum/anhydrite precipitation and nondeposition of magnesium sulfates. If some mechanism by which magnesium can also be removed is present in the system, then carnallite also cannot precipitate, and the primary potash mineral laid down will be sylvite. Mechanisms by which calcium enrichment and magnesium depletion can occur include dolomitization of associated limestones or of a limestone precursor,[20] interactions with hydrothermal waters,[21] and clay mineral cation exchange.[22] Sulfate depletion, which also will lead to nondeposition of magnesium sulfates, can be accomplished through brine mixing.[23]

Potash-bearing evaporites can be divided into two different types: magnesium sulfate-rich deposits (containing the minerals polyhalite, hexahydrite, kieserite, and epsomite), and magnesium sulfate-poor deposits.[24] In the former type, the primary potash mineral is carnallite, while the latter is characterized by sylvite and carnallite. The magnesium sulfate-rich evaporites, such as the Stassfurt horizon of the Permian Zechstein 2, exhibit the same mineralogy that is expected to result from evaporation of modern seawater. The magnesium sulfate-poor potash deposits probably precipitated from brines that were high in calcium and constitute 60% or more of known potash basins.[25] The fact that these two types of potash deposits also display a distinctive temporal relationship, with magnesium sulfate-rich types occurring only in the Permian (280 million years ago), Miocene (24 million years ago), and Quaternary (2 million years ago) *(see figure 3)*, may suggest changes in the composition of seawater throughout Phanerozoic (the whole period from 570 million years ago to now) time, or that many potash evaporite deposits did not precipitate from seawater, but are the result of evaporation of nonmarine or mixed marine-nonmarine waters.[26] Figure 4 shows the geographical distribution of potash deposits that contain little or no associated magnesium sulfate salts. Many of these basins are smaller than the magnesium sulfate-rich evaporite basins, and some show an elongated shape that could suggest formation in a graben valley (a valley formed by the subsidence of rock between at least two vertical fault plans) setting.

Exploration

Evaporite deposits that are found in cratonic basins are usually associated with biogenic deposits such as shelf carbonates and fringing reefs, and with clastic redbed deposits. Some evaporite deposits are found at continental margins that were sites of tectonic extension during the Mesozoic and Cenozoic periods. The high solubility of evaporite minerals precludes the formation of salt outcrops in most parts of the world, and their occurrence is generally limited to the subsurface. The proximity of evaporite deposits may be inferred from saline waters in springs and wells, solution breccias, or thick outcrops of gypsum or anhydrite. Domal or collapse structures at the surface may indicate salt domes, or piercement structures, such as those found under and around the Gulf of Mexico,[27] and under the North Sea and in the Zechstein basin.[28] Domes or anticlines that show on outcrop several periods of upward growth during a broad range of geologic time can generally be expected to have a central core of evaporites. The distribution and shape of subsurface salt structures can also be determined by geophysical techniques such as gravity and seismic methods.[29]

The origin of salt domes is believed to be due to the effect of gravity on layered rock where a lower density material (salt) is overlain by higher density material (sandstones, compacted shales, and carbonates). The shear strength of halite and potash salts is very low compared to other geologic materials, and their low compressibility maintains their low density even under deep burial conditions. Low shear strength is further abetted by high temperatures associated with deep burial. Over geologic time, salt can be squeezed upward due to the effect of gravity on a denser overburden with or without the addition of lateral tectonic compression, and its flow can be modeled as a viscous fluid.[30] Points of instability, brought about by intersections of fault systems or differential loading, are sites for nucleation of salt "pillows," or salt hills in the subsurface. As the salt masses continue to rise, anticlines formed in the overlying layers can be pierced by upward salt movement and result in the development of mushroom-shaped salt diapir structures which, in extreme cases, can become completely detached from the rest of the salt deposit.[31] In the arid climate of northern Iran, the salt diapirs have pierced the surface and flow downhill as "salt glaciers." The structure of the original depositional layering in the salt inside of a diapir is highly deformed and chaotic,[32] and may not be suitable for conventional potash mining techniques.

The vast majority of evaporite deposits were discovered as a result of drilling for petroleum. Evaluation of oil and gas exploration geophysical logs, such as gamma-ray, neutron, sonic, caliper, density, and resistance logs is useful in interpretation of evaporite lithology, stratigraphy, and mineralogy.[33] The gamma-ray log detects the gamma radiation from the natural potassium isotope K^{40} and is particularly useful for providing a continuous measure of the potassium content of the salt section.[34] Bromine content of salt layers has been used to evaluate potash potential and is useful as an indication of the stage of

evaporation, especially in waters that were predominantly marine in origin. During evaporation of a halite precipitating brine, the substitution of bromine for chlorine in the crystal lattice increases. Because precipitation of potash occurs in highly concentrated brines, the halite in and near potash beds should contain more bromine. A bromine concentration profile from seawater would show a regularly increasing bromine content toward the top of the halite bed *(see figure 5)*, while a salt precipitated from mixtures of seawater and other waters or brines or a salt that has undergone extensive postdepositional recrystallization by ground waters may show an irregular profile or one that shows no increase in bromine concentration. In northeastern Thailand, one of few potash deposits that was not found by accident by petroleum exploration was discovered by the use of bromine geochemistry.[35]

Some general guidelines for evaluating the features peculiar to an evaporite deposit that may determine the success of a mining operation were given by Adams and Hite.[36] The initial appraisal of a deposit is based on drill cores spaced on 0.5 to 1.5 km centers, depending on the depth and complexity of the deposit. The salt cores are logged with attention to all mappable stratigraphic, lithologic, and mineralogic features, and the potash horizons are sampled by individual geological units for chemical analysis. It is generally sufficient to analyze for K, Na, Ca, Mg, Cl_2, SO_4, and H_2O. The chemical analysis and the megascopic mineralogy estimated from hand specimen and thin section are used together with the stratigraphic data to develop a geologic interpretation to be evaluated in terms of the factors listed in Adams and Hite[37] to determine the potential for a minable deposit or the need for additional drilling or metallurgical tests.

ANNUAL REVIEW

Issues

Horizon Potash Corp. of Carlsbad, NM, closed for 2 months at the end of the year when its export market to Latin America became unprofitable due to low prices. The aggressive (price cutting) marketing by some offshore potash sources into the Brazilian market has caused prices on the coast of Brazil to drop below $158 per ton.[38] Carlsbad, NM, producers cannot sell all that they produce in the domestic market and depend on the Latin American market to maintain sales levels, and therefore, production levels.

Production

Domestic potash production, in K_2O equivalents, declined about 3%, to 1.7 million metric tons in 1992, from that of 1991. Of the total production for the year, 73% was standard, coarse, and granular muriate of potash, also known as potassium chloride, and 14% was sulfate of potash, also known as potassium sulfate.

Great Salt Lake Minerals Corp. increased its potassium sulfate production by purchasing potassium chloride from two States and Canada. Those purchases were subtracted from the production of the two States and the imports from Canada to prevent double counting in the "apparent consumption" calculation.

The remaining 12% of production included manure salts, soluble and chemical grades of muriate of potash, and sulfate of potash-magnesia, also known as potassium magnesium sulfate. In muriate of potash, "standard," "coarse," and "granular" refer to their particle sizes and are known as the three muriates, a term that ignores the soluble and chemical grades. "Standard" and "soluble" grades of muriate of potash and sulfate of potash also have industrial end uses. "Manure salts" formerly referred to high-grade "run-of-mine" ore and was applied to a few crops; 25% K_2O sylvinite ore is approximately 40% KCl, which can be used on sugar beets. Currently, it refers to a mixture of white KCl and NaCl for industrial uses.

The New Mexico potash producers accounted for 82% of the total marketable potash salts production, down from last year's 84% due to the temporary closure of Horizon Potash Corp.'s operation at the end of the year. The production of crude salts (ore) in New Mexico was 16 million tons with an average K_2O content of 12.7%, a 9% decrease in ore grade compared with that of 1991. In comparisons with the mined ore grades of other countries, langbeinite ore is mined in New Mexico and 8% K_2O langbeinite ore is 35%$K_2SO_4 \cdot 2MgSO_4$, a profitable ore grade. There were five producers operating six mines in 1992. Horizon Gold Corp. purchased AMAX Potash Corp. in February and renamed the operation Horizon Potash Corp. Horizon Gold Corp. renamed itself Horizon Resources Corp. Other producers were Eddy Potash Inc. owned by Trans-Resources Inc., IMC Fertilizers Inc. (IMCF), Mississippi Chemical Corp., New Mexico Potash Corp. owned by Trans-Resources Inc., and Western Ag-Minerals Co. owned by Rayrock Resources of Canada. All the New Mexico potash producers mined underground bedded ore zones and all except Western Ag-Minerals mined sylvinite ore (the mixture of sylvite and halite from which most muriate of potash originates) and beneficiated the ore to 95% pure (60% K_2O) muriate of potash. Several forms of beneficiation were used: the flotation of sylvite (potassium chloride) from halite was used at Eddy Potash, Horizon Potash, and Mississippi Chemical. The IMCF plant used both heavy-media separation and flotation, and New Mexico Potash used dissolution-recrystallization. Western Ag-Minerals and IMCF mined langbeinite ore and beneficiated the ore by washing, heavy-media separation, and flotation to sulfate of potash-magnesia. The IMCF personnel mined both sylvinite and langbeinite 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 Texasgulf Inc., which is owned by Elf Aquitaine Inc., from an underground bedded sylvinite

deposit by two-well solution mining and solar evaporation. The sylvinite salts from the solar ponds were beneficiated by flotation to separate sylvite from halite. Great Salt Lake Minerals 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 fractional crystallization. The company announced plans to increase the potash production by about 80% by about 1995. The plan is for an 80.94 square km acre solar evaporation pond on the west side of the North Arm of the Great Salt Lake, which will preevaporate brine. This brine will be transferred to the present ponds for continued evaporation. GSLMC 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. The Reilly-Wendover operation of Reilly Industries Inc. produced muriate of potash and manure salts from near-surface brines at the west end of the Bonneville Salt Flats Raceway. The Reilly-Wendover operation has agreed to a Bonneville Salt Flat Raceway rebuilding process that is contingent upon a Bureau of Land Management 3-year study.

One oil and gas firm in Utah sought partners for testing inclined solution mining along potash anticlines and beneficiation by solar evaporation about 10 km north of the Moab Salt site.

The sulfate of potash manufacturing plant in Utah reopened during the year and produced about 5,000 tons. The company continued to operate under chapter 11.

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. Although there are plans to increase soda ash production at the Argus plant, it is not clear how this will affect the potash production capacity at the Trona plant.

In Michigan, Kalium Chemical Ltd. continued pilot plant development of a deep ore body and the technology to extract muriate of 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.

Consumption and Uses

Due to several corrections in 1991, import data that were not included in the 1991 Annual Report apparent domestic consumption of all forms of potash in 1991 declined about 4% compared with that of 1990. Using the recalculated 1991 apparent domestic consumption of all forms of potash, apparent domestic consumption of all forms of potash in 1992 increased 2%. About 55.5% of domestic sales of potash was in the first half of the year, indicating good spring sales that made up for the poor sales, due to wet weather, in the fall of 1991.

According to the Potash & Phosphate Institute, the shipments of agricultural potash from Canadian and United States producers increased 9% from 1991 to 1992. The shipments of nonagricultural potash were essentially unchanged for a total (agricultural plus nonagricultural) increase of 8% from 1991 to 1992. The major States receiving agricultural potash from Canadian and United States producers, in decreasing order, were Illinois, Iowa, Ohio, Indiana, Minnesota, Missouri, and Wisconsin. These seven States received 53% of the total. Domestic producers accounted for 6% of the agricultural shipments to Illinois, 6% of the agricultural shipments to Iowa, 7% of the agricultural shipments to Ohio, 6% of the agricultural shipments to Indiana, 2% of the agricultural shipments to Minnesota, 59% of the agricultural shipments to Missouri, and 2% of the agricultural shipments to Wisconsin. The major receiving States of domestically produced agricultural potash, in decreasing order, were Missouri, Texas, California, Kansas, Florida, and Arkansas, and these States received 57% of the total. The major States receiving agricultural sulfates of potash 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. The rest of the world potash import tonnages are counted only at the entering port and are not tracked to the States in which the potash is used.

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 69% of the total.

Stocks

Yearend producers' stocks declined more than 17% compared with those of 1991. Yearend stocks represented about 16% of annual production or about 8 weeks of average production.

Prices

The average annual price, $189.30 per ton f.o.b. mine, of U.S. potash sales of all types and grades was about 6% greater than that of 1991. The average price was $189.12 for the first half of the year and $189.56 for the second half of the year. The average annual price of the three grades of muriate was $135.43, up slightly from that of last year. For the full calendar year standard grade averaged $134.79 per ton; coarse grade, $131.94; and granular grade, $136.41. The average annual price for all grades of sulfate of potash averaged $329.31 per ton, an increase of 3%.

Foreign Trade

Total potash exports of the United States as reported by the Bureau of the

Census increased 6%, with most of the increase in sulfate of potash. The major destinations for U.S. potash exports were Latin America and the Pacific Basin countries. Latin America received about 62% of all U.S. potash exports. About 87% of U.S. exports to Latin America was muriate of potash while sulfate of potash was about 9% and sulfate of potash-magnesia was about 4%. In this region, receiving about 62% of the shipments, in decreasing order, were Brazil and Mexico. The Pacific Basin countries were the second largest destination with more than 25% of the total. About 64% of the U.S. exports to the Pacific Basin was sulfate of potash while muriate of potash was 21% and sulfate of potash-magnesia was about 15%. In the Pacific Basin countries, China and Japan, in decreasing order, received about 76% of the shipments. China received only sulfate of potash, and Japan received muriate of potash, sulfate of potash, and sulfate of potash-magnesia, nearly one-half of which was sulfate of potash-magnesia. Europe received about 47,500 tons of potash, 86% of which was muriate of potash. "Other," which includes Canada and Middle Eastern and African countries, received about 5% of the exports, of which 62% was sulfate of potash-magnesia.

Considering exports by product, 81% of the muriate of potash went to Latin America while 10% went to Europe and 8% went to the Pacific Basin and 1% went to "other." For sulfate of potash, 68% went to the Pacific Basin, 24% went to Latin America, 4% went to "other," and 4% went to Europe. For sulfate of potash-magnesia, 42% went to the Pacific Basin, 31% went to "other," 25% went to Latin America, and 2% went to Europe.

Potash Co. of Saskatchewan (PCS) agreed in February to be the sales agent for Horizon Potash Corp. in the southwestern United States and in Latin America. In early summer, three other U.S. potash producers hired PCS as their sales agent into Latin America. These were Eddy Potash Inc., Mississippi Chemical Corp. and New Mexico Potash Corp.

Potash imports for consumption into the United States as reported by the Bureau of the Census increased less than 2% compared with those of 1991. Muriate of potash imports increased more than 1% while sulfate of potash increased about 22%. Imports of muriate of potash from Canada increased about 1% to 3.82 million tons. Imports of muriate of potash from the former U.S.S.R. increased about 70%, to about 196,000 tons, while imports from Germany and Israel combined dropped about 39% from that of 1991.

World Review

World potash production was estimated to have declined about 7% from that of 1991. World prices,[39] as exemplified by the per ton price of standard muriate of potash, f.o.b. Vancouver, Canada, were level at $183 per ton ($110 per ton of product) through July then rose about $7 per ton. In late August, the Government of India announced a cessation of fertilizer price subsidies for the Indian farmer. From that date forward prices tended to decline to the end of the year for some producers as they attempted to maintain cash-flow and not for other producers as they reduced production given the lower expected demand. In December, it became apparent that the Government of China was also reducing the fertilizer subsidies to the Chinese farmers through the announcement of independent traders in a free-market import sector. The lower subsidy is likely to decrease the consumption of fertilizer, including potash, in China for several years. By the end of December, the Vancouver price had returned to $183 per ton ($109 to $111 per ton product) but the delivered price in Brazil was reported at $183 per ton. Sources of potash that were competing into the Brazilian market seemed to be Germany, Spain, the United States, and some unofficial sources in the former U.S.S.R. Three countries in Latin America, Columbia, Peru, and Venezuela, and three countries in Asia, Bangladesh, Indonesia, and Sri Lanka, are rumored to be reducing their subsidies for fertilizer.

Concerning the future demand for potash and the GATT talks, should price protection, for example, for Japanese rice farmers be dropped, the demand for potash in Japan will drop. Any increase in rice production in some other country for export to Japan, such as a developing country in Latin America or the Pacific Basin (or perhaps the United States), may not increase potash consumption in the same amount as the Japanese farmers decrease potash consumption. Russia, which was a net exporter of grains before the 1917 Revolution, launched an initiative called *Russia's Bread* to reach self-sufficiency in grain production again. The attitudinal, technological, and infrastructure changes that will be needed for self-sufficiency will be difficult. The 2-year initiative is probably optimistic but will eventually succeed, decreasing demand for Australian, Canadian, European, and United States grains (and the demand for potash in those countries). Perhaps Russia may eventually export grains to Western Europe, further decreasing the demand for potash in that region in the intermediate term.

Population growth in many developing countries will not necessarily increase the demand for potash through the demand for food. There has to be wealth increases along with the population increases to pay for the food and the potash. Some developing countries may choose to invest their money, in the short and intermediate term, in other areas leading to wealth creation, such as infrastructure or education, rather than into fertilizer, which is almost a "present consumption" commodity.

Brazil.—Companhia Vale do Rio Doce announced plans to increase production capacity at the Taquari-Vassouras site from 120,000 tons to 300,000 tons.

Canada.—In 1991, Potash Co. of America, owned by Rio Algom Ltd. of Canada, reported production at the Sussex Mine at 443,000 tons, above the 420,000-ton rated capacity for the plant. Because the company reported a total of 643,000 tons, this means that the solution mine at

Patience Lake produced about 200,000 tons. Denison Mining Ltd., having suffered a large financial loss in 1990, sold its 60% share of the Denison-Potacan Mine in New Brunswick in April. The price was estimated to be $15 million plus the assumption by the buyers of $104 million in debt. The company was renamed the Potacan Mining Co. and the mine was renamed the Potacan Mine. The buyers were Potacan (Potash Co. of Canada, Ltd.), a 50%-50% joint venture of France's Groupe Entreprise Miniere et Chemique and Germany's Kali und Salz AG, who had owned 40% of the mine. The joint venture started as a sales organization for French and German potash producers before the Second World War and developed the Alwinsal Mine in Saskatchewan between 1964 and 1968. The Alwinsal Mine was the third mine expropriated by PCS in 1977 and was renamed the PCS Lanigan Mine Div. In 1991, PCS sold the experimental potassium sulfate plant at Big Quill Lake to the employees. The plant uses ion exchange resins to capture sulfate ions from the sodium sulfate-laden lake water. Using under-grade muriate from PCS, the process washes away the sulfate ions with potassium ions. The resulting solution enters crystallizers where a high-purity potassium sulfate forms.

In 1992, Canadian potash mines had 114 mine-weeks of shut downs in addition to Cory Mine operating only its crystallizers, Lanigan Mine not operating its older mill, and Allan Mine operating on a 5-day week. PCS formed a limited partnership with Florida Favorite Fertilizer Inc., which was delinquent on payments for potash, among other items. Florida Favorite operates in Florida and Georgia of the United States. International Minerals & Chemicals (Canada) Ltd. received approval for plans to replace the present mines, known as K1 and K2, with a new mine shaft and mine that would be about 6.5 km from the present K2 mill and 11 km from the present K1 mill. A second shaft is planned. The new shaft will provide access to its present reserves but will not be connected underground to the present mine workings, which has a direct connection to an aquifer. The Saskatchewan Environment and Public Safety Department approved the plans. Ore would be transported from the new shaft to the mills by capsules in a 1.0668 m subsurface pipeline using air pressure. RTZ Corp. PLC of England sold its interest in Rio Algom Ltd. in Canada but kept control of Potash Co. of America. Environmental concern has become evident concerning the potash mine salt tailings piles in Saskatchewan but the final disposition of the salt piles has not become evident. Both mines in New Brunswick designed their mines for returning tailings to the mines, but it may not be financially possible to retrofit such processes to the earlier Saskatchewan mines. Both New Brunswick mines have found that returning mill tailings to the mine adds significant costs. PCS Sales became the sales agent for Horizon Potash Co. of Carlsbad, NM, early in the year. PCS Sales will be the agent for Horizons' sales into the southwestern United States and exports to Latin America. Later in the year, Mississippi Chemical Co. and Trans-Resources' mines, New Mexico Potash and Eddy Potash, signed agency agreements that PCS will handle their potash sales into Latin America. Late in the year the Province of Saskatchewan exchanged the PCS bonds for PCS stock and reduced its ownership of PCS from about 38% to about 11%.

Chile.—Sodiedad Quimica y Minera de Chile (Soquimich) bought Amax Corp.'s 63.75% ownership in the long-studied Sociedad Minera Salar de Atacama (Minsal) Project in the Salar de Atacama. Soquimich is an iodine, sodium nitrate, and mixed sodium nitrate-potassium nitrate producer in northern Chile. The ore being mined at the present time by Soquimich cannot be beneficiated to better than a 30% mixture of potassium nitrate in sodium nitrate. By purchasing potassium chloride Soquimich can convert sodium nitrate to potassium nitrate. Potassium chloride from the Minsal site would decrease imports of potassium chloride from Canada. Soquimich has also been buying some potassium chloride from the Cyprus Foote Mineral lithium production site on the Salar de Atacama. Soquimich will reduce Amax's original potassium chloride production plans to about 300,000 tons per year of product. Soquimich also announced plans to increase its potassium nitrate capacity from 240,000 tons of product to 340,000 tons of product, which would require more potassium chloride.

China.—The production capacity at Lake Qarhan (Chaerhan) in the Tsaidam Basin in Qinghai Province should move forward with technical help from Dead Sea Works (DSW) of Israel and financial investment from DSW and the Eisenberg Group's UDI finance and trading company of Israel. The two Israel groups will purchase 12.5% each of equity in the China National Chemical Co. for $20 million each. DSW will also supply technical expertise and capital equipment worth $70 million toward the $300 million plant of 800,000 tons per year of KCl. DSW hopes to apply its cold crystallization process to a site remote from indigenous energy supplies. The site was first developed by the Chinese after the Second World War, producing up to about 20,000 tons of KCl per year. In 1982, Jacobs International of Dublin, Ireland, contracted with Chinese authorities to develop a 200,000-ton-per-year KCl plant as a pilot plant for the 800,000-ton-per-year KCl plant. The resource was a near-surface brine, and solar ponding was the desired method of crystallization. (The Tsaidam Basin is about 37° N. while the solar evaporation ponds of the Great Salt Lake are about 42° N. and the two sets of solar ponds at the southern tip of the Dead Sea are about 31° N.) The brine crystallizes carnallite, as do the Dead Sea potash operations. In 1992, the site was reported to have never surpassed 100,000 tons per year of KCl production.

Egypt.—BHP Minerals International reports potash ore intersections of 32 m during exploration by drilling to 2,164 m near the Red Sea about 27° N.

European Community.—The European Potash Producers Association (APEP) filed charges of dumping before the European Economic Commission against the "peristroika" potash (always potassium chloride) from the former U.S.S.R. in 1990. In April 1992, the Commission imposed provisional minimum prices on those imports of potassium chloride. The minimum price for standard muriate was $189.35[40] per ton (ECU92 per ton product or $113.60 per ton product) and for granular muriate was $212 per ton (ECU103 per ton product or $127.20 per ton product). In October, the definitive ruling was published using lower minimum prices of $185 per ton (ECU86.92 per ton product or $111 per ton product) for standard-grade muriate and $210 per ton (ECU 98.65 per ton of product or $126 per ton of product) for granular muriate. This was a 2% discount for the perceived lower quality of potash from the former U.S.S.R.

Germany.—Rossleben of Mitteldeutsche Kali AG (MdK) was shut down permanently on the last day of 1991. Salzdetfurth of Kali und Salz AG (K+S) shut down permanently in March 1992. Mitteldeutsche Kali AG was owned through 1992 by Treuhandanstalt and consists of three plants at Zeilitz, Bischofferode, and Unterbreizbach, and four mines at Zeilitz, Bischofferode, Merkers, and Unterbreizbach.

At the end of the year K+S and Treuhandanstalt announced their intention of forming a joint-venture company. K+S will own 51% of the joint-venture company and will manage the company.

K+S will, sometime in the next 5 years, shut down the mine at Bergmannsseggen-Hugo and the mine and plant at Niedersachsen-Riedel. Mitteldeutsche Kali will close down the plant at Merkers Mine while connecting the mine underground to the other mine in the area, Unterbreizbach. Mitteldeutsche Kali will eventually shut down the Bischofferode plant in the Sud-Harz district. This will leave open the Zielitz Mine and plant and the Unterbreizbach Mine and plant. The Merkers Mine and K+S Hattorf Mine will feed the Unterbreizbach plant. The remaining operations will be Wintershall Neuhof Ellers, Sigmundshall (of K+S), and Unterbreizbach and Zeilitz of MdK. Employment changes in the potash industry in Germany have been truly wrenching. The former East German potash industry employed 32,000 workers in 1988 and is heading toward 7,000 workers. K+S lost 1,400 workers when it closed Salzdetfurth at the end of 1991 and will lose another 1,000 to reach 6,500 workers. K+S has not announced the job loss due to the closure of Bergmannsseggen-Hugo and Neidersachsen-Reidel.

India.—India announced cessation of subsidies for fertilizers to farmers in August. Demand is forecast to drop by as much as 50% in the next fertilizer year (April 1993 to March 1994). For the current Indian fertilizer year (April 1992 to March 1993), potash usage is forecast to drop to 1.7 million tons KCl, from a previously expected 2.4 million tons.

Israel.—Haifa Chemicals, owned by Trans-Resources of the United States, announced plans to increase capacity from 300,000 to 400,000 tons of KNO_3 with a $105 million investment near Mishor Rotem. The Israeli Government will grant about $63 million for this project. World consumption of KNO_3 is put at 600,000 tons per year with a growth rate of 7% to 8% per year. One magazine[41] reported KNO_3 plant closures in France, Poland, and the former German Democratic Republic. The Government of Israel sold 18% of its holdings in Israel Chemicals Ltd., parent of DSW, for $225 million in February on the Tel Aviv Stock Exchange. It is not clear how this affects DSW. DSW announced studies to build evaporation ponds south of the Dead Sea Graben, near Yotvata, to which Dead Sea brine would be pumped for the production of salt, making this a preconcentration pond. The salt would be exported from Eliat, and the bitterns would be piped back to the present DSW ponds for carnallite production. The added potash production was expected to be sold to China and India. DSW apparently withdrew from the U.S. east coast market (1990, 221,600 tons; 1991, 113,000 tons; and 1992, 72,000 tons).

Jordan.—Arab Potash Co. will finish a 240,000-ton-per-year capacity increase in 1994 and is considering another 240,000 tons per year by 1997. Final tonnage is estimated at 1.3 million tons as KCl.

Spain.—The decline of Grupo Torres SA into receivership did not affect the Spanish potash industry because all of the potash mines are currently state owned.

Former U.S.S.R.—It has been estimated[42] that former U.S.S.R. potash consumption has fallen by 2.5 million tons of product between 1988 and 1991 or 35% while the Eastern European countries' potash consumption has fallen by 1.5 million tons of product or 50% between 1988 and 1991. There was a 2-month strike at the Belarus potash mines for higher wages. The European Community placed a floor price for imported former U.S.S.R. potash in April by a provisional finding of dumping and set definitive minimum prices, in October, on former U.S.S.R. potash (see European Community section). The new former U.S.S.R. fertilizer export firm, AgroChimExport, did not handle all of the potash leaving the country in the latter half of the year. "Peristroika potash" flowed into the world potash trading arena, which drove down prices on the east coast of Latin America and, to a lesser extent, in the Pacific Basin and Asia. AgroChimExport and three potash firms, Sylvinit, Uralkali, and Byeloruskali, formed two joint-venture trading firms during the year. One was based in Austria and named Belurs GmbH. The other was based in Singapore and named Agrosin.

United Kingdom.—Cleveland Potash Ltd. increased its granular potash capacity by 33% to 320,000 tons per year of KCl

with the addition of a fourth compactor.

OUTLOOK

The world potash industry currently is in a situation of overcapacity, even with the recent shutdowns of capacity in Germany, and seems likely to remain so for a decade. The United States will lose some capacity before the year 2000, Thailand is likely to replace that capacity, while China and Egypt may add more capacity.

The problem is the decline in demand among the developed market countries since 1979 (the second world oil shock) and in many of the former centrally planned economies since 1988. Demand in several developed economies may drop as subsidies for agriculture are revised downward in those countries. This demand may shift demand to several developing countries, giving the developing economy countries in Latin America and the Pacific Basin added growth. The Latin America and Pacific Basin countries are the regions of potash demand growth in the world. They were approximately one-third the level of the developed countries in 1988 and no reasonable growth rate would bring these regions' aggregate demand level to the developed market economy countries' 1988 level in the near future. Another region of declining demand, the former centrally planned economies once consumed as much as the developed countries, and some of these countries have decreased their level of potash consumption to one-half their former level. It is currently unclear what a reasonable demand path into the future for the Eastern Europe and former U.S.S.R. countries is, or even what direction that path will take for the next 5 years.

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[1]Adapted with Sherilyn Williams-Stroud's permission from the forthcoming chapter on Potash by Williams-Stroud, Hite and Searls in the Society of Mining, Metallurgy and Exploration's book Industrial Rocks and Minerals, to be published in the fall of 1993. Published with the permission of Dr. Donald Carr, editor.

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TABLE 1

SOME MINERALS, ORES, AND PRODUCTS OF POTASH DEPOSITS

Name	Formula	K_2O, equivalent weight percent	Remarks
MARINE EVAPORITE DEPOSITS			
MINERALS			
Chlorides:			
Sylvite	KCl	63.17	Principal ore mineral.
Carnallite	$KCl \cdot MgCl_2 6H_2O$	16.95	Ore mineral and contaminant.
Kainite	$4KCl \cdot 4MgSO_4 \cdot 11H_2O$	19.26	Important ore mineral.
Bischofite	$2MgCl_2 \cdot 12H_2O$	—	Accessory contaminant.
Halite	NaCl	—	Principal ore contaminant.
Sulfates:			
Polyhalite	$K_2SO_4 \cdot MgSO_4 \cdot 2CaSO_4 \cdot H_2O$	15.62	Ore contaminant.
Langbeinite	$K_2SO_4 \cdot 2MgSO_4$	22.69	Important ore mineral.
Leonite	$K_2SO_4 \cdot MgSO_4 \cdot 4H_2O$	25.68	Ore contaminant.
Schoenite (picromerite)	$K_2SO_4 \cdot MgSO_4 \cdot 6H_2O$	23.39	Accessory.
Glaserite (aphthitalite)	$3K_2SO_4 \cdot Na_2SO_4$	42.51	Do.
Syngenite	$K_2SO_4 \cdot CaSO_4 \cdot H_2O$	28.68	Do.
Bloedite	$Na_2SO_4 \cdot MgSO_4 \cdot 4H_2O$	—	Do.
Loeweite	$6Na_2SO_4 \cdot 7MgSO_4 \cdot 15H_2O$	—	Do.
Vanthoffite	$3Na_2SO_4 \cdot MgSO_4$	—	Do.
Kieserite	$MgSO_4 \cdot H_2O$	—	Common ore contaminant.
Hexahydrite	$MgSO_4 \cdot 6H_2O$	—	Accessory.
Epsomite	$MgSO_4 \cdot 7H_2O$	—	Do.
Anhydrite	$CaSO_4$	—	Common ore contaminant.
ORES			
Sylvinite[1]	KCl + NaCl	10-35	Canada, United States, former U.S.S.R., Brazil, Congo, Thailand.
Hartsalz	$KCl + NaCl + CaSO_4 + (MgSO_4 \cdot H_2O)$	10-20	Germany.
Carnallitite[2]	$KCl \cdot MgCl_2 \cdot 6H_2O + NaCl$	10-16	Germany, Spain, Thailand.
Langbeinite[3]	$K_2SO_4 \cdot 2MgSO_4 + NaCl$	7-12	United States, former U.S.S.R.
Mischsalz	Hartsalz + Carnallite	8-20	Germany.
Kainite	$4KCi \cdot 4MgSO_4 \cdot 11H_2O + NaCl$	13-18	Italy, Ethiopia.
PRODUCTS			
Potassium chloride	KCl	63.17	Principal potassium product.
Potassium sulfate	K_2SO_4	54.05	Artificial product.
Potassium-magnesium-sulfate (langbeinite)	$K_2SO_4 \cdot 2MgSO_4$	22.69	Natural product (New Mexico).
Manure salts	KCl + NaCl	40-60	Former U.S.S.R., East Germany.
OTHER SOURCES			
Alunite	$K_2Al_6(SO_4)_4(OH)_{12}$	11.4	
Niter (caliche)	$KNO_3 + NaNO_3 + Na_2SO_4 + NaCl$	.6-1.9	Chile.
Potassium nitrate	$KNO_3 + NaNO_3$	10-14	

[1]May contain one or more sulfate minerals or carnallite.

[2]May contain sylvite.

[3]May contain sylvite and leonite, kainite, or other sulfate minerals.

Source: Modified after Adams, 1968.

TABLE 2

THEORETICAL PRIMARY PRECIPITATION OF STABLE CHLORIDE ASSEMBLAGES FROM NORMAL SEAWATER PLUS STATIC EVAPORATION AT 25° C

(Without reaction at transition points)

Layer	Mineral assemblages		Thickness of layer (meters)
	Mineral	Percentage	
A	Halite	100	100.0
B_1	Halite	72	6.3
	Bloedite	28	
B_2	Halite	20	4.5
	Epsomite	80	
C_1	Halite	29	6.3
	Epsomite	30	
	Kainite	41	
C_2	Halite	21	5.7
	Hexahydrite	3	
	Kainite	76	
C_3	Halite	11	1.7
	Kieserite	4	
	Kainite	85	
D_1	Halite	12	3.6
	Kieserite	40	
	Carnallite	48	
E	Halite	0.5	38.0
	Kieserite	1	
	Carnallite	0.5	
	Bischofite	98	

Source: Adapted from Braitsch, 1971, by Adams and Hite, 1983.

TABLE 3
SALIENT POTASH[1] STATISTICS

(Thousand metric tons and thousand dollars, unless otherwise specified)

	1988	1989	1990	1991	1992
United States:					
Production	2,999	3,132	3,360	3,446	3,341
K_2O equivalent	1,521	1,595	1,713	1,749	1,705
Sales by producers	2,802	3,008	3,391	3,327	3,467
K_2O equivalent	1,427	1,536	1,716	1,709	1,766
Value[2]	$240,300	$271,500	$303,300	r$304,500	$334,406
Average value per ton of product dollars	$85.75	$90.28	$89.46	$91.52	$96.45
Average value per ton of K_2O equivalent do.	$168.37	$176.74	$176.80	$178.20	$189.36
Exports[3]	783	945	1,016	1,256	1,330
K_2O equivalent	380	446	470	624	663
Value[4]	NA	NA	$136,100	NA	NA
Imports for consumption[3 5]	6,964	e5,618	6,952	r6,862	6,980
K_2O equivalent	4,217	e3,410	4,164	r4,158	4,227
Customs value	$623,000	$501,300	$545,700	$549,600	$577,800
Consumption, apparent[7]	8,983	e7,680	r9,327	r8,933	9,117
K_2O equivalent	5,264	e4,500	r5,410	r5,243	5,330
Yearend producers' stocks, K_2O equivalent	248	307	303	343	283
World: Production, marketable K_2O equivalent	r31,820	r28,916	r27,772	r26,094	e24,327

eEstimated. rRevised. NA Not available.

[1]Includes muriate and sulfate of potash, potassium magnesium sulfate, and some parent salts. Excludes other chemical compounds containing potassium.

[2]F.o.b. mine.

[3]Excludes potassium chemicals and mixed fertilizers.

[4]F.a.s. U.S. port.

[5]Includes nitrate of potash.

[6]Imports probably underreported.

[7]Calculated from production plus imports minus exports plus or minus industry and Government stock changes.

TABLE 4

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_2O equivalent		Gross weight		K_2O equivalent		Value[e] [1]		Gross weight		K_2O equivalent	
	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992
January-June:														
Muriate of potash, 60% K_2O minimum:														
Standard	322	340	197	208	393	351	240	214	30,200	28,400	38	97	23	59
Coarse	106	92	65	57	83	123	51	75	7,400	9,700	38	33	23	20
Granular	622	642	378	391	777	722	471	439	64,000	59,100	86	132	52	80
Chemical	9	9	5	5	8	9	5	5	W	W	1	1	(2)	1
Potassium sulfate	237	246	120	125	235	305	119	154	37,700	50,300	80	56	41	29
Other potassium salts[3]	429	398	111	106	445	497	119	129	W	W	160	143	35	31
Total[4]	1,723	1,728	876	891	1,940	2,007	1,005	1,016	177,900	192,200	402	462	174	220
July-December:														
Muriate of potash, 60% K_2O minimum:														
Standard	352	324	214	198	283	320	173	195	22,900	26,700	107	98	65	60
Coarse	112	101	69	62	86	90	53	54	6,800	7,400	64	45	39	28
Granular	600	533	363	323	478	492	289	299	37,700	41,500	208	175	126	106
Chemical	9	7	6	4	9	7	6	4	W	W	1	1	1	1
Potassium sulfate	215	232	109	118	180	221	92	113	29,800	37,600	115	68	58	34
Other potassium salts[3]	431	416	111	109	351	331	92	85	W	W	242	228	55	55
Total[4]	1,723	1,613	873	814	1,387	1,460	704	750	126,600	142,206	738	616	343	283
Grand total[4]	3,446	3,341	1,749	1,705	3,327	3,467	1,709	1,766	304,500	334,406	XX	XX	XX	XX

[e]Estimated. W Withheld to avoid disclosing company proprietary data; included in "Total." XX Not applicable.

[1]F.o.b. mine.

[2]Less than 1/2 unit.

[3]Includes soluble muriate, manure salts, and potassium magnesium sulfate.

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

TABLE 5
PRODUCTION AND SALES OF POTASH IN NEW MEXICO

(Thousand metric tons and thousand dollars)

Period	Crude salts[1] (mine production)		Marketable potassium salts				
			Production		Sold or used		
	Gross weight	K_2O equivalent	Gross weight	K_2O equivalent	Gross weight	K_2O equivalent	Value[e 2]
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[3]	16,286	2,250	2,951	1,474	2,895	1,470	250,867
1992:							
January-June	8,247	1,095	1,439	731	1,658	826	145,578
July-December	7,792	949	1,345	663	1,212	610	111,042
Total[3]	16,039	2,044	2,783	1,395	2,869	1,436	256,620

[e]Estimated.
[1]Sylvinite and langbeinite.
[2]F.o.b. mine.
[3]Data may not add to totals shown because of independent rounding.

TABLE 6
SALIENT U.S. SULFATE OF POTASH[1] STATISTICS

(Thousand metric tons of K_2O equivalent and thousand dollars)

	1989	1990	1991	1992
Production	166	219	230	243
Sales by producers	147	221	211	267
Value[2]	$47,355	$70,226	$67,432	$87,884
Exports[3]	78	124	104	158
Value[4]	NA	r$43,300	NA	NA
Imports[3]	32	26	29	35
Value[5]	$11,700	$11,000	$11,800	$13,600
Consumption, apparent[6]	101	123	136	146
Yearend producers' stocks	42	39	58	34

[r]Revised. NA Not available.
[1]Excluding potassium magnesium sulfate.
[2]F.o.b. mine.
[3]Bureau of the Census.
[4]F.a.s. U.S. port.
[5]C.i.f. to U.S. port.
[6]Calculated from production plus imports minus exports plus or minus industry stock changes.

TABLE 7

SALES OF NORTH AMERICAN POTASH, BY STATE OF DESTINATION

(Metric tons of K_2O equivalent)

State	Agricultural potash		Nonagricultural potash	
	1991	1992	1991	1992
Alabama	75,808	86,341	156,276	169,071
Alaska	466	2,141	98	416
Arizona	3,435	3,649	693	782
Arkansas	55,035	62,225	457	602
California	73,301	85,358	9,327	7,333
Colorado	11,287	12,818	1,753	3,387
Connecticut	999	2,398	516	458
Delaware	26,908	20,779	49,992	47,968
Florida	148,866	169,878	1,216	1,545
Georgia	133,009	140,501	1,868	1,940
Hawaii	22,346	7,495	—	23
Idaho	27,105	29,381	1,028	223
Illinois	518,709	549,257	10,011	6,874
Indiana	314,219	310,805	2,771	3,269
Iowa	347,002	441,900	5,307	3,503
Kansas	39,330	47,723	2,550	4,166
Kentucky	104,903	127,890	676	674
Louisiana	99,253	125,756	1,546	2,461
Maine	4,638	6,734	706	705
Maryland	26,580	28,591	183	238
Massachusetts	2,797	10,776	291	290
Michigan	170,310	180,550	6,958	7,101
Minnesota	273,820	278,284	2,810	2,851
Mississippi	43,261	73,678	46,745	46,653
Missouri	223,017	253,652	3,675	3,035
Montana	11,877	13,374	20	68
Nebraska	31,858	32,772	1,719	1,310
Nevada	447	221	37	107
New Hampshire	573	452	224	243
New Jersey	5,035	4,289	756	823
New Mexico	9,950	7,437	10,650	12,465
New York	51,741	57,810	720	654
North Carolina	100,816	108,351	669	961
North Dakota	21,902	26,102	13	12
Ohio	374,328	348,282	61,714	66,048
Oklahoma	16,683	21,956	2,174	1,754
Oregon	26,956	34,724	1,980	1,373
Pennsylvania	59,411	58,048	3,494	2,517
Rhode Island	709	1,055	38	24
South Carolina	52,562	69,049	54	64
South Dakota	14,587	16,372	99	151
Tennessee	90,284	104,648	454	355
Texas	144,426	141,909	29,007	23,584
Utah	14,451	22,391	13,914	8,867

TABLE 7—Continued

SALES OF NORTH AMERICAN POTASH, BY STATE OF DESTINATION

(Metric tons of K_2O equivalent)

State	Agricultural potash		Nonagricultural potash	
	1991	1992	1991	1992
Vermont	6,898	8,262	132	833
Virginia[1]	68,482	73,734	285	221
Washington[1]	43,767	40,591	4,228	3,468
West Virginia	13,079	29,622	743	937
Wisconsin	200,846	206,267	34,578	33,427
Wyoming	2,784	2,531	1,041	1,299
Total[2]	4,110,858	4,488,808	476,199	477,132

[1]This State's data were not published in the 1991 yearbook.
[2]Data may not add to totals shown because of independent rounding.

Source: Potash & Phosphate Institute.

TABLE 8

SALES OF NORTH AMERICAN MURIATE OF POTASH TO U.S. CUSTOMERS, BY GRADE

(Thousand metric tons of K_2O equivalent)

Grade	1989	1990	1991	1992
Agricultural:				
Standard	310	263	251	271
Coarse	2,036	1,882	1,862	1,988
Granular	1,658	1,658	1,482	1,651
Soluble	342	334	349	383
Total	4,346	4,137	3,944	4,293
Nonagricultural:				
Soluble	116	131	85	107
Other	305	314	387	365
Total	421	445	[1]473	472
Grand total	4,767	4,582	4,417	4,765

[1]Data do not add to total shown because of independent rounding.

Source: Potash & Phosphate Institute.

TABLE 9

PRICES[1] OF U.S. POTASH, BY TYPE AND GRADE

(Dollars per metric ton of K_2O equivalent)

Type and grade	1990		1991		1992	
	January-June	July-December	January-June	July-December	January-June	July-December
Muriate, 60% K_2O minimum:						
Standard	129.84	120.52	126.21	132.27	132.78	137.05
Coarse	137.32	129.07	143.36	129.17	128.72	136.38
Granular	135.36	131.60	135.63	130.29	134.64	138.99
All muriate[2]	133.25	124.38	133.25	130.84	133.48	138.04
Sulfate, 50% K_2O minimum	326.34	307.47	315.67	324.32	325.87	334.03

[1]Average prices, f.o.b. mine, based on sales.
[2]Excluding soluble and chemical muriates.

TABLE 10
U.S. EXPORTS OF POTASH, BY TYPE

	Approximate average K_2O content (percent)	Quantity (metric tons)		Value (thousands)
		Product	K_2O equivalent	
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	r67,400	NA
Potassium nitrate	45	r16,000	r7,200	NA
Total	XX	r1,256,300	r624,000	NA
1992:				
Potassium chloride, all grades	61	708,500	432,200	NA
Potassium sulfate	51	309,800	158,000	NA
Potassium magnesium sulfate	22	292,600	64,400	NA
Potassium nitrate	45	18,600	8,400	NA
Total	XX	1,329,500	663,000	NA

rRevised. NA Not available. XX Not applicable.

Source: Bureau of the Census.

TABLE 11

U.S. EXPORTS OF POTASH, BY COUNTRY[1]

(Metric tons of product)

Country	Potassium chloride		Potassium sulfates, all grades[2]		Potassium nitrate		Total[3]	
	1991	1992	1991	1992	1991	1992	1991	1992
Algeria	91	—	—	—	—	—	91	—
Argentina	8,873	5,884	5,456	4,589	—	—	14,330	10,470
Australia	36	16,400	15,840	8,525	3	—	15,880	24,925
Bahamas	20	—	49	20	—	—	69	20
Bangladesh	—	—	6,300	—	—	—	6,300	—
Barbados	21	—	18	—	—	—	39	—
Belgium	15,540	—	—	815	—	—	15,540	815
Belize	2,175	1,813	271	276	—	—	2,446	2,089
Bolivia	417	4,375	—	—	—	—	417	4,375
Brazil	297,120	311,980	11,450	750	—	—	r308,570	312,730
Canada	7,424	8,515	67,910	87,850	4,115	4,914	79,450	101,280
Chile	17,170	32,460	23,730	16,430	—	—	40,900	48,890
China	54,050	—	122,600	161,420	—	—	r176,650	161,420
Colombia	9	1	22,930	4,551	—	1	22,940	4,553
Costa Rica	34,020	53,810	25,620	38,170	—	—	59,640	91,980
Cote d'Ivoire	—	—	—	4,200	—	—	—	4,200
Dominican Republic	34,420	27,010	3,987	7,184	—	18	38,410	34,210
Ecuador	21,790	22,530	7,109	4,490	—	—	28,890	27,020
Egypt	1,649	1	—	—	—	—	1,649	1
Fiji	—	3,447	—	—	—	—	—	3,447
France	4	44,580	—	—	10	6	14	44,590
Germany	168	91	—	—	—	2	168	93
Guatemala	10,610	9,748	1,581	5	—	—	12,190	9,753
Haiti	—	—	—	—	—	88	—	88
Honduras	16,720	5,951	1,575	2,174	—	—	r18,295	8,125
Indonesia	—	3	—	11,570	—	—	—	11,570
Ireland	6,971	—	—	—	—	—	6,971	—
Israel	—	—	511	38	1	4	512	42
Italy	75	6,091	11,780	16,000	8	—	11,860	22,090
Jamaica	5,534	3,249	—	—	—	12	5,534	3,261
Japan	47,760	16,380	120,280	127,950	8,415	9,098	r176,455	153,430
Korea, Republic of	5,240	6,117	1,786	646	—	2	7,026	6,765
Malaysia	—	—	12,510	—	—	—	12,510	—
Martinique	5,814	—	3,000	—	—	—	8,814	—
Mexico	53,420	63,440	31,870	50,130	3,315	4,434	r88,605	118,000
Netherlands	—	—	1,646	204	—	—	1,646	204
New Zealand	18	21	52	36	—	—	70	57
Nicaragua	3,090	1,500	—	1,500	—	—	3,090	3,000
Panama	8,059	14,280	265	2,905	—	—	8,324	17,185
Peru	5,725	7,047	2,100	4,000	—	—	7,825	11,050
Philippines	5	14,990	24	14,500	—	—	29	29,490
Saudi Arabia	571	—	—	1	—	—	571	1
Singapore	—	—	r1	—	—	—	r1	—
South Africa, Republic of	5,499	—	r2,010	11,020	—	2	r7,509	11,020
Spain	—	1,000	100	—	—	—	100	1,000

See footnotes at end of table.

TABLE 11—Continued

U.S. EXPORTS OF POTASH, BY COUNTRY[1]

(Metric tons of product)

Country	Potassium chloride		Potassium sulfates, all grades[2]		Potassium nitrate		Total[3]	
	1991	1992	1991	1992	1991	1992	1991	1992
Sweden	408	538	—	—	—	—	408	538
Taiwan	—	—	243	195	—	—	243	195
Thailand	—	—	5,000	5,000	3	—	5,003	5,000
Trinidad and Tobago	1,429	2,431	—	—	r1	—	r1,430	2,431
United Kingdom	13,070	15,510	11	11	—	—	13,080	15,520
Uruguay	—	7,266	—	—	—	—	—	7,266
Venezuela	45,510	5	20	15,270	35	—	r45,565	15,275
Other	r95	6	r100	37	r3	16	r198	59
Total[3]	730,600	708,500	509,700	602,400	r16,000	18,600	1,256,300	1,329,500

rRevised.

[1]The Bureau of the Census ceased publication of value data in 1985, but now makes value by code, by month, available.

[2]Includes potassium magnesium sulfate.

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

Source: Bureau of the Census.

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF POTASH, BY TYPE

	Approximate average K_2O content (percent)	Quantity (metric tons)		Value (thousands)	
		Product	K_2O equivalent[e]	Customs	C.i.f.
1991:					
Potassium chloride	61	r6,745,000	r4,114,500	$528,500	$634,700
Potassium sulfate	51	r55,700	r28,400	10,100	11,800
Potassium nitrate	45	22,300	10,000	6,000	6,900
Potassium sodium nitrate mixtures	14	r39,100	5,500	5,000	r5,700
Total	XX	r6,862,100	r4,158,400	549,600	r659,100
1992:					
Potassium chloride	61	6,836,000	4,170,000	549,100	645,800
Potassium sulfate	51	67,700	34,600	11,800	13,600
Potassium nitrate	45	39,100	17,600	11,300	12,600
Potassium sodium nitrate mixtures	14	36,900	5,200	5,600	6,200
Total[1]	XX	6,979,700	4,227,300	577,800	678,200

eEstimated. rRevised. XX Not applicable.

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

Source: Bureau of the Census, as adjusted by the U.S. Bureau of Mines.

TABLE 13
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.	
	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992
Belgium	3,000	2,000	r5,457	7,751	362	21	19	—	r8,838	9,772	r$1,419	$1,625	r$1,684	$1,915
Belarus[2]	—	59,159	—	—	—	—	—	—	—	59,159	—	5,064	—	5,756
Canada	r6,232,537	6,311,620	r482	1,064	1	4	r12,791	8,556	r6,245,811	6,321,244	r487,547	505,572	r587,260	596,888
Chile	—	—	—	—	r13,283	13,882	r26,055	28,155	r39,338	42,037	r5,893	7,788	r6,850	8,663
France	—	1,500	r5,248	1,977	—	—	—	2	r5,248	3,479	r1,012	543	r1,257	658
Germany	r130,759	72,120	r44,290	56,902	—	5	—	—	r175,049	129,027	r18,044	14,991	r20,866	17,633
Israel	r185,224	120,006	—	—	r8,285	24,697	—	—	r193,509	144,703	r20,676	19,881	r23,119	21,888
Italy	—	—	30	—	86	—	—	—	116	—	27	—	30	—
Latvia[2]	—	62,158	—	—	—	—	—	—	—	62,158	—	4,619	—	5,264
Poland	—	—	—	—	218	106	—	—	218	106	89	56	111	68
Russia[2]	—	184,938	—	—	—	50	—	—	—	184,988	—	15,215	—	16,286
Ukraine[2]	—	21,200	—	—	—	—	—	—	—	21,200	—	1,887	—	2,596
U.S.S.R.[3]	r192,940	—	—	—	1	—	—	—	r192,941	—	r14,403	—	r17,327	—
United Kingdom	211	288	—	—	—	—	—	—	211	288	125	115	143	133
Other	333	1,013	236	52	27	301	178	198	774	1,564	376	405	428	480
Total[1]	r6,745,004	6,836,002	r55,743	67,746	r22,263	39,066	r39,043	36,911	r6,862,053	6,979,725	r549,612	577,761	r659,076	678,228

rRevised.
[1]Data may not add to totals shown because of independent rounding.
[2]Formerly part of the U.S.S.R; data were not reported separately until 1992.
[3]The U.S.S.R. dissolved in Dec. 1991.

Source: Bureau of the Census, as adjusted by the Bureau of Mines.

TABLE 14

MARKETABLE POTASH: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons of K_2O equivalent)

Country	1988	1989	1990	1991	1992e
Belarus[2]	—	—	—	—	3,600
Brazil	54	97	66	r101	100
Canada[3]	8,154	7,014	7,345	r7,406	4,7,327
Chile e	5,25	25	25	20	20
China e	r22	r28	r20	r24	25
France	1,502	1,195	r1,292	1,129	1,130
Germany:					
Eastern states	3,510	r3,199	r2,653	—	—
Western states	2,290	2,182	r2,216	—	—
Total	5,800	r5,381	r4,869	r3,902	4,3,470
Israel	1,244	1,273	1,311	r1,320	1,300
Italy	95	112	51	r31	100
Jordan	785	792	841	r805	800
Russia[2]	—	—	—	—	3,500
Spain	855	741	r751	585	600
Ukraine[2]	—	—	—	—	200
U.S.S.R.[6]	11,301	10,200	9,000	r e8,560	—
United Kingdom	460	462	488	r462	450
United States	1,521	1,595	1,713	1,749	4,1,705
Total	r31,820	r28,916	r27,772	r26,094	24,327

eEstimated. rRevised.

[1]Table includes data available through Apr. 26, 1993.

[2]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[3]Official Government figures.

[4]Reported figure.

[5]Figure represents officially reported output by Servicio Nacional de Geologia y Mineria (SERNAGEOMIN) of potassium nitrate product (gross weight basis) converted assuming 14 % K_2O equivalent.

[6]Dissolved in Dec. 1991.

FIGURE 1

CLASSIC REFLUX DEPOSITIONAL MODEL FOR EVAPORITE DEPOSITION

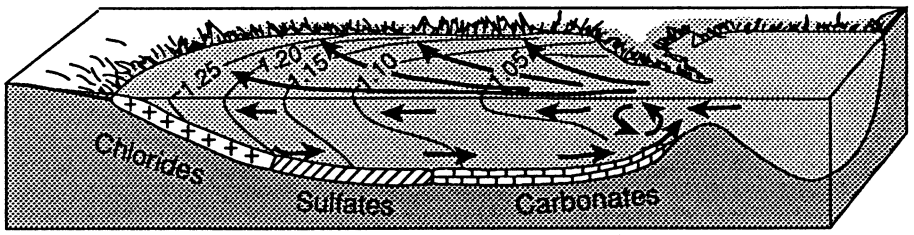


FIGURE 2
TWO POSSIBLE EVAPORITE DEPOSITIONAL PATTERNS

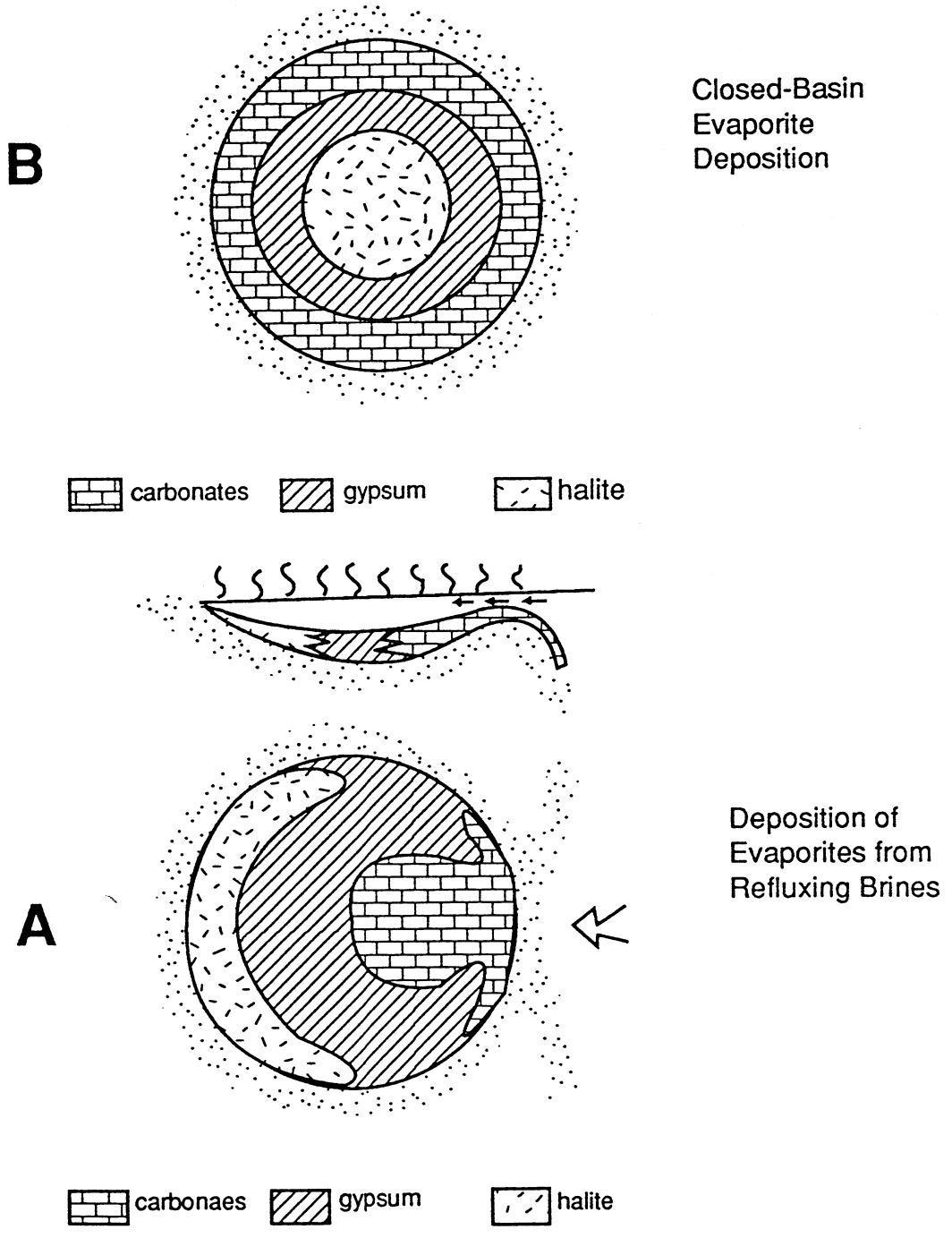


FIGURE 3
MAGNESIUM SULFATE-RICH POTASH DEPOSITS

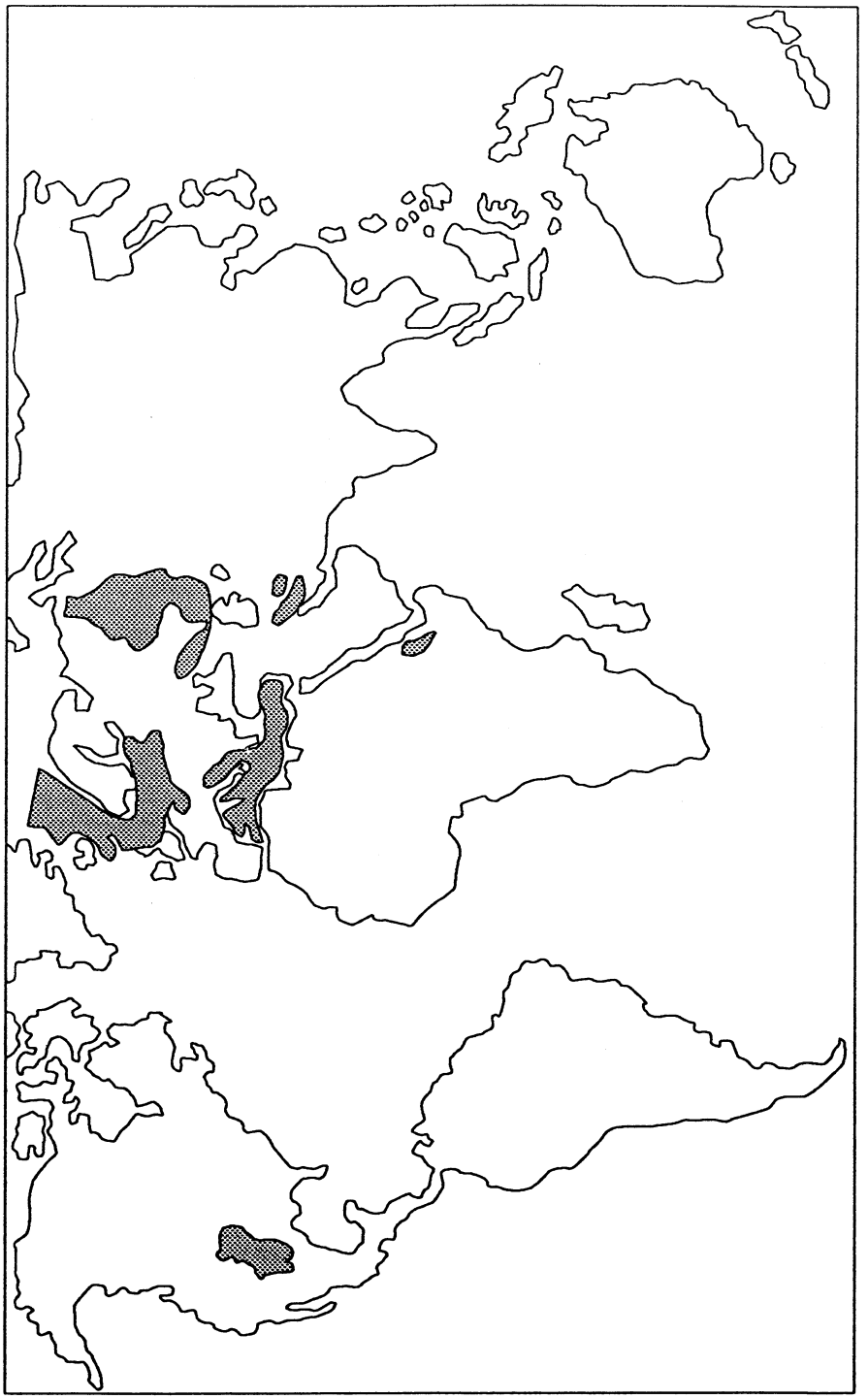


FIGURE 4
MAGNESIUM SULFATE-DEFICIENT POTASH DEPOSITS

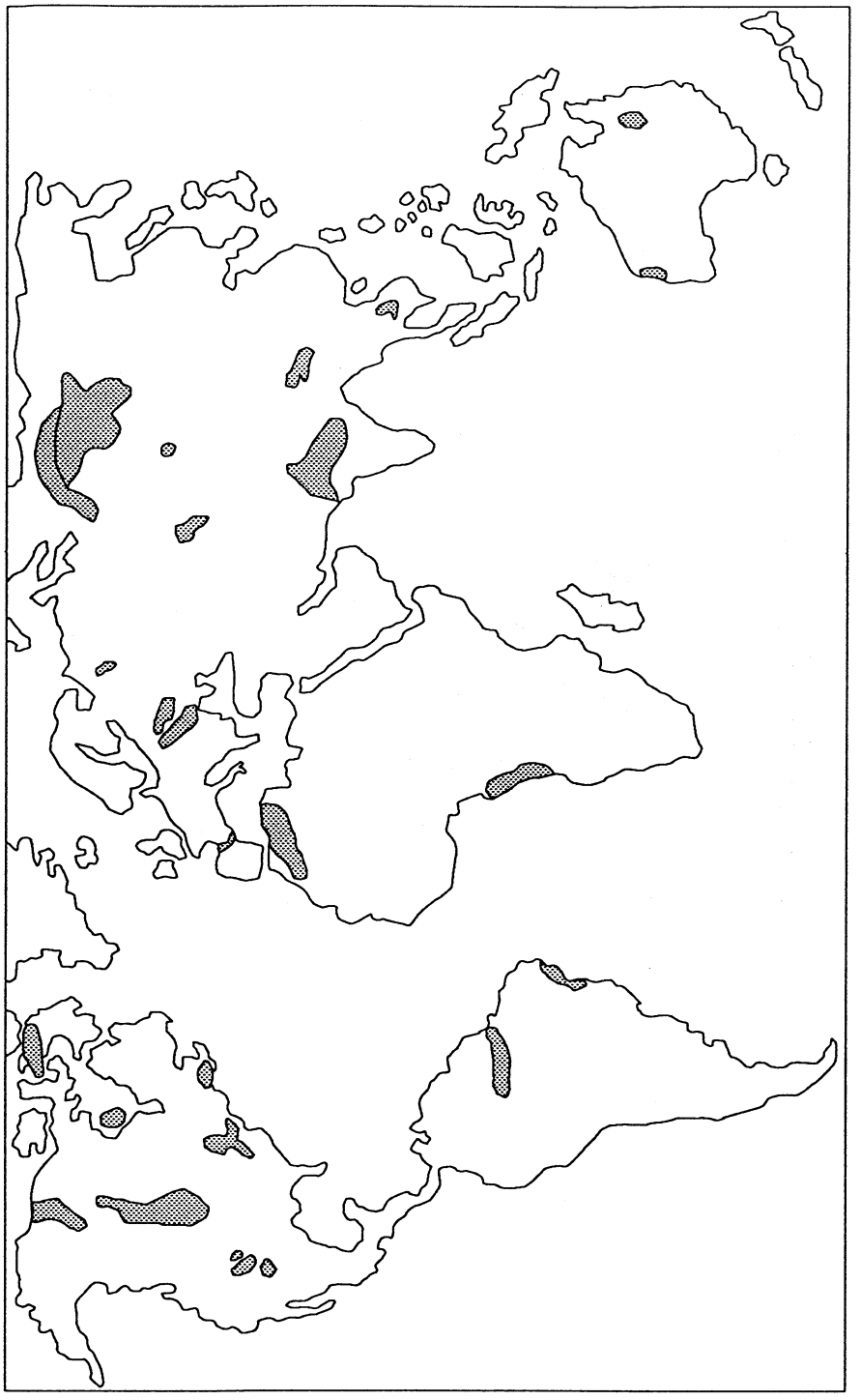
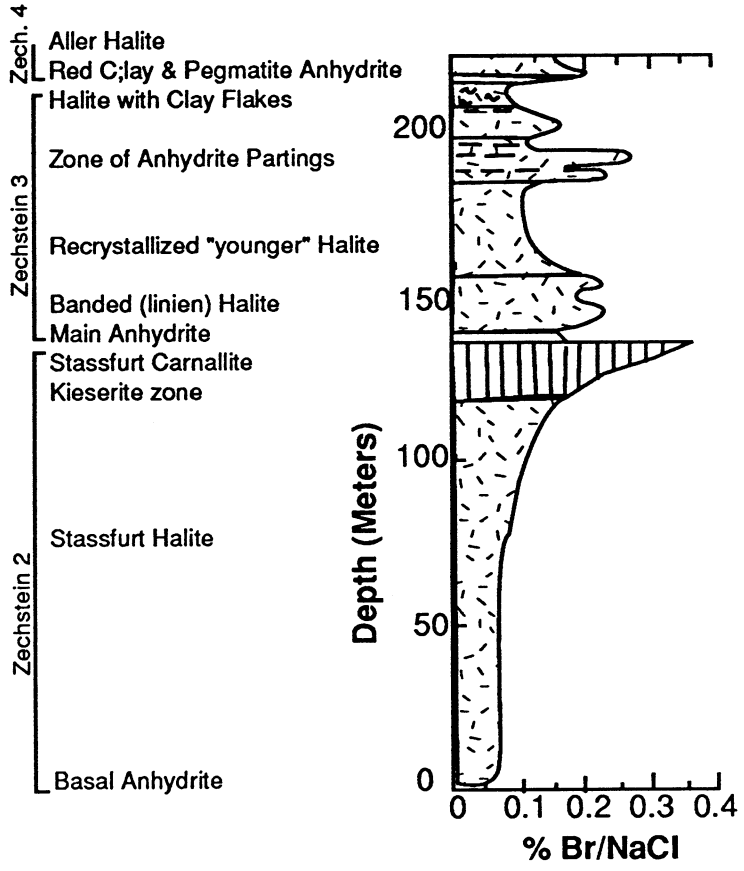


FIGURE 5

BROMINE CONCENTRATION PROFILE IN THE ZECHSTEIN DEPOSIT



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 Ms. Kelly A. Dorney, management analyst; Mr. John C. Macke, management analyst; and Mr. Renaldo Summerset, management analyst. The international data tables were prepared by Mr. Harold Willis, international coordinator.

The rare earths are a relatively abundant group of elements that range in crustal abundance from cerium, the 25th most abundant element of the common elements at 60 parts per million, to lutetium, the 61st most abundant element at 0.5 part per million. The rare earths were discovered in 1787 by Lieutenant Karl Axel Arrhenius when he collected the black mineral ytterbite (later renamed gadolinite) from a fluorspar mine near the village of Ytterby, Sweden. With similar chemical structures, the rare-earth elements proved difficult to separate. It was not until 1794 that the first element, an impure yttrium oxide, was isolated by Finnish chemist Johann Gadolin.

The rare earths are iron gray to silvery lustrous metals; typically soft, malleable, and ductile; and usually reactive, especially at elevated temperatures or when finely divided. Densities range from 2.99 grams per cubic centimeter for scandium, a lightweight metal slightly denser than aluminum, to 9.84 grams per cubic centimeter for lutetium, a moderately dense metal similar to bismuth and actinium. The rare earths' unique properties are used in a wide variety of applications.

Domestic mine production of rare earths increased in 1992. The domestic economy recovered slowly during the year and inflation rose a modest 3%. Estimated domestic apparent consumption declined about 9%; however, reported sales by the major domestic processor increased 3%. *(See table 1.)* Demand increased for rare earths used in automobile catalytic converters, permanent magnets, and lighting phosphors.

The domestic use of scandium in 1992 remained small. Commercial demand was extremely small, with most metal and compounds sold for research and analytical standards. Minor amounts were used in specialty lighting and semiconductors.

DOMESTIC DATA COVERAGE

Domestic mine production data for rare earths are developed by the U.S. Bureau of Mines (USBM) from the voluntary survey, "Rare Earths, Thorium, and Scandium." The two mines to which a survey form was sent responded, representing 100% of known mine production. Production data from one company processing tailings was also collected. Mine and tailings production data are withheld to avoid disclosing company proprietary data.

BACKGROUND

Definitions, Grades, and Specifications

The rare earths are defined by the USBM as a group of 17 elements composed of scandium, yttrium, and the lanthanides. Rare earths are classified chemically as members of the IIIB subgroup of the periodic table.[1]

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 with the common ore-forming anions. It is a member of the first transition series of elements.

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, the second most abundant rare earth in the Earth's crust. Yttrium is a member of the Second Transition Series.

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. The lanthanides are part of the third transition series. 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 antimony, bismuth, cadmium, and thallium.

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, composed of the first seven lanthanides (atomic numbers 57 through 63) and the heavy rare-earth elements (HREE) or yttrium subgroup, composed 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).[2] 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 commonly 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.

Ferrocerium is a pyrophoric alloy of mischmetal and iron. A typical ferrocerium 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 nearly 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 99.99999% 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.

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 produced in the United States 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-monazite concentrate (predominantly 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 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 source of yttrium. It is typically 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, produced in southern China, is the principal source of yttrium. The ores vary by locality, but two principal concentrates, an yttrium concentrate and a europium concentrate, are produced. The yttrium concentrate is enriched in the heavy-rare earths and has greater than 60% yttrium oxide. Although the europium concentrate grades from 0.5% to nearly 1% europium oxide and 12% yttrium oxide, it is predominantly enriched in lanthanum oxide, 33% to 43%.

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, crystal, rod, wire, chips, powder, sheet, foil, plate, sputtering plates, and custom cast and machined shapes. Alloys such as mischmetal, rare-earth silicide, ferrocerium, and other rare-earth alloys are available in a variety of ingot shapes and sizes.

Rare-earth magnet alloys are produced to 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, and magnetized and unmagnetized.

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 rare-earth companies 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, mill, and refinery at Mountain Pass, CA. The other principal producer, RGC (USA) Minerals Inc., operated a mine and wet and dry concentrating plants at Green Cove Springs, FL. Except for Molycorp, all other domestic refiners have operated independently.

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 or separated compounds. The major processes used in separating rare earths are precipitation, solvent extraction (SX), and ion exchange (IX). 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 production is reported only from China and the Commonwealth of Independent States (C.I.S.). Although minor amounts of scandium have been 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 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. Most scandium is sold in oxide form. A small group of companies produce scandium metal, primarily for lighting and research purposes.

Geology-Resources

Rare-earth minerals occur in a variety of geologic environments. Concentrations exist in igneous, sedimentary, and metamorphic rocks. Rare earths are mined primarily from igneous and sedimentary deposits. The geologic age of the deposits range from Recent to Precambrian.

The rare earths are constituents in more than 100 minerals, but only a few are recovered for commercial production. Bastnasite, monazite, xenotime, and rare-earth-bearing clay are the major sources of the world's rare-earth supply. Other sources are loparite, uraniferous phosphorites, synchisite, and byproduct solutions from processing uranium.

Bastnasite.—Bastnasite, a rare-earth fluocarbonate mineral, 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 known from Kazakhstan. 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 hardness of 4 to 4½ on the Mohs scale.[3] 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.[4] 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 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's bastnasite is hydrothermal in origin and formed by alteration of dolomite in the presence of large amounts of fluorine.[5] 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. It 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) described from Italy and from Marmara, Greece, respectively.[6] 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 grey, and black. It has the following mineralogical properties: transparent to subtranslucent; resinous, waxy, vitreous, or subadamantine luster; density of 4.6 to 5.4 grams per cubic centimeter; and a hardness of 5 to 5½ on the Mohs scale.[7] 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.[8]

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.[9]

Although China's Bayan Obo deposit is known primarily as the world's largest bastnasite deposit, 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.[10] One of the richest grade deposits in the world, the Mount Weld carbonatite grades 15 million metric tons at 11.2% REO, including a 1.3-million-metric-ton zone at 23.6% REO.[11] 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.—Commercial 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 and metals, especially gold, ilmenite, rutile, uranium, and zircon.

Exploration methods to locate rare earths include surface and air reconnaissance with magnetometric, electromagnetic, and radiometric equipment. Other techniques include satellite imagery, aerial photography, and remote sensing. The application of geologic principles to develop depositional models is also used. After identifying a match for a depositional model or an indicator from one of the other methods, a ground survey of the region is conducted. A typical ground survey would include geologic mapping; rock, soil, and gas sampling; geophysical testing; surface radiometric surveying; and geochemical testing of the water, rocks, and plants.

Following visual identification of a rare-earth mineral, a systematic subsurface drilling and sampling program is conducted to determine ore grades and individual rare-earth contents.

Because rare-earth minerals are often associated with the radioactive elements uranium and thorium, many rare-earth deposits were discovered during exploration for these elements. Prospectors searching for radioactive minerals discovered the Mountain Pass, CA, bastnasite deposit.

Most monazite heavy-mineral deposits were discovered by exploring for recent and ancient alluvial deposits using radiometric and magnetometric equipment. Discovery 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 are also mined from a hard-rock deposit. The ore is recovered as a byproduct of iron ore mining by open pit methods. However, 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. A bastnasite concentrate and a mixed bastnasite-monazite concentrate are produced as flotation byproducts during processing for the iron ore.

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 describe above.

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 1992 constant dollars, were lower. The 1992 price for bastnasite concentrate remained unchanged from that of the previous year. Adjusting for inflation using U.S. Government implicit price deflators for gross domestic product, bastnasite prices were actually

3.1% lower or in terms of dollars, cost the consumer $0.08 less per kilogram of REO. Monazite concentrate's price in 1992 decreased substantial from last year's level, down almost 54%. Adjusted for inflation, monazite's price was an additional 3.1% lower or in terms of dollars, cost the consumer $0.53 less per kilogram of REO.

Concentrates of bastnasite and monazite have traditionally been low priced. Significant value is added when the concentrates are separated into the individual REO's or other compounds. Mischmetal prices also have been historically low, with kilogram prices remaining in the $7 to $13 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 REO 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. Bastnasite prices have increased progressively since that time, doubling in price between 1974 and 1980 as a result of the domestic energy crisis.

Monazite's price is more complex than bastnasite's. 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 6, shows an overall increase in price through 1985. In the 1950's, its price was $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 seen in monazite's price through 1990. In 1991, however, a decline in monazite prices signaled an oversupply, the result of the availability of low-cost separated rare earths from China, a downturn in the U.S. economy, and the decision by a major domestic consumer to switch from monazite to a thorium-free rare-earth feed material. Monazite's price continued to decline in 1992 as a result of decreased demand. *(See figures 1 and 2.)*

Costs.—U.S. mine and mill operating costs to produce concentrates of bastnasite and monazite differ substantially. The cost to mine bastnasite is greater than that for monazite. Bastnasite, as a primary product, incurs all costs of production, whereas monazite, as a byproduct, accounts for only a fraction of the production costs. The cost to recover monazite is based almost entirely on the expenses made 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 mostly 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). Capital expenditures for plant expansions and other major capital improvements represent the balance of significant costs. These costs are commonly added to long-term debt, but occur intermittently and are typically based on an increase in market demand.

Costs to comply with environmental regulations continue to increase. These costs are mostly indirect operating costs, which include waste treatment and disposal, water purification, systems monitoring, reclamation, administration, and legal and technical personnel.

Tariffs.—U.S. tariff rates, specific to the rare earths, including scandium and yttrium, are unchanged for 1992 and 1993. 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 present rates until new negotiations are completed. U.S. tariff rates for rare earths are listed in the Harmonized Tariff Schedule for 1993, publication 2567, as compiled by the United States International Trade Commission.

Depletion Provisions.—Depletion is defined as the exhaustion of mineral or oil and gas reserves by mining or drilling of wells and the resulting production from these mines or wells.[12] 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 allowance: cost depletion and percentage depletion.[13] Cost depletion is calculated by dividing the adjusted basis of the mineral property by the total number of recoverable units. Percentage depletion is figured by taking a percentage, specified for certain minerals (elements), 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 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.—Toxicity of rare earths may be broadly classified into two groups—nonradioactive and radioactive. The relative risk is greater from

nonradioactive rare earths because there are few naturally occurring radioactive isotopes.

Nonradioactive.—Toxicity of rare earths is dependent on the chemical form, its route of administration, and the individual rare earth.[14] Only limited data are available for humans, with most research acquired from experiments on small vertebrates. Overall, the rare earths are considered only slightly toxic.[15] Orally administered lanthanides are poorly absorbed by the gastrointestinal tract and have very low toxicity. Administered at levels as high as 1 to 10 grams of lanthanide oxides and lanthanide sulfates per kilogram (kg) of body weight, the compounds were not lethal to small vertebrates.[16]

Lanthanides administered by routes other than orally are absorbed at greater rates and are thus more toxic. Intravenous injection is the most toxic method. Pharmacologic responses to intravenous-administered lanthanides were calcification, hypotension, hypoglycemia, and an increase in the time for blood coagulation. The production of skin and lung granulomas (in rats and mice) after exposure to oxides, fluorides, chlorides, and metals by prolonged breathing, intradermal or intraperitoneal injection, or subcutaneous implantation requires extensive protection to prevent exposure through cuts and abrasions of the skin or through inhalation. Symptoms of toxicity observed (in mice and rats) included anorexia, writhing, ataxia (loss of voluntary muscle control), diarrhea, dyspnea (labored respiration), walking on the toes with arched back, and sedation.

Humans exposed to airborne lanthanides reported itching, insensitivity to heat, and a sharpening of the senses of taste and smell.[17] Chronic exposure to lanthanide dust can lead to *rare-earth pneumoconiosis*.[18] This condition has been noted in those exposed to lanthanide oxide-bearing fumes from carbon arc lamps. Intravenous injections of lanthanum chloride solutions in humans produced abdominal cramps, chills, fever, hemoglobinemia, hemoglobinuria, and muscle pain.[19]

Intratracheal injections of 50 milligrams (mg) of a mixed lanthanide oxide into rats were 100% lethal within 24 hours, the result of pulmonary edema.[20] However, a similar injection of 200 mg/kg of the rare-earth ore monazite into mice produced no ill effects.[21] Extreme care also must be taken when exposed to finely divided rare-earth metals and metallic powders to avoid burns from rapid and possibly instantaneous oxidation, especially if inhaled. Certain finely divided rare-earth metals, alloys, and metal powders also may present the additional hazard of oxidizing rapidly enough to explode.

Radioactive.—Toxicity from rare earths also may occur from radioactive lanthanides. Only neodymium, samarium, gadolinium, and lutetium have naturally occurring radioactive isotopes. Neodymium's one radioactive isotope, Nd^{144}, represents 23.85% of the naturally occurring material and is an alpha emitter. Samarium has three alpha emitting natural isotopes: Sm^{147}, Sm^{148}, and Sm^{149}, which represent 14.97%, 11.24%, and 13.83% of the natural occurring material, respectively. Gadolinium's sole alpha emitting isotope is Gd^{152}, with a natural abundance of only 0.2%. Lutetium also has one naturally occurring radioactive isotope, Lu^{176}, with an abundance of 2.59%. It is the only natural lanthanide isotope that decays by negative beta emission.

Manufactured isotopes were produced primarily for use in nuclear medicine. The relative health risks for these materials varied depending on the application and dosage.

It should be noted that the rare earths often exist in ore and concentrates in association with other elements that have vastly different properties, including varying toxicities and possibly radioactive emissions. 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 domestic quarterly average number of employees on-site, are shown in figure 3. Following a 5-year trend of increasing employment, industry employment dropped almost 10% in 1992. The decrease was primarily the result of several plant closures by Molycorp, Inc. Data were furnished by the U.S. Department of Labor and compiled by the USBM. *(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.

Bastnasite production increased in 1992, changing its previous 11-year productivity trend from a slight decrease to a slight increase. *(See figure 4.)*

The 11-year trend for domestic monazite capacity utilization continued to show a decline. However, monazite's decrease, because it is a byproduct of titanium and zirconium minerals, is primarily a function of demand for the primary products and to a lesser extent a function of decreased demand for monazite in 1991 and 1992. *(See figure 5.)*

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Legislation and Government Programs

The calendar year 1992 included the U.S. Government fiscal years for 1992 and 1993. Public Law 102-109, the National Defense Authorization Act for Fiscal Years 1992 and 1993, covered the year 1992 through October 22 and continued specific previous authorizations for disposal of all stocks in the National Defense Stockpile (NDS) classified as excess to goal. Public Law 102-484, the National Defense Authorization Act for Fiscal Year 1993, covered the remainder of the year 1992. Stocks of rare earths in sodium sulfate were all classified as excess to goal at yearend 1992 and were inventoried at 457 tons. However, rare earths in the NDS were not authorized for disposal in the calendar year.

Issues

Molycorp, Inc. closed its plants at Louviers, CO, and Washington, PA, and consolidated operations at Mountain Pass, CA.[22] The closures were reportedly in response to continued competitive world markets, especially from suppliers in China, Japan, and Eastern Europe. A 3-year modernization and expansion was completed at Mountain Pass, with startup scheduled for the first half of 1993. Sales of lanthanides reportedly increased 3% in 1992, primarily from increased demand for cerium for use in automobile catalytic converters and ultraviolet-absorbing glass.

Production

Three domestic operations, two mines and a tailings processor, produced rare earths in 1992. The United States was the world's second largest producer of rare earths in 1992. Producers were Molycorp, Inc., a wholly owned subsidiary of Unocal Corp., RGC (USA) Minerals Inc., and Nord Ilmenite Corp., a subsidiary of Nord Resources.

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 increased from the previous year's level of 16,465 tons REO to 20,699 tons REO.

Monazite was produced as a byproduct of titanium and zirconium minerals production by RGC (USA) Minerals Inc. RGC (USA) operated a placer dredging operation at Green Cove Springs, FL. Production decreased 57% from last year's level, primarily the result of decreased demand for the primary products.

Monazite was also recovered by Nord Ilmenite Corp., a subsidiary of Nord Resources, from tailings at Jackson, NJ. The tailings were reprocessed primarily for their zircon and ilmenite content. Reprocessing of the tailings was completed at yearend, and all remaining stocks of low-grade monazite were reportedly sold for further upgrading.

Refined lanthanides were produced by three companies. Molycorp produced refined compounds from bastnasite at its separation plant at Mountain Pass, CA. Rhône-Poulenc Basic Chemicals Co. produced lanthanide compounds from rare-earth intermediate compounds at its facility at Freeport, TX, and Davison Specialty Chemical Co. refined rare earths from rare-earth chloride at its operations in Chattanooga, TN.

Three scandium processors operated in 1992. High-purity products were available in various grades with scandium oxide produced up to 99.999% purity.

Sausville Chemical refined scandium concentrates at its facilities in Garfield, NJ, to produce scandium oxide, fluoride, nitrate, chloride, and acetate.

Boulder Scientific Co. processed scandium at its Mead, CO, operations. Scandium concentrates were derived from a variety of ores. Boulder's main ore source was thortveitite-bearing tailings from the mined-out Crystal Mountain fluorite mine near Darby, MT.

Interpro, a subsidiary of Concord Trading Corp., refined scandium at its plant in Golden, CO. Interpro processed stocks of scandium concentrates previously generated by the Energy Fuels Nuclear uranium plant at Bingham Canyon, UT.

Reactive Metals and Alloys Corp. (REMACOR) was the only domestic producer of mischmetal.

Principal domestic producers of neodymium-iron-boron magnet alloys were the Delco Remy Div. of General Motors, Anderson, IN; Molycorp, Inc., York, PA; Neomet Corp., West Pittsburg, PA; and Rhône-Poulenc Basic Chemicals Co., Phoenix, AZ. Leading U.S. producers of rare-earth magnets were the Delco Remy Div. of General Motors, Anderson, IN; Hitachi Magnetics, Edmore, MI; Crucible Materials, Elizabethtown, KY; and IG Technologies, Valparaiso, IN.

Consumption and Uses

Domestic reported consumption of rare earths increased 9% in 1992 compared with that of 1991. Bastnasite consumption was 1% higher than in 1991, while monazite consumption remained the same. Shipments of rare-earth products from domestic processors of ore, concentrates, and intermediate concentrates were equivalent to 11,736 tons of REO, down 15% from the 13,753 tons shipped in 1991.

Consumption of mixed rare-earth compounds remained unchanged from the 1991 level, while consumption of purified compounds decreased 18%. Higher consumption of purified compounds was primarily the result of continued strong demand for neodymium-iron-boron magnets and increased domestic demand for lamp phosphors. Growth in the permanent magnet sector was estimated at 7% to 12% in 1992.

The producers of mischmetal, rare-earth silicide, and other rare-earth alloys consumed 19% more rare earths in 1992 than in 1991, while shipments of these goods gained 20% during the same period. Shipments of high-purity rare-earth metals decreased 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, 27%; ceramics, glass polishing compounds, and glass additives, 26%; and miscellaneous uses in phosphors, electronics, permanent magnets, lighting, and research, 13%.

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 alloys to ultrahigh-purity individual metals and compounds. Quantities vary by application and range from tonnage quantities to milligrams. Following are some of the uses, in order of increasing atomic number, of rare earths, including the metals, oxides, and both inorganic and organic compounds.

Scandium.—Metal halide lamps to improve color appearance and produce

high output, laser crystal (GSGG), aluminum alloys, dual-anode tube in X-ray spectrometers, semiconductors, tracer material, collimators in neutron lenses.

Yttrium.—High-temperature superconductor (YBaCuO), incandescent lamp mantle, phosphor for cathode-ray tubes (reddish orange), trichromatic fluorescent lighting phosphor (reddish orange), metal halide lamp phosphor (reddish orange), high-temperature sensing phosphor, oxygen sensor ceramic, laser crystals (YAG, YLF), gemstone simulants (CZ and YAG), microwave ferrite (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 filter, and semiconductors, acetylene lights, deoxidizer for vanadium and other nonferrous metals, solid oxide fuel cell electrolyte and anode, refractory crucibles and coatings, 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 phosphor (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 ($LaNi_5$), 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 flatting agents, waterproofing and mildewproofing, dying and printing 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, oxidizer in self-cleaning ovens, 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, cryogenic refrigeration ($PrNi_5$).

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, 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), tungsten cermet for space power system.

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, infrared absorbing glass.

Europium.—Cathode-ray tube phosphor (reddish orange), trichromatic fluorescent phosphor (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, 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 in scanning devices to detect osteoporosis (Gd-153), 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), dopant in laser crystals.

Dysprosium.—Permanent magnet addition (NdFeB), nuclear reactor control

rods, semiconductors (DyAs, DySb, DyP), measurement of neutron flux, atomic weight determination, high-temperature sensing phosphor.

Holmium.—Dopant in laser crystal, getter in vacuum tubes, 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, 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, additive in special glass.

Lutetium.—High-temperature sensing phosphor, nuclear technology.

Stocks

U.S. Government stocks of rare earths in the NDS remained at 457 tons throughout 1992. Rare-earth stocks held in the stockpile were contained in sodium sulfate and were inventoried on a contained-REO basis. NDS stocks of rare earths were not available for sale in 1992.

Industry stocks of rare-earth ores and concentrates held by 17 producing, processing, and consuming companies decreased 6%. Bastnasite concentrate stocks held by the principal producer and three other processors increased 71% from the 1991 level. Yearend stocks of monazite increased 24%.

Stocks of other rare-earth concentrates gained 199%. Stocks of mixed rare-earth compounds were essentially unchanged, as stocks of purified compounds decreased 6%. Yearend stocks of mischmetal, rare-earth silicide, and other alloys containing rare-earths gained 19%, while inventories of high-purity metals remained steady.

Prices

Prices for rare earths were mixed in 1992. Published prices were generally nominal and subject to change without notice. Competitive pricing policies remained in effect with prices for most rare-earth products quoted on a daily basis.

The price range of Australian monazite (minimum 55% rare-earth oxide including thoria, f.o.b./f.i.d.),[23] as quoted in Australian dollars (A$),[24] decreased substantially from A$650 to A$700 per metric ton at yearend 1991 to A$300 to A$350 per metric ton at yearend 1992. Changes in the United States-Australia foreign exchange rate in 1992, resulting from a weaker Australian dollar, caused the corresponding U.S. dollar to be up $0.07 against the Australian dollar at yearend. The U.S. price range, converted from Australian dollars, decreased from US$494 to US$532[25] per metric ton in 1991 to US$207 to US$241[26] per metric ton in 1992.

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 1992. Concentrate prices have been unchanged since 1990.

The price of cerium concentrate was quoted by Molycorp at $5.73 per kilogram ($2.60 per pound) of contained cerium oxide at yearend 1992, an increase of $0.66 from the 1991 price of $5.07 per kilogram ($2.30 per pound). The yearend price of lanthanum concentrate was unchanged from the 1991 level of $3.08 per kilogram ($1.40 per pound) of REO contained. Prices for cerium concentrate and lanthanum concentrate are quoted for 907-kilogram minimum (2,000-pound minimum), f.o.b. shipping point.

The nominal price for basic neodymium-iron-boron alloy, compiled by the USBM, was $28.66 per kilogram ($13.00 per pound) at yearend, f.o.b. shipping point, 1,000-pound minimum. Most alloy was sold with additions of cobalt (up to 15%) or dysprosium (up to 5%). The cost of the additions was based on market pricing; with cobalt at $33.07 per kilogram ($15.00 per pound) the cost would be about $0.33 for each percent addition per kilogram ($0.15 for each percent addition per pound).

The price for standard-grade mischmetal was $12.68 per kilogram.

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, 1992, and through the end of the year, as shown in table 2. *(See table 2.)*

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, 1992 as shown in table 3. *(See table 3.)*

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 1992 as shown in table 4. *(See table 4.)*

No published prices for scandium oxide in kilogram quantities were available. Yearend 1992 nominal prices for scandium oxide per kilogram were compiled by the USBM from information from several suppliers and processors. Prices trended lower and were as follows: 99% purity, $1,500; 99.9% purity, $3,000; 99.99% purity, $5,000; and 99.999% purity, $10,000.

Scandium metal prices, as listed by the Johnson Matthey Aesar Group, were as follows: 99.99% purity, lump, sublimed dendritic, ampouled under argon, $312.00 per gram; 99.9% purity, 250-micron powder, ampouled under argon, $559.00 per 2 grams; and 99.9% purity, lump, vacuum remelted, ampouled under argon, $405.00 per 2 grams; 99.9% purity, foil, 0.025 millimeters (mm) thick, ampouled under argon, 25 mm by 25 mm, $117.00 per item.

Prices for kilogram quantities of scandium metal in ingot form have historically averaged about twice the cost

of the oxide while higher purity distilled scandium metal was approximately five times the cost.[27]

Foreign Trade

Rare-earth imports showed mixed results in 1992. Imports increased in four major categories and declined in two categories. U.S. imports of ore and compounds are shown in tables 5 and 6. As in the previous 3 years, France dominated the import market. *(See tables 5 and 6.)*

U.S. imports of monazite concentrate (thorium ores and concentrates) remained at zero for the second consecutive year as a major domestic processor switched to a thorium-free rare-earth feed material. Imports of cerium compounds increased 48% from those of last year as cerium demand increased for use in automotive exhaust catalysts, UV-absorbing glass additives, and polishing compounds. Principal sources, by quantity, were China, France, and Japan. Imports of individual rare-earth compounds, other than cerium compounds, also increased in 1992. The 12% gain was mainly for feed material for permanent magnet alloys. Principal sources were China and France.

Imports of mixed rare-earth compounds decreased almost 67% as demand fell for plant feed materials. India, China, and Malaysia were the major suppliers, in order of decreasing volume. U.S. imports of rare-earth metals increased 24% during the year. Principal sources for the metals were Austria and China. Increased demand for permanent magnet alloys were believed to be the primary reason for the increased imports. Imports of mixed rare-earth chlorides fell 53%, with India as the principal source. Ferrocerium imports increased about 13% with most material originating from Belgium, Brazil, and France. The principal sources of U.S. imports, in terms of volume of equivalent REO contained, are displayed in figure 6. *(See figure 6.)*

U.S. exports of rare earths were mixed. Exports of cerium compounds increased 41% from 1991's level. Principal destinations were Brazil and Canada. Exports of ferrocerium and other pyrophoric alloys also increased, up almost 30%. Rare-earth compound exports declined 27%, mostly the result of decreased demand from Japan. U.S. exports of rare-earth metals fell 38%, with principal destinations reported as Canada and the Republic of Korea. Domestic exports of rare earths are shown in table 7. Based on the limited available export data, Brazil, Japan, and Taiwan were the leading destinations of rare earths from the United States in 1992. This was a shift from 1991 data when, in order of decreasing volume, Canada, Japan, and Brazil were the leaders. Principal destinations of U.S. exports are displayed in figure 7. *(See table 7 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. Minor production was also reported from Madagascar. Significant quantities of rare earths were also 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, Taiwan, Thailand, and the United States.

Smaller amounts of rare earths, especially yttrium, were obtained from the mineral xenotime. Xenotime was recovered primarily as a byproduct of processing for tin minerals in Indonesia, Malaysia, and Thailand, 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 and rocks loparite, synchisite-(Y), and uraniferous phosphorites. *(See table 8 and table 9.)*

Scandium was recovered as a byproduct of processing ore for beryllium, iron, tin, and tungsten in China, and was previously produced as a byproduct of uranium processing in the United States. In the C.I.S., scandium was recovered as a byproduct of uranium.

Reserves.—World reserves of rare earths were estimated by the USBM at 100 million metric tons of contained REO. World reserves were revised upward for 1992 as a result of additional data on the C.I.S. Rare-earth reserves for the C.I.S., which were previously estimated, were reported at 21.4 million tons.[28] China has the largest share of world reserves with 43%. *(See figure 8.)*

Australia.—Ashton Rare Earths Ltd., a subsidiary of Ashton Mining Ltd., postponed its decision to develop the Mount Weld rare-earth deposit until 1993.[29] Ashton secured mining and environmental approvals and continued rare-earth market studies. Located 35 kilometers south of Laverton, Western Australia, the carbonatite's principal ore minerals are a low-thorium secondary monazite and cheralite. Mount Weld is one of the richest grade rare-earth deposits in the world with reserves of 15.4 million tons grading 11.2% REO, which includes 1.3 million tons grading 23.6% REO.[30]

Woodburn Mineral Sands closed its mineral sands mine at Newrybar, New South Wales, in response to depressed market demand and low prices. Capacity of the plant was 24,000 tons per year. Production from Woodburn was mostly low-grade ilmenite and high-grade (ceramic-grade) zircon.[31] The closure was not expected to affect monazite markets.

Westralian Sands Ltd. (WSL) reported production of 1,590 tons of monazite in 1992. Production increased 300 tons from the previous year's level. Price weakness and overcapacity in the mineral sands industry caused the company to operate only one mine in 1992, the Yoganup North, near Boyanup, Western Australia. Rehabilitation continued at WSL's two other mines, the North Capel and Yoganup Extended.[32]

Production of monazite in Queensland (small quantities) ceased at the end of

1991.[33] The decline in demand is the result of the growing availability of alternative concentrates and compounds that are free or nearly free of radiation.

Consolidated Rutile Ltd. (CRL) cut back production at its mines on North Stradbroke Island, Queensland, during the year due to poor market conditions. Production from the Gordon and Bayside Mines was scaled back to 5 days per week starting August 1991 followed by closure of the Bayside operation in February 1992. Production at CRL's smaller Amity operation was closed permanently in May 1992. The Bayside Mine resumed production by yearend.

The Queensland Department of Resource Industries introduced new guidelines for environmental management of mined lands. CRL developed a comprehensive plan for the long-term management of its resources on North Stradbroke Island to address the new guidelines. The plan includes detailed studies of the flora and fauna, research to improve rehabilitation of mined land, and periodic audits of rehabilitation procedures and objectives.[34]

Exploration activity for mineral sands continued in the Eucla Basin area of Western Australia. Centenary International Mining Ltd. had previously reported Eocene age deposits in the Balladonia area grading up to 3.6% heavy minerals in a 12-meter section. Exploration by Ramsgate Resources Ltd. on the Kakarook mineral sands project in the basin discovered two sections, one 8 meters thick at 2.35% heavy minerals and another 6 meters thick at 2.18% heavy minerals. Ramsgate reportedly dropped its interest in the project due to poor market conditions and a lack of additional capital investment.[35]

RGC Mineral Sands Ltd., a subsidiary of Renison Goldfields Consolidated Ltd., applied for exploration licenses to search for heavy minerals on the Northern Territory islands of Bathurst and Melville. The exploration will reportedly be a joint venture among the Tiwi Land Council, Tiwi Resources Pty. Ltd., and RGC Mineral Sands Ltd. As Renison's mineral sands operations have continued to move northward, the company announced that it would close its Perth office and open a smaller divisional office at Geraldton, Western Australia.

Brazil.—In 1991, the latest available data, production of rare-earth chlorides, other rare-earth compounds, and mischmetal was 1,308 tons, 152 tons, and 277 tons, respectively. Reserves are distributed in the States of Rio de Janeiro, 54%; Espírito Santo, 6.7%; Bahia, 10.6%; and other localities, 28.7.[36]

Nuclemon Mínero-Química Ltda. started work on a project to construct a rare-earth refinery in Brazil. Facilities to produce high-purity compounds of europium, gadolinium, and samarium was scheduled to be installed in the second quarter of 1992.

Brazil and China signed an international agreement in 1990 to collaborate on future research to produce Brazilian minerals, oxides, and metals of rare earths. Representatives in the agreement are the Centro de Technologia Mineral (CETEM) and the Institute for the Research and Applications of Rare-Earth Minerals and Metals at the Technical University of Peking, China.

CETEM and two European countries, Italy and Germany, agreed to study the separation of rare earths, using Brazilian minerals. Research on the processing and separation of REO's will be done at an Italian university in Trento, where the Italians have obtained elements using new methods of separation. German researchers will focus on identifying and analyzing rare-earth ore minerals and will forward the data to CETEM. As part of the project a group of about 30 Government and private companies are trying to enter the rare-earth market, which is valued at millions of dollars per year. Brazil's exports totaled about $1.87 million in 1991.

Canada.—Exploration by geologists from Formosa Resources Corp. located a suite of alkalic igneous rocks containing rare earths in the Kechika River region of northern British Columbia. Yttrium oxide values up to 1.13% were found locally. The company also reported locating a phosphorite deposit in southeastern British Columbia grading 20% to 22% phosphorus and 600 to 700 parts per million yttrium.[37]

China.—Rare-earth production in 1992 totaled 21,340 tons of REO, edging out the United States as the world's leading producer.[38] The 32% increase was due to increased production of concentrates from Baotou, Nei Monggol Autonomous Region, and in the Provinces of Shandong and Sichuan. China reportedly consumed 9,270 tons of REO domestically in 1992, up 12% from that in 1991. Exports of rare earths increased 23% to 9,875 tons of REO. The principal increase was in the export of rare-earth chlorides (thorium-free) used as separation plant feed and in mischmetal production.

Gansu Rare Earth Corp. has reportedly developed a new separation technology. Capacity of its refinery in Baiyin City, Gansu Province, is 10,000 tons per year of rare-earth chloride.

India.—Indian Rare Earths Ltd. (IRE) completed plans to increase capacity to produce cerium hydrate and didymium carbonate from rare-earth chloride. Recovery rates at IRE's mineral sands processing plants in southern India were also upgraded.[39] Mineral production at IRE's Chavara and Manavalakurichi plants reportedly improved substantially during the 1990-91 fiscal year.

IRE began a prefeasibility study for installation of a rare-earth separation plant at Alwaye. The plant is slated to produce high-purity separated compounds, including neodymium and praseodymium.

Various mineral sands projects were under development by IRE. A mineral sands deposit at Kudiraimozhi, Tamil Nadu, has proceeded to the environmental permitting phase. The Bhimli project in the State of Andhra Pradesh entered the prefeasibility stage, and a flowsheet for the project was completed. Development of the Ayiramthengu project in Kerala was in the land acquisition phase. Ayiramthengu was estimated to contain mineral sands reserves sufficient for a 20-

to 30-year mine life.

Japan.—Demand for rare earths increased to 5,316 tons of REO in 1989. The market depended entirely on imported materials, primarily from China, France, and the United States. Japanese rare-earth processors produced 4,052 tons REO in 1989. In 1992, market prices for rare earths in Japan, in yen per kilogram, were as follows: yttrium oxide, 99.99%, 8,000; lanthanum oxide, 99.99%, 1,800 to 2,000; cerium oxide, 99.95%, 2,600 to 2,900; europium oxide, 99.99%, 30,000; samarium-cobalt alloy, 8,500 to 10,000; neodymium-iron-boron alloy, 4,000.[40]

Russia.—Mining with nuclear bombs reportedly occurred in Kola Peninsula apatite deposits between 1972 and 1984. A primary source of phosphate and rare earths, the Khibini nepheline syenite deposit was fractured with 2-kiloton plutonium explosive charges to improve recovery rates. Environmental concerns that the residual radioactive contamination may be above safe levels warrants investigating any apatite and loparite mined from the region, including phosphate and rare-earth products processed from the ores.[41]

Thailand.—Production values of the rare-earth minerals monazite and xenotime, and other mineral sands byproducts decreased in 1990. Based on data from the Thailand Department of Mineral Resources, the value of production, in millions of dollars, for 1986 through 1990 was 4.1, 4.8, 7.1, 5.2, and 1.4, respectively.

Turkey.—The state-owned mining and banking company, Etibank, was seeking foreign partners in the development of a thorium-barite-fluorite-rare-earth deposit. Near the city of Karkin, the deposit contains rare earths in the mineral bastnasite. Drilling to 50 meters has delineated 30.3 million tons of ore grading 3.14% REO.[42]

Vietnam.—A pilot plant for processing monazite was supplied to Vietnam by the Government of India. At Phung in Ha Tay Province (25 kilometers from Hanoi), the plant has a capacity to process 50 tons of monazite per year to produce rare-earth chloride and trisodium phosphate. Radioactive thorium also will probably be produced as a byproduct. The plant was supplied to Vietnam under a co-operative agreement on the utilization of atomic energy for peaceful purposes.[43]

Current Research

Researchers at Schott Glass Technologies, Inc. developed a glass that will allow up to 30 weight-percent rare-earths as dopants. The glass, lanthanum-sodium silicate, was designed to accommodate various rare earths for application in absorbing narrow band light emission. The filter glass may be used for eye protection from lasers, fiber optics, and research.[44]

Nippon Mining Co. of Japan has produced an ultrahigh-purity yttrium. At 99.99999% purity, the yttrium was produced by a combination of chemical and electron beam refining. The ultrapure material may have use in a variety of high-tech applications, including superconductors, electronics, optics, and lasers.[45]

Using rare-earth phosphors, scientists at Hitachi Maxwell created invisible bar codes for use in packaging. Benefits of the invisible bar code is that it will not detract from the packaging design and will be difficult to counterfeit or alter.[46]

Matsushita Battery Industrial Co. announced the development of a rare-earth-nickel hydride battery for automobiles. The new batteries will power an electric car for 70 kilometers on a 15-minute charge and can be recharged up to 1,500 times, 3 times more than a lead acid battery.[47]

A theoretical model on grain size, density, and gradient as it relates to heavy minerals in the Fall Zone, a region of abrupt change in stream gradient in the Eastern United States, was prepared by the U.S. Geological Survey. Development of the model and additional research will allow development of more effective predictive models of placer mineral occurrences. Dependent on the upstream source terranes, areas at or near the Fall Zone may be targeted for coarse-grained sediments and placer gold exploration whereas the Inner Coastal Plain has potential for finer grained monazite, zircon, rutile, and ilmenite deposits.[48]

Research at the U.S. Geological Survey examined the use of geochemical and sediment survey data in exploring for titanium-hafnium-rare-earth element-and uranium placers in the Mid-Atlantic States. Using data from the National Uranium Resource Evaluation Program (NURE), hydrogeochemical and stream sediment element analyses were determined to be diagnostic and may predict the presence of commercially important heavy-mineral concentrations. Concentrations of these elements can indicate the presence of commercially important heavy-minerals, including ilmenite (Ti), rutile (Ti), zircon (Zr), monazite (REE), and xenotime (REE). This method is potentially important for identifying similar studies in other largely unexplored regions in the United States, especially the Central Plains.[49]

OUTLOOK

Known world rare-earth reserves are sufficient to meet world demand well into the 21st century. Considering the likelihood that additional deposits of rare earths will continue to be located and assuming reasonable increases in energy, transportation, processing, and environmental costs, world resources are more than adequate to fulfill demand for the foreseeable future.

Recent shifts in the rare-earth industry to nonradioactive or low-radioactive feed materials is expected to continue because the costs to monitor and dispose of radioactive waste products continues to increase. In the long-term, however, thorium-bearing monazite is forecast to return as a principal feed material due to its low cost and availability.

Domestic demand in 1993 is expected to grow modestly in line with the economy. Particular segments of the industry, including neodymium-iron-boron

permanent magnets and cerium-containing automobile catalytic converters, are expected to show strong growth.

Competitive world markets are expected to continue in the future. In addition to the strong presence of Australia, China, and the United States as rare-earth suppliers, the future economic restructuring of Eastern Europe and the C.I.S. may greatly expand potential market opportunities. Significant reserves and production capacity exist in Kazakhstan, Russia, and the rest of the C.I.S. Australia's future potential is also considerable, possessing both large reserves and several high-grade deposits.

The long-term outlook is for an increasingly competitive and diverse group of rare-earth suppliers. The economic base of the rare-earth industry has continued to grow. Future market fluctuations are expected to diminish as the industry rapidly matures and diversifies. Demand is forecast to continue to grow as improved knowledge of the rare earths continues to generate new commercial applications, a trend that is expected to continue.

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TABLE 1
SALIENT U.S. RARE-EARTH STATISTICS

(Metric tons of rare-earth oxides (REO) unless otherwise specified)

	1988	1989	1990	1991	1992
Production of rare-earth concentrates	[1]11,533	[1]20,787	[1]22,713	[2]16,465	[2]20,699
Exports[e] [3]					
Cerium compounds	NA	1,433	1,730	1,369	1,935
Rare-earth metals, scandium, and yttrium	NA	425	241	[r]59	36
Ores and concentrates	4,415	NA	NA	[4]459	—
Rare-earth compounds, organic or inorganic	NA	NA	1,460	[r]1,793	1,306
Ferrocerium and pyrophoric alloys	89	[r]74	83	[r]2,113	2,737
Imports for consumption[e] [3]					
Monazite	1,058	426	440	—	—
Metals, alloys, oxides, compounds	912	6,125	4,489	6,114	[e]5,433
Stocks, producers and processors, yearend	W	W	W	W	W
Consumption, apparent[e]	16,800	27,770	28,700	22,100	20,200
Prices, yearend, dollars per kilogram:					
Bastnasite concentrate, REO basis	2.54	2.76	2.87	2.87	2.87
Monazite concentrate, REO basis	1.15	1.19	1.19	.93	.41
Mischmetal, metal basis	12.35	12.35	11.02	11.02	12.68
Employment, mine and mill[e] [5]	320	381	397	411	372
Net import reliance[e] [6] as a percent of apparent consumption	29	23	20	25	27

[e]Estimated. [r]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.

[1]Comprises only the rare earths derived from bastnasite, as reported in Unocal Corp. annual reports.

[2]Comprises only the rare earths derived from bastnasite, as obtained from Molycorp, Inc., company representative.

[3]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export categories for 1989-92 are not necessarily comparable with those of previous years.

[4]Data from The Journal of Commerce Trade Information Service.

[5]Employment at a rare-earth mine in California and at a mineral sands operation in Florida, and a mineral sands tailings operation in New Jersey. The latter mines produced monazite as a byproduct, and employees were not assigned to specific commodities.

[6]Imports minus exports plus adjustments for Government and industry stock changes.

TABLE 2
MOLYCORP RARE-EARTH OXIDE PRICES

Product (oxide)	Percent[1] purity	Quantity (pounds)	Price per pound
Cerium	99.00	200.00	$10.50
Dysprosium	96.00	50.00	60.00
Erbium	98.00	50.00	65.00
Europium	99.99	25.00	450.00
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	30.00
Terbium	99.90	44.10	375.00
Yttrium	99.99	50.00	52.50

[1]Purity expressed as percent of total REO.

TABLE 3
MOLYCORP RARE-EARTH COMPOUND PRICES

Product (compound)	Percent[1] purity	Quantity (pounds)	Price[2] per pound
Cerium carbonate	99.0	150	$5.75
Cerium fluoride	Tech. grade	250	3.50
Cerium nitrate	96.0	250	2.90
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

[1]Purity expressed in terms of REO equivalent.
[2]Priced on a contained REO basis.

TABLE 4
RHÔNE-POULENC RARE-EARTH OXIDE PRICES

Product (oxide)	Percent purity	Quantity (kilograms)	Price per kilogram
Cerium	99.50	20	$16.00
Dysprosium	95.00	20	95.00
Erbium	96.00	20	175.00
Europium	99.99	10	1,200.00
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	30.00
Samarium	96.00	25	90.00
Terbium	99.90	5	575.00
Thulium	99.90	5	2,750.00
Ytterbium	99.00	10	220.00
Yttrium	99.99	50	90.00

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF MONAZITE, BY COUNTRY

Country	1988		1989		1990		1991[1]		1992[1]	
	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)
Australia	382	$237	180	$117	—	—	—	—	—	—
Indonesia	1,144	687	594	413	800	$686	—	—	—	—
Malaysia	197	125	—	—	—	—	—	—	—	—
Thailand	201	105	—	—	—	—	—	—	—	—
Total	1,924	1,154	774	530	800	686	—	—	—	—
REO content[e]	1,058	XX	426	XX	440	XX	—	XX	—	XX

[e]Estimated. XX Not applicable.
[1]No data reported by the Bureau of Census for 1991 and 1992.

Source: Bureau of the Census. REO content estimated by the U.S. Bureau of Mines.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY

Country	1990		1991		1992	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Cerium compounds, including oxides, hydroxides, nitrate, sulfate chloride, oxalate: (2846.10.0000)						
Austria	500	$3,663	1,400	$20,291	12,005	$136,703
Brazil	—	—	—	—	2,300	11,500
China	67,100	95,565	6,000	50,529	131,068	715,620
France	287,925	1,818,998	379,104	3,135,018	534,523	4,174,266
Germany	578	47,585	79,951	47,498	30	17,552
Japan	2,585	65,683	77,465	1,647,700	128,196	2,926,126
Netherlands	—	—	—	—	369	37,971
Russia[1]	—	—	—	—	24	4,100
U.S.S.R.[2]	2	2,394	2	2,532	1	2,200
United Kingdom	540	6,608	1,040	9,355	172	8,364
Total	359,230	2,040,496	544,962	4,912,923	808,688	8,034,402
Rare-earth compounds, including oxides, hydroxide, nitrate, and other compounds except chlorides: (2846.90.5000)						
Belgium	—	—	—	—	59,017	225,980
Canada	7,106	952,667	11,287	1,369,709	732	76,333
China	23,064	796,937	154,843	2,477,305	496,260	3,037,119
France	4,757,461	25,382,258	3,337,395	19,036,155	3,457,977	21,396,888
Germany	52,252	474,042	839	99,207	1,156	105,928
Hong Kong	1,750	31,137	5,115	166,067	34	24,912
Hungary	6,224	24,738	10,099	47,699	5,121	26,733
Japan	62,829	2,263,418	132,902	6,922,345	94,373	8,842,106
Korea, Republic of	10	4,300	—	—	2,999	60,569
Netherlands	—	—	98	26,506	400	80,220
Norway	13,905	1,352,905	9,514	901,297	975	221,511
Russia[1]	—	—	—	—	799	20,916
South Africa, Republic of	134	1,043,390	—	—	—	—
Sweden	—	—	—	—	114	11,852
Switzerland	5	2,159	—	—	—	—
Taiwan	200	9,130	—	—	—	—
U.S.S.R.[2]	58,480	4,396,963	9,500	1,659,821	—	—
United Kingdom	6,226	590,897	1,715	721,596	12,862	441,114
Other	—	—	19,856	650,864	15,470	139,230
Total	4,989,646	37,324,941	3,693,163	34,078,571	4,148,289	34,711,411
Mixtures of rare-earth oxide except cerium oxide: (2846.90.2010)						
Austria	50	1,736	1,566	175,641	14,266	975,392
China	68,194	1,267,819	277,943	2,597,046	109,119	1,663,993
Côte d'Ivoire	1,000	36,021	—	—	—	—
Estonia	—	—	—	—	4,000	12,088
France	31,249	3,326,187	44,734	4,452,935	70,782	6,031,045
Germany	2,804	606,921	6,506	1,011,363	7,550	1,259,266
Hong Kong	378	17,922	80,384	868,111	4,950	143,560
India	—	—	399,928	240,522	—	—

See footnotes at end of table.

TABLE 6—Continued

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY

Country	1990		1991		1992	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Mixtures of rare-earth oxide except cerium oxide—Continued: (2846.90.2010)						
Japan	26,717	$1,132,707	21,968	$2,364,992	42,657	$3,568,048
Norway	1,332	173,069	242	42,758	7	1,350
Taiwan	4,150	72,201	19,205	196,464	301	24,599
U.S.S.R.[2]	1,956	362,539	8,536	247,233	—	—
United Kingdom	12,898	1,020,471	31,265	941,229	41,339	1,173,735
Total	150,728	8,017,593	892,277	13,138,294	294,971	14,853,076
Rare-earth metals, whether intermixed or alloyed: (2805.30.0000)						
Austria	20,119	205,012	1,400	32,000	68,000	335,973
Belgium	—	—	4,950	19,800	—	—
Brazil	52,669	320,682	30,866	208,963	18,072	125,973
Canada	—	—	—	—	—	—
China	107,919	562,349	131,480	1,480,056	175,846	1,353,740
Denmark	—	—	—	—	2	3,000
France	100	4,520	—	—	—	—
Germany	—	—	34,500	181,579	7,760	90,523
Hong Kong	—	—	741	33,727	675	94,660
Japan	3,440	153,259	6,767	232,527	1,834	210,406
Norway	150	28,602	50	8,205	45	6,771
Sweden	981	181,924	—	—	—	—
Taiwan	—	—	—	—	100	7,250
U.S.S.R.[2]	2,258	312,653	2,400	57,086	150	75,000
United Kingdom	11,170	1,278,221	12,666	1,075,301	8,109	797,443
Other	34	3,102	—	—	—	—
Total[1]	198,840	3,050,324	225,820	3,329,244	280,593	3,100,739
Mixtures of rare-earth chlorides, except cerium chloride: (2846.90.2050)						
Austria	40	5,500	4,246	117,165	45	4,011
Brazil	710,988	1,193,349	—	—	—	—
China	42,620	1,249,338	104,300	1,467,839	205,661	2,501,856
Côte d' Ivoire	500	345,273	—	—	—	—
Estonia	—	—	—	—	1,000	9,288
France	784	2,976	—	—	2,022	94,709
Germany	—	—	1	4,000	51	4,721
India	211,160	219,725	2,971,130	2,336,576	1,064,732	821,455
Japan	318,189	9,179,220	65,581	4,453,877	33,401	3,625,637
Malaysia	53,260	170,926	203,874	220,838	217,350	308,314
Netherlands	13,500	173,624	—	—	—	—
Norway	1	1,640	—	—	31	7,600
Taiwan	11,656	169,621	3,000	37,262	1,615	11,526
United Kingdom	197	31,473	25,110	252,121	57,494	302,787
Other	56	70,297	—	—	—	—
Total[1]	1,362,951	12,812,962	3,377,242	8,889,678	1,583,402	7,691,904

See footnotes at end of table.

TABLE 6—Continued

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY

Country	1990		1991		1992	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Ferrocerium and other pyrophoric alloys: (3606.90.3000)						
Austria	27,201	$496,180	20,414	$406,476	5,158	$122,408
Belgium	4,126	$54,974	3,400	$64,023	17,109	$331,266
Brazil	20,469	251,636	20,596	260,672	34,200	454,907
Canada	—	—	1,250	2,417	—	—
France	33,071	565,458	44,340	628,533	46,443	669,429
Germany	5,768	87,960	159	6,460	—	—
Hong Kong	—	—	500	5,099	—	—
Japan	495	12,780	2,250	46,905	2,720	34,780
United Kingdom	2,000	26,000	—	—	—	—
Other	—	—	88	3,486	—	—
Total	93,130	1,494,988	92,997	1,424,071	105,630	1,612,790

[1]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[2]Dissolved in Dec. 1991; however, information is not available for individual countries, other than those listed in this table.

Source: Bureau of the Census.

TABLE 7

U.S. EXPORTS OF RARE EARTHS, BY COUNTRY

Country	1991		1992	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Cerium compounds: (2846.10.0000)				
Argentina	2,400	$20,869	17,596	$63,751
Australia	21,009	89,837	454	4,030
Austria	—	—	4,632	50,868
Belgium	2,523	16,960	4,738	35,821
Brazil	228,459	724,330	699,907	1,877,191
Canada	292,633	2,022,321	364,122	3,059,470
China	2,400	19,656	—	—
Colombia	882	4,200	—	—
Ecuador	—	—	720	3,427
Egypt	3,433	26,240	2,499	4,158
France	35,904	212,097	42,202	279,966
Germany	108,502	1,001,295	82,861	541,511
Greece	1,794	2,621	2,480	13,865
Hong Kong	106,868	655,274	93,715	534,379
Indonesia	700	54,710	1,920	3,455
Israel	3,347	21,159	3,850	26,644
Italy	12,000	74,277	15,424	98,187
Japan	231,140	1,037,752	146,363	663,341
Korea, Republic of	61,051	963,527	65,187	703,928
Mexico	30,628	74,835	24,860	150,790
Netherlands	794	7,052	8,288	53,729
Norway	—	—	500	2,921
Philippines	—	—	960	5,338
Portugal	5,760	27,603	13,500	61,560
Saudi Arabia	960	4,944	1,920	10,724
Singapore	39,520	159,591	178,121	791,412
Spain	25,440	145,467	15,360	94,504
Switzerland	—	—	72	14,361
Taiwan	118,741	518,094	92,629	546,995
Thailand	13,552	102,551	15,626	114,475
Trinidad and Tobago	3,672	51,437	5,365	68,600
United Kingdom	5,976	38,766	29,150	209,418
Venezuela	7,897	52,849	—	—
Other	550	64,234	—	—
Total	1,368,535	8,194,548	1,935,021	10,088,819
Rare-earth compounds: (2846.90.0000)				
Australia	650	7,650	342	4,550
Belgium	43,893	166,487	415	119,868
Brazil	19,059	129,782	23,505	214,658
Canada	39,973	825,404	184,664	538,427
Chile	—	—	149,527	161,369
China	—	—	11,020	77,200
Finland	—	—	16,581	584,053
France	418,723	576,858	222,720	308,960
Germany	93,284	2,424,107	37,641	2,125,749

See footnote at end of table.

TABLE 7—Continued

U.S. EXPORTS OF RARE EARTHS, BY COUNTRY

Country	1991		1992	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Rare-earth compounds—Continued: (2846.90.0000)				
Italy	276	$58,412	75	$21,292
Japan	927,538	12,299,03	526,292	6,128,194
Korea, Republic of	63,766	1,764,122	2,804	231,686
Lebanon	—	—	8,988	42,783
Mexico	77,536	139,340	19,120	146,103
Netherlands	29,517	786,771	1,109	33,555
Netherlands Antilles	—	—	14,274	30,170
Singapore	124	200,708	83	140,855
Spain	2,318	33,200	20,510	61,162
Taiwan	8,588	458,967	32,475	972,425
United Kingdom	14,623	170,877	21,322	545,748
Venezuela	1,089	9,401	—	—
Other	52,135	903,347	12,996	282,202
Total	1,793,092	20,954,467	1,306,463	12,771,009
Rare-earth metals, including scandium and yttrium: (2805.30.0000)				
Australia	—	—	25	$6,250
Bahamas	18,954	$18,745	—	—
Canada	10,215	194,712	13,780	205,997
France	833	160,392	1,327	44,814
Germany	27	8,340	2,550	202,308
India	5	5,000	140	36,150
Japan	25,337	1,874,990	5,647	293,319
Korea, Republic of	—	—	7,934	38,970
Netherlands	150	7,350	—	—
Singapore	—	—	212	5,926
Taiwan	—	—	388	32,708
United Kingdom	1,966	288,068	2,344	109,616
Venezuela	1,000	6,650	—	—
Other	548	118,612	2,105	121,687
Total	59,035	2,682,859	36,452	1,097,745
Ferrocerium and other pyrophoric alloys: (3606.90.0000)				
Argentina	13,553	31,855	7,892	11,784
Australia	124,567	262,556	120,862	292,453
Bahrain	—	—	28,182	36,368
Barbados	55,737	64,048	56,027	65,593
Belgium	204	5,832	2,180	78,249
Brazil	2,200	14,071	186,466	70,916
Canada	37,261	1,987,397	35,038	1,861,877
Costa Rica	7,483	66,690	—	—
Cyprus	14,834	16,863	—	—
Denmark	5,377	84,920	3,451	77,378
Dominican Republic	—	—	42,846	111,124
Ecuador	42,400	138,512	—	—

See footnote at end of table.

TABLE 7—Continued

U.S. EXPORTS OF RARE EARTHS, BY COUNTRY

Country	1991		1992	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Ferrocerium and other pyrophoric alloys—Continued: (3606.90.0000)				
El Salvador	12,955	$15,300	37,540	$47,331
France	18,555	343,857	10,789	212,528
Germany	243,520	1,533,980	222,508	1,014,354
Greece	47,717	120,052	81,509	51,073
Honduras	—	—	58,874	69,530
Hong Kong	319,632	521,546	367,885	598,736
Indonesia	3,838	24,050	10,160	36,930
Jamaica	50,407	75,019	49,517	58,150
Japan	50,392	646,589	85,496	547,235
Jordan	29,046	16,012	43,002	49,613
Korea, Republic of	—	—	36,585	177,984
Kuwait	—	—	35,370	47,673
Lebanon	—	—	16,511	25,492
Mexico	22,437	146,497	8,180	145,531
Netherlands	137,208	213,570	25,385	68,649
Netherlands Antilles	—	—	20,893	66,425
New Zealand	—	—	26,600	56,030
Nicaragua	—	—	2,163	10,000
Philippines	—	—	38,594	142,023
Saudi Arabia	81,868	215,764	110,231	176,990
Singapore	214,026	294,713	167,748	445,949
Sweden	148	3,000	140	280,428
Switzerland	14,354	20,094	3,967	41,362
Taiwan	18,920	919,670	516,500	7,915,177
Thailand	468	14,097	3,733	11,000
United Arab Emirates	131,392	184,428	175,785	246,484
United Kingdom	166,491	195,298	32,127	218,456
Other	246,179	1,166,519	66,606	475,090
Total	r2,113,169	9,342,799	2,737,342	15,841,965

rRevised.

Source: Bureau of the Census.

TABLE 8

MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons, gross weight)

Country[2]	1988	1989	1990	1991	1992e
Australia e	3 11,872	13,000	11,000	5,000	5,000
Brazil	r 2,633	r 2,503	r 1,656	r e 1,600	1,600
China	2,127	1,782	2,382	1,185	1,800
India e	4,000	4,300	r 4,500	r 4,500	4,500
Malaysia	2,920	2,948	3,323	r 1,981	1,500
South Africa, Republic of e	1,200	1,200	3 1,317	1,300	1,300
Sri Lanka e	200	200	200	200	200
Thailand	590	631	377	e 400	400
United States	W	W	W	W	W
Zaire	168	175	124	e 120	100
Total	r 25,710	r 26,739	r 24,879	r 16,286	16,400

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

[1]Table includes data available through Apr. 22, 1993.

[2]In addition to the countries listed, Indonesia, North Korea, Republic of Korea, Nigeria, and the former 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.

[3]Reported figure.

TABLE 9

RARE EARTHS: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons of REO equivalent)

Country[2]	1988	1989	1990	1991e	1992e
Australia e	3 6,530	7,150	6,050	3,850	3,850
Brazil	r 2,633	r 2,503	r 1,656	r 1,303	1,400
Canada e	100	100	—	—	—
China	29,640	25,220	16,480	16,150	17,000
India e	2,200	r 2,365	r 1,925	2,750	2,750
Malaysia	1,630	1,646	r 1,828	r 1,050	3 435
Madagascar:					
Bastnasite	3	3	3	3	3
Monazite	(4)	(4)	(4)	(4)	(4)
South Africa, Republic of e	660	660	3 724	715	715
Sri Lanka e	110	110	110	110	110
Thailand	375	365	358	e 360	360
U.S.S.R. e 5	8,500	8,500	8,500	8,500	8,000
United States 6	11,533	20,787	22,713	16,465	3 20,699
Zaire	92	96	68	e 65	60
Total	r 64,006	r 69,505	r 60,415	r 51,376	r 55,382

eEstimated. rRevised.

[1]Table includes data available through June 25, 1993.

[2]In addition to the countries listed, rare-earth minerals are believed to be produced in Indonesia, North Korea, Mozambique, and Vietnam, but information is inadequate to formulate reliable estimates.

[3]Reported figure.

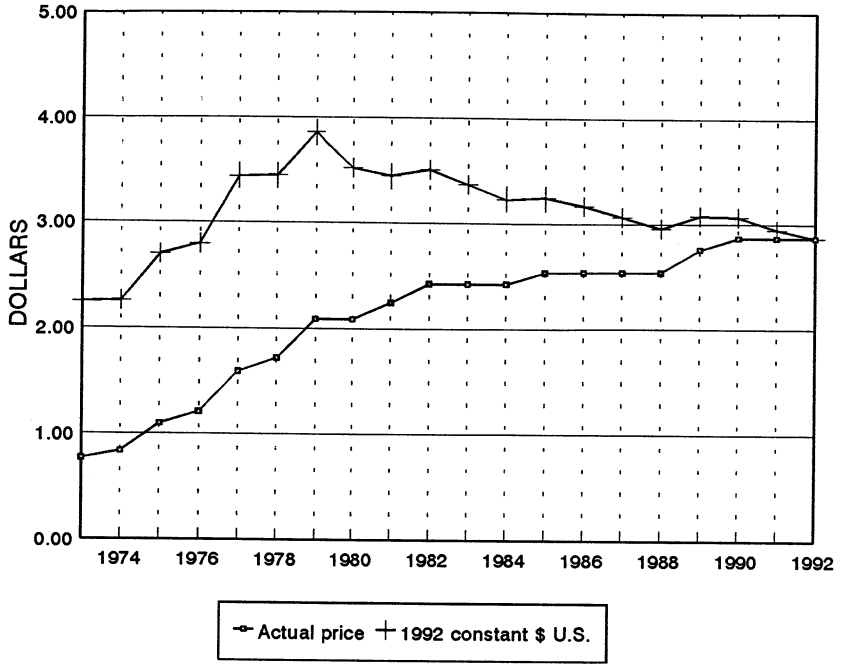
[4]Less than 1/2 unit.

[5]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

[6]Comprises only the rare earths derived from bastnasite as reported in Unocal Corp. annual report, 1990 and from company sources.

FIGURE 1

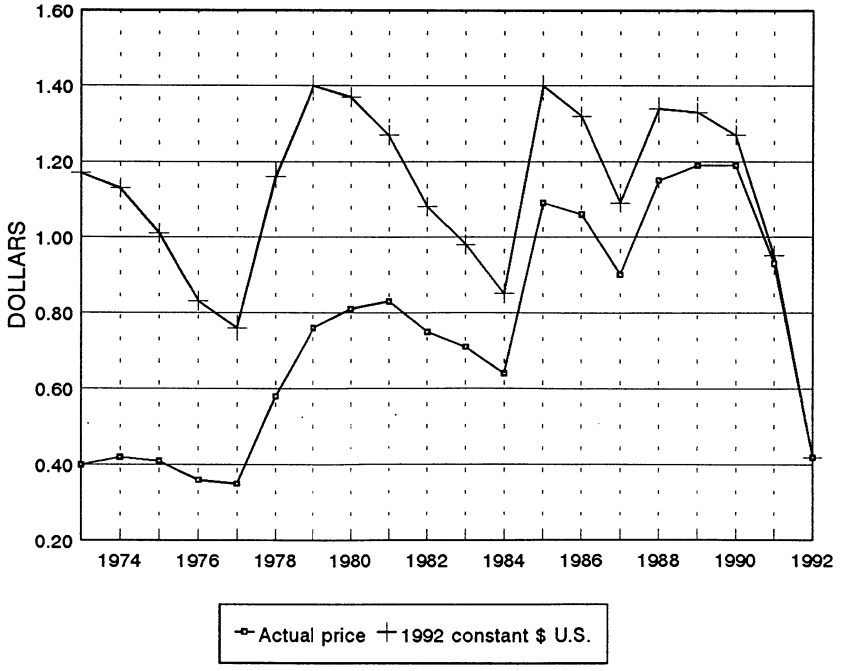
BASTNASITE CONCENTRATE PRICES[1]



[1]60% REO content.

FIGURE 2

MONAZITE CONCENTRATE PRICES[1]



[1]55% REO content.

FIGURE 3

U.S. RARE-EARTH MINE AND MILL EMPLOYMENT

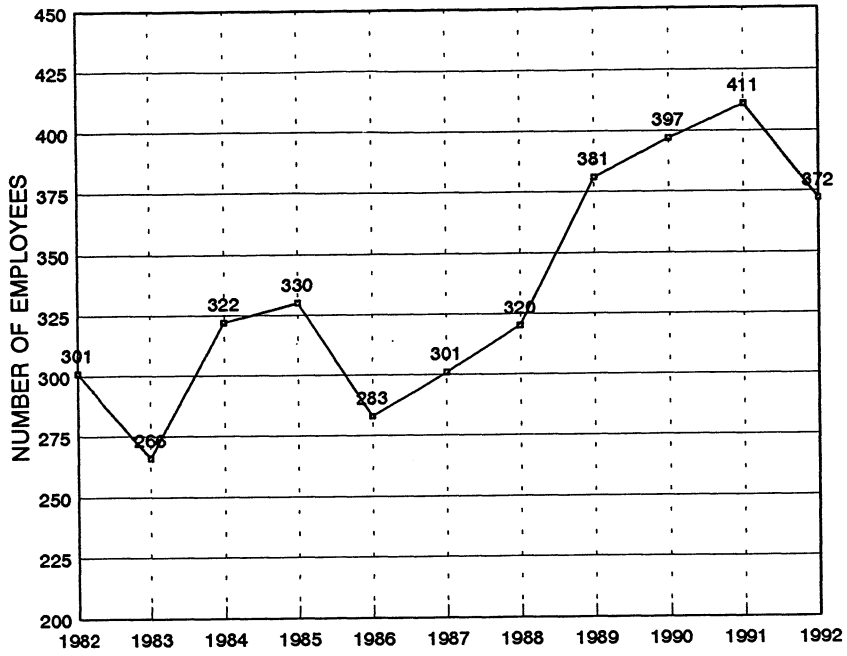


FIGURE 4

U.S. BASTNASITE CAPACITY UTILIZATION

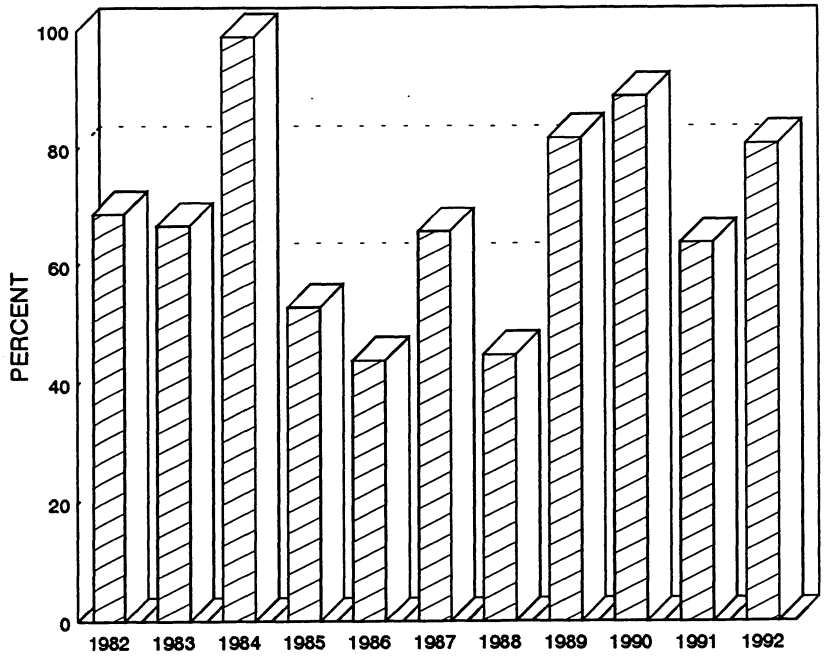


FIGURE 5
U.S. MONAZITE CAPACITY UTILIZATION

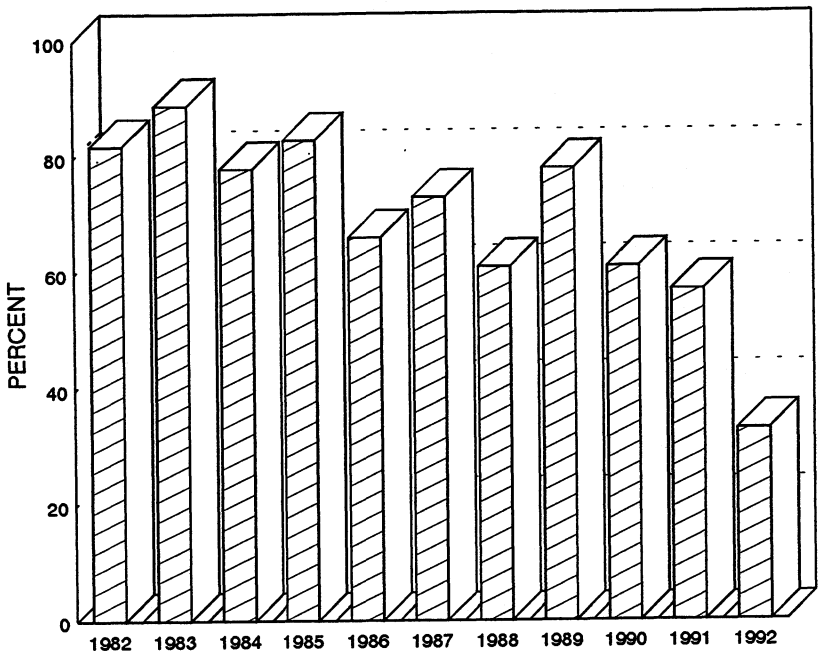
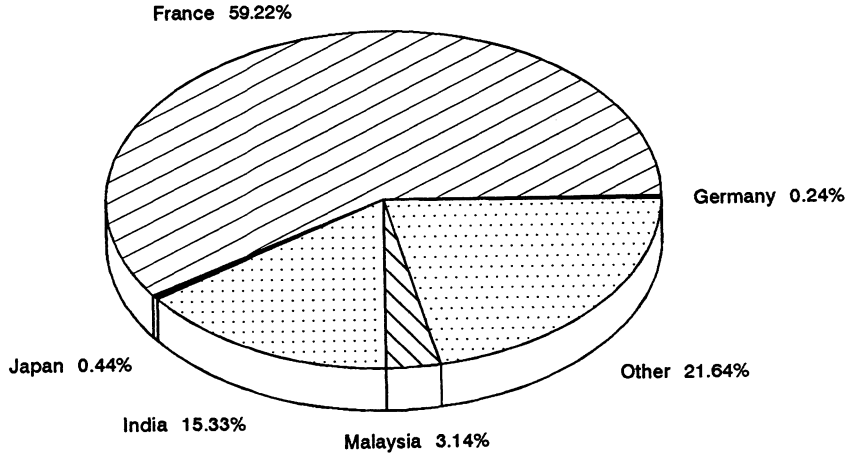
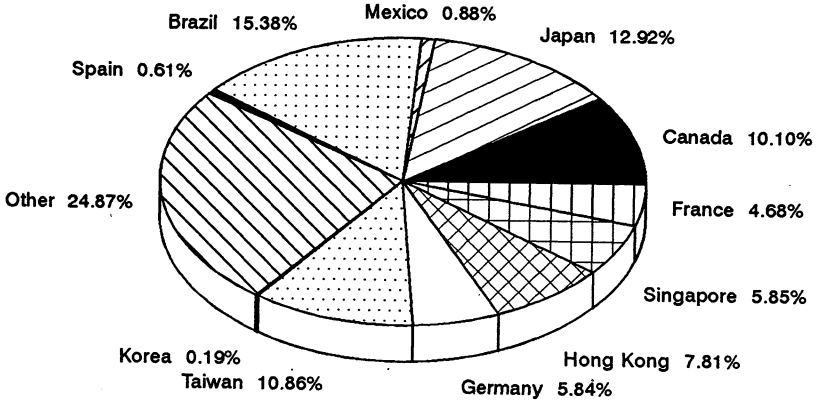


FIGURE 6
U.S. IMPORTS OF RARE EARTHS
(Percent REO)



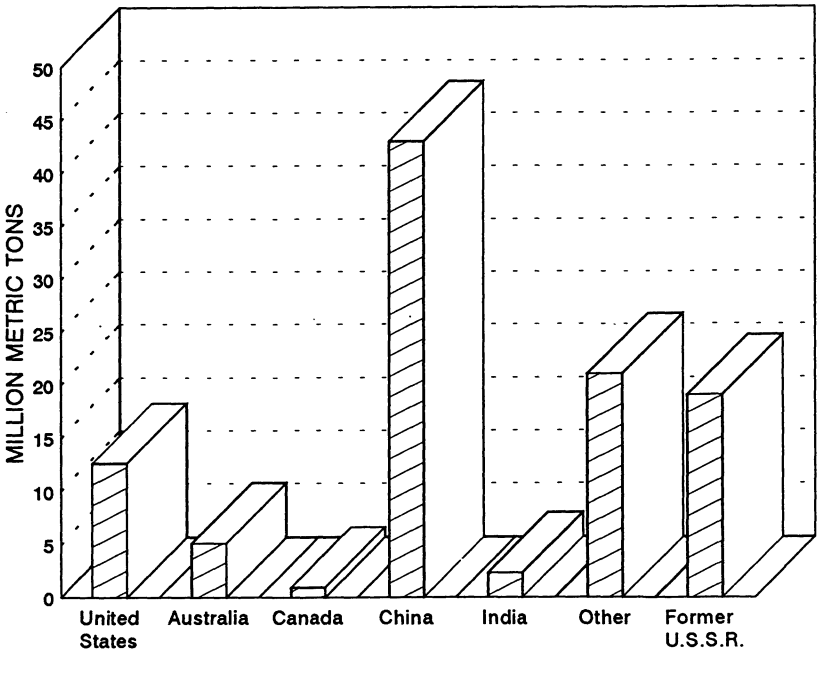
Source: Bureau of the Census.

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 James F. Carlin, Jr., Daniel Edelstein, James H. Jolly, Janice L. W. Jolly, John F. Papp, and Patricia A. Plunkert

Mr. Carlin, a physical scientist in the Branch of Metals, has been the tin specialist for 13 years and is currently the acting lead specialist. Mr. Edelstein, a physical scientist in the Branch of Metals, has 10 years of experience as a commodity specialist dealing with copper and its byproduct metals. Mr. Jolly is a geologist with more than 35 years of mining experience, including positions with Hecla Mining Co., Roan Selection Trust, and the U.S. Geological Survey. He was a mineral commodity specialist for the U.S. Bureau of Mines (USBM) for 20 years and the zinc specialist for the past 11 years before retiring in mid-1992. Mrs. Jolly is a geologist with more than 30 years in the mining industry, including 17 years with the USBM. Mrs. Jolly served as the copper specialist for the USBM for 10 years and is currently the Statistician for the International Copper Study Group, in Lisbon, Portugal. Dr. Papp, a physical scientist with 21 years of USBM experience, has been the commodity specialist for chromium since 1983 and was the coordinator for this report. Ms. Plunkert, a chemist with 24 years of USBM experience, has been the commodity specialist for aluminum since 1987.

INTRODUCTION[1]

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 1992 exceeded $7.6 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 supply and recycling statistics for those same metals. Figure 1 shows a general flow scheme for recycling.

As part of its Commodities and Materials Program, the USBM 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 publication examines and reports on minerals and materials trends as well as environmental aspects of the entire life cycle of minerals use.

The USBM's Research Directorate conducted research in 1992 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. To increase the efficiency of recycling, the USBM investigated the control of impurities such as magnesium and zinc in aluminum scrap and the removal of copper from ferrous scrap. The USBM also investigated methods to remove heavy-metal contaminants from mineral processing and manufacturing wastes and to stabilize those heavy metals not removed.

Because of the increasing importance of recycling to domestic metal supply and the intense public interest, the USBM initiated this separate chapter on nonferrous metal recycling as part of its Annual Report series in 1991. A separate chapter on iron and steel scrap already has been part of this series for many years. The focus of this chapter is on aluminum, copper, lead, tin, and zinc recycling.

ALUMINUM[2]

Domestic Data Coverage

Domestic recycling data for aluminum are developed by the USBM from a voluntary survey, "Aluminum Scrap," of U.S. operations. Of the 94 companies and/or plants to which monthly or annual survey requests were sent, 83 responded, representing 92% of the total scrap consumed shown in table 5.

In 1992, the number of companies responding to the USBM's aluminum scrap survey increased. This was partially responsible for the large increase in recovered secondary aluminum compared with that of the previous year. Also, the secondary data for 1991 were revised downward, owing to a double-counting error that did not become evident until this year.

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 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 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 nd 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.

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 before 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.

Aluminum recovered from scrap has shown a tenfold increase since 1950. 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 cycle 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.

Aluminum scrap, in one form or other, is recovered by almost every segment of the domestic aluminum industry. Integrated aluminum companies, secondary aluminum smelters, independent mill fabricators, foundries, and chemical producers can recover aluminum from scrap. Integrated aluminum companies and 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 die casters, who cast other metals, the secondary aluminum smelter is totally dependent upon 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 also can 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 melted down.

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 integrated aluminum companies. The types of scrap processed by these companies tend to be more segregated than those processed by the secondary smelters. Integrated aluminum companies 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. Integrated aluminum companies also operate can recycling programs. These companies have set up thousands of collection centers around the country for used beverage containers. 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.

Aluminum scrap also is 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 pounds 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 1992, the USBM estimated that more than 2.7 million metric tons (Mmt) 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 supplied 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. The aluminum industry reported that the recycling rate for all-aluminum beverage cans reached a record high of 67.9%. *(See figure 2.)*

With the introduction of its secondary aluminum ingot contract, the London Metal Exchange (LME) began storing aluminum alloy ingot in its warehouses around the world. At yearend 1992, the LME reported that its U.S. warehouses held a total of 10,120 metric tons of aluminum alloy ingot. Worldwide the total was 15,540 tons by yearend. *(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, the recycling rate for all-aluminum beverage cans reached a record high, as 62.74 billion aluminum UBC's were recycled in 1992. It was the 21st consecutive year that the number of cans returned for recycling has increased. In 1972, when statistics were first tabulated, 1.2 billion cans were returned. The recycling rate in 1992 was 67.9%, up from the 1991 rate of 62.4%.

The three largest domestic automakers, Chrysler Corp., Ford Motor Co., and General Motors Corp., announced the formation of the Vehicle Recycling Partnership (VRP) to research and promote the recovery and reuse of materials from junked cars. According to the companies, the partnership was expected to propose methods for increasing the amount of recycled materials used in autos and trucks as well as recovering more from the vehicles. The automakers also stated that the partnership was expected to look into developing industry guidelines in such areas as materials selection and compatibility, bonding methods and materials, painting, and design for disassembly. Research in these areas reportedly would be carried out in the laboratories of the three automakers and by other industries, universities, and research institutes.

Reynolds Metals Co. announced that it was expanding its aluminum foil and foil container recycling program from the 5 cities that served as the test markets for the program in 1991 to more than 60 metropolitan areas covering half the nation. In its expanded program, Reynolds would extend its "Great Balls of Foil" contest to schools in 30 of the new locations. A total of more than 2,000 schools in these markets would compete to build the largest ball of aluminum foil and then recycle it for cash and other prizes.

Alcan Rolled Products Co. and Anheuser-Busch Recycling Corp. reportedly teamed up in Florida for a "Foil to Foliage" program. The program enabled residents of Brevard County to drop off their aluminum foil at an Anheuser-Busch collection center, and cash equal to the value of the returned aluminum would be donated to the nonprofit "Keep Brevard Beautiful" organization.

Barmet Aluminum Corp. and IMCO Recycling Inc. announced plans to construct a $16 billion, 120,200-metric-ton-per-year (mt/yr) (265-million-pound-per-year) aluminum recycling facility to be situated near Barmet's Urichsville, OH, rolling mill. Under the reported agreement, IMCO would have the exclusive rights to recycle Barmet-purchased scrap at this plant for a period of 10 years. As the new plant comes on-stream, Barmet's recycling plant at Urichsville will be phased out. The plant, which reportedly would recycle UBC's and dross and would increase IMCO's aluminum recycling capacity by 50%, was expected to be fully operational by mid-1993.

Metal Resources Inc., a scrap metals recycler and processor of aluminum drosses and aluminum UBC's, announced plans to double the capacity of its Loundon, TN, facility. Upon completion of the project, scheduled for early 1993, the company reportedly would be able to process about 10,900 tons (24 million pounds) of aluminum per month. Before the planned expansion, the company stated that it processed nearly 2 billion UBC's per year.

U.S. Reduction Co. reported that construction had begun on a new 27,200-mt/yr (60-million-pound-per-year) aluminum recycling plant in Tipton, IN. The company expected the plant to reach full production capacity by the second quarter of 1993. The plant reportedly would provide specification liquid metal and ingot to aluminum automotive diecasters and foundries.

Aluminum Smelting and Refining Inc. reported that the company had closed its secondary aluminum plant. The decision to close the privately owned plant reportedly came after months of attempts

to sell the company had failed.

Markets and Prices.—Purchase prices for aluminum scrap, as quoted by the American Metal Market (AMM), fluctuated during the year, and closed the year at higher 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, 45 to 46 cents per pound; old sheet and cast aluminum, 38 to 39 cents per pound; and clean dry aluminum turnings, 39 to 40 cents per pound.

Prices for UBC's also fluctuated during the year, but closed about 8 cents per pound higher than prices at the beginning of the year. Aluminum producers' buying prices for processed and delivered UBC's, which began the year at a range of 32 to 37 cents per pound, reached a high for the year of 44 to 47 cents per pound in late April. The price range at the end of the year was 40 to 42 cents per pound.

Secondary aluminum ingot prices, as quoted by AMM, fluctuated during the year, but closed higher than prices at the end of 1991. The yearend 1992 price ranges for selected secondary aluminum ingots were as follows: alloy 380 (1% zinc content), 68 to 69.5 cents per pound; alloy 360 (0.6% copper content) and alloy 413 (0.6% copper content) 71.5 to 72.5 cents per pound; and alloy 319, 69.5 to 71 cents per pound.

Metals Week instituted an A-380 aluminum alloy price with the following specifications; 8% to 9.5% silicon, 1% iron, 3% to 4% copper, 0.5% manganese, 0.1% magnesium, 0.5% nickel, 0.35% tin, and 2.9% zinc. The price was for standard ingot in 45,000-pound truckload amounts delivered customer works. The price represented a range of spot transaction prices conducted by a survey of major suppliers and buyers. Weekly and monthly quotations began in July. The 1992 annual average price, based on 6 months of prices, was 57.081 cents per pound.

In May, the LME announced the introduction of a secondary aluminum alloy contract. Three-month trading began on October 6, and cash trading began on January 4, 1993. Trading was conducted in U.S. currency. The LME based its contract on three secondary aluminum alloy specifications: U.S.380-1, Japanese ADC12, and German DIN226.

Foreign Trade.—Exports of aluminum scrap decreased dramatically in 1992, reaching their lowest level in 8 years. Japan continued to be the principal destination of aluminum scrap exported, accounting for almost one-half of the total in 1992.

Imports for consumption increased about 25% compared with those of the previous year. Canada remained the major shipping country to the United States, supplying almost two-thirds of the total aluminum scrap imports in 1992. *(See tables 7 and 8.)*

World Review.—According to preliminary data published by the World Bureau of Metal Statistics in August 1993, world production of secondary aluminum was about 5.9 Mmt in 1992. According to its statistics, the United States was the world's largest producer of secondary aluminum, followed by Japan at about 1.5 Mmt and Germany at about the 0.5-Mmt level.

Italy.—Reynolds Europe Recycling, a subsidiary of Slim Cisterna, announced the start up of a 65,000-mt/yr secondary aluminum facility in Venafro. The new plant consisted of two production lines. One line recycled aluminum scrap and produced extrusion billet, and the other recycled aluminum UBC's and produced rolling ingot. The new plant reportedly would concentrate on the production of extrusion billets until the aluminum UBC collection network was extended to support the feed material required by the rolling ingot portion of the plant.

Japan.—Mizushima Ferroalloy Co. announced the completion of a 15,000-mt/yr secondary aluminum alloy ingot plant. The company stated that about three-fourths of the UBC feed for the plant would be imported.

Malaysia.—Several companies from Finland, Japan, Malaysia, and Singapore announced the formation of a joint venture, Johore Aluminium Processing Sdn Bdh, to construct a 7,500-mt/yr secondary aluminum smelter in the southern Malaysian state of Johore. Construction reportedly was set to begin in January 1993 with full commissioning set for July. The plant was expected to produce diecasting and casting-grade material for sale to markets in Southeast Asia.

Switzerland.—Alusuisse-Lonza Holding Ltd. announced plans to close its subsidiary, Metallwerke Refonda, at the end of May. The company cited low prices, high operating costs, and a shortage of scrap as reasons for the closure of its 35,000-mt/yr secondary aluminum plant in Niederglatt.

Current Research.—Bench-scale tests by the USBM have shown that magnesium (Mg) and zinc (Zn) can be readily distilled from common aluminum alloys. For example, treating a 50-gram charge of alloy 7075 at 840° C under a vacuum of 0.1 torr decreased Mg and Zn from 2.2 and 5.6 weight-percent (wt %), respectively, to less than 0.1 wt % in 10 minutes. The results show that temperature and pressure strongly influence distillation rates. Changes in the alloy composition did not have a noticeable effect on distillation rates. Even though the distillation rates were high, they were less than predicted by distillation equations. Possible explanations for this were explored. A conceptual apparatus for integrating distillation into a secondary smelter is discussed.[3]

Outlook

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 rate in the recovery of aluminum in countries outside the United States, where the aluminum beverage can already dominates the market. In the long term, as 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 SCRAP[4]

Background

Definitions, Grades, and Specifications.—The Institute of Scrap Recycling Industries, Inc. (ISRI) recognizes about 53 classes of copper and copper alloy scrap. Although there are several grades within each, the major unalloyed scrap categories are No. 1 copper (common names—Barley, Berry, Candy, and Clove), which contains greater than 99% copper, and No. 2 copper (common names—Birch, Cliff, and Cobra). Although No. 1 copper may be consumed directly (remelt) or processed through a refinery, No. 2 copper requires refining before it is consumed. In addition, there are numerous scrap types designated by alloy composition, and special designations for low copper content scrap such as skimmings, ashes, and residues, which contain 12% to 30% copper. Even lower copper content scrap includes electronic scrap, refining slags, printed circuit board and other clad materials, and metal-laden waste liquors.

Copper scrap for trade may be classified as new, generated during the manufacturing of finished products, or old, recovered from used, wornout, or obsolete products. Scrap that is recycled internally by the producer or consumer (home or run-around scrap) is generally discounted when measuring scrap demand.

A manufacturer may generate up to 60% scrap as clippings, trimmings, stampings, borings, and turnings when processing copper and copper-base products into finished articles. This new, or mill-return, scrap is readily used by brass and copper tube mills to generate new semifabricates. Secondary materials, both old and new scrap, that require minimal processing are commonly called direct melt scrap. In 1992, direct melt scrap provided about 830,000 tons or about 70% of copper from all secondary materials.

Resources.—Since World War II, the ever-increasing reservoir of copper products in use, much of which is eventually recycled as old copper, has provided annually between 19% and 33% of U.S. apparent industrial consumption, and on average, has provided about 18% of world copper consumption. The U.S. industry's contribution to the secondary materials reservoir of items in use, discarded, or abandoned in place, over the same period, has increased from about 16 Mmt in 1940 to more than 71 Mmt in 1992. This secondary materials reservoir does not include a sizable and growing pool of new scrap that is recycled every year. New scrap currently makes up about 24% of U.S. apparent consumption of copper; copper in old and new scrap comprises about 44% of apparent consumption. In 1940, the world copper reservoir of copper materials in use, or abandoned in place, was about 33 Mmt. By 1992, this reservoir of potentially recoverable secondary materials was estimated at about 194 Mmt of copper.

The annual U.S. contribution to the unrecovered copper reservoir of items in use or abandoned has been increasing since 1983 at the rate of about 1.2 Mmt/yr. Of this amount, more than one-half of the unrecovered copper remains in the consumer and general use sectors. 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. Copper is one of the most recycled of metals, but still much would appear to be entering solid waste disposal sites; the amount has been estimated as high as 50% of the unrecovered products. Copper has few applications that are dissipative by nature; only about 0.5% of total copper consumed may be lost and unretrievable from uses such as chemical production.

The availability of secondary copper is linked with the quantity of products consumed and their life cycles, or duration. Many estimates have been made about individual products; product life cycles may even vary from country to country, according to construction methods and concepts. However, copper in electrical plants and machinery averages 30 years; in nonelectrical machinery, 15 years; in housing, 35 years; and in transportation, 10 years. 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. The rate of old scrap recovery is limited not only by copper's long life and its essential uses, but also by the sensitivity of scrap collection to market prices.

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 source of secondary copper is cable scrap. Whereas previously burning of the cable to remove the plastic parts 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 sorting techniques to separate the insulating materials (fluff) from the metal.

Processing complex copper-containing

materials, such as drosses, flue dust, catalysts, collector dust, slimes from electroplating wastewater, and metal-rich slags from converter processes, requires versatile production processes. Most old scrap must be reprocessed by either 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 to produce refined ingot, wire bar, slab, or billet. 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 cast into anode form for further processing in an electrolytic refinery. Byproducts, such as tin and precious metals, may be recovered 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. Reverberatory or electric rotary melting furnaces are used for casting various copper forms, such as slabs, cakes, or billets. ASARCO Incorporated shaft furnaces may be used in series with holding furnaces in conjunction with continuous casting systems.

Most processing plants have built-in water recirculation systems in which some of the metal content is recaptured and reused. In general, a combination of various hydrometallurgical techniques such as precipitation, cementation, ion exchange, solvent extraction, reverse osmosis, gaseous reduction, and electrolysis are used to treat process waters. Cementation has been successfully employed to recover copper from waste effluents. Solvent extraction and ion exchange are highly selective methods for separation of copper from other common metals in solution. Mechanical and thermal dismantling, and more recently, leaching and solvent extraction and electrowinning procedures, have proved effective in treatment of certain types of electronic scrap. Electrowinning recovery also is used for processing waste liquors that contain copper and other metals.

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.

Economic Factors.—Prices paid for scrap are related generally to the current refined copper price, but the spread between the two prices must be sufficient to allow for processing costs and the inherent costs of scrap preparation (collection, sorting, shipping, chopping, briquetting, etc.). Processing by scrap smelters becomes uneconomic as the gap between scrap and refined price narrows. 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 19 cents in 1992. The low spreads in the early 1970's were caused by price controls placed on U.S. copper during this period. The very high spreads of the late 1980's, which averaged more than 30 cents per pound, as shown in figure 3, were the result of high refined copper prices and a good supply of scrap. Price spreads also tend to widen when speculative interest is active on the 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.

Annual Review

Consumption.—Copper ranks third in world metal consumption after steel and aluminum. The major copper consuming nations or areas of the world are Western Europe (29%), United States (20%), Japan (15%), the former U.S.S.R. (7%), and China (6%); about 11 Mmt of primary and secondary refined copper was consumed in 1992. About 72% of the metal consumed in the United States was for electrical and electronic uses, finding widespread application in all sectors of the economy. Nonelectrical construction (14%), machinery (5%), transportation (5%), ordnance (2%), and miscellaneous (2%) end uses make up the remainder of demand.

In 1992, about 1.7 Mmt of copper-base scrap (old and new), containing an estimated 1.22 Mmt of recoverable copper, was consumed in the United States. An additional 57,000 tons of copper was recovered from aluminum-, nickel-, and zinc-base scrap. The total copper recovered from scrap was valued at $3 billion. Recycled copper was derived 57% from new scrap and 43% from old scrap. Purchased new scrap derived from fabricating operations yielded 722,351 tons of contained copper, 74% of which was recovered at brass mills. Copper recovered from old scrap made up 24% of U.S. apparent copper consumption (primary refined production plus copper recovered from old scrap plus net imports and net stock changes). *(See figure 4.)* About 20% of U.S. refined copper production was from scrap. Five secondary smelters and a small 450-mt/yr secondary electrowinning plant had a combined copper capacity of 440,000 tons in 1992. In addition, about 28 ingotmakers, 40 brass mills, and 750 foundries, chemical plants, and other manufacturers also consumed copper scrap in the United States. Brass mills, smelters, and ingotmakers accounted for most of scrap consumption.

In 1992, the major copper scrap types consumed were: No. 1 copper, 27%; No. 2 copper, 23%; leaded yellow brass, 17%; yellow and low brass, 7%; automobile radiators, 5%; red brass, 4%; and low-grade ashes and residues, 10%. A wide variety of alloys made up the remaining 8%. Brass and copper tube mills processed 65% of the No. 1 copper and most of the cartridge cases and yellow brass, while the secondary smelters and ingotmakers processed 88% of the No. 2 scrap and most of the auto radiators and red brass scrap. *(See tables 9-17.)*

Foreign Trade.—The United States is one of the largest international sources for copper scrap, followed by France, Germany, and the United Kingdom. U.S. exports of copper scrap have been increasing since the 1960's, when the Far East nations began to industrialize. More recently, China has become a significant importer of U.S. copper scrap. Canada and Mexico were the leading sources for U.S. imports of copper and copper alloy scrap in 1992. U.S. copper scrap exports increased from 17,000 tons in 1950 to 247,000 tons in 1992. In 1992, U.S. scrap exports were valued at $282 million, while scrap imports were valued (c.i.f.) at $284 million. *(See tables 18 and 19.)*

World Review.—The Western European countries make up the largest single market for scrap in the world. Germany, Italy, France, the United Kingdom, and Belgium are the leading consumers. The United States is second after the European Community (EC) in total scrap consumption. Asia, mostly Japan, is the third largest scrap consuming area of the world. Copper scrap accounted for 36% of annual copper consumption in the countries of the EC, compared with about 42% of total annual copper consumption in the United States. In recent years, about 21% of refined copper in the United States and 40% of the refined copper produced in Western Europe was derived from copper scrap. On average, copper from scrap accounts for about 18% of the world's refined copper production.

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. The Asian countries export very little scrap, and most of this goes to other Asian countries. Asian imports of scrap from Western countries have grown significantly in recent years. China, in particular, has increased its imports of U.S. generated scrap over the past 3 years.

Outlook

Over the next decade, copper scrap will continue to be a premium material for the U.S. semifabricating industry. Because scrap is usually a lower cost alternative to primary metal, it will continue to be of great interest to Far Eastern countries as they expand their industries. Recovery of copper from the large and growing reservoir of copper products in use may be limited by the following factors: (1) copper prices, (2) life of products, (3) available recovery technologies, and (4) rate of copper consumption. Affecting the availability of new scrap is the recent industry observation that the amount of new scrap being generated by manufacturing plants has been cut by as much as 50%, owing to increased production efficiencies. Another factor that will affect copper scrap collection, use, and processing over the next decade is the limitation on lead in copper plumbing alloys, as a result of legislation limiting the content to 2% lead or less.

Without successful implementation of new recovery technologies, the recovery of copper in all parts of the economy will be impeded by increased legislative requirements. New technologies, some of which have been introduced, are expected to increase recovery of copper from wastewaters, electronic scrap, and other scrap with low copper content. 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.

World consumption of copper in scrap was estimated to be 5 Mmt in 1992 and is forecast to be about 7.2 Mmt by the year 2000. Of this amount, 1.8 Mmt in 1992 and 2.8 Mmt in 2000 will be as secondary refined copper.

LEAD[5]

Refined lead is a soft, heavy metal, that was one of the first metals used by humankind. It has a low melting point, which makes it among the easiest metals to cast, it is the most corrosion-resistant common metal, and has unusual electrical properties. In terms of tonnage of metal consumed, demand for lead is surpassed only by aluminum, copper, iron, and zinc. The United States is the world's largest producer and consumer of refined lead. The domestic demand for lead has changed significantly over the past 20 years. In 1972, dissipative uses of lead, particularly gasoline additives, pigments, ammunition, and chemicals, amounted to more than 400,000 tons, or about 30% of reported consumption of 1.35 Mmt. In 1992, following the phase out of lead-based gasoline additives and pigments for interior paint, dissipative use accounted for less than 10% of a total demand of 1.24 Mmt.

About 74% of the domestic consumption of lead metal is metal recovered from both new and old lead scrap. In 1992, 917,000 tons of metal valued at $494 million was recovered from both new and old scrap. Lead scrap is traded on world markets. In 1992, the United States exported about 63,000 tons of lead scrap with a value of $15 million. Imports of lead scrap for the year totaled about 200 tons worth $65,000. *(See tables 20, 21, 22, and 23.)*

Old scrap is the predominant form of recovery of lead scrap. In 1992, old scrap accounted for 94% of the total of 917,000 tons of lead scrap recovered. Used batteries supply about 91% of that old scrap. The battery industry dominates the lead scrap field just as it dominates the primary lead usage category. In recent years, integrated battery manufacturers and secondary smelters have expanded smelting capacity to fill a vacuum left by the closure of small- and medium-sized, nonintegrated, battery breaking, and/or secondary smelters that have closed due to environmental-related pressure. Similarly, the independent scrap dealer is playing a diminished role as battery manufacturers are entering into buy-back arrangements with retail outlets, both as a marketing tool for new batteries and as a means of ensuring feedstock to their smelters and downstream manufacturing operations.

Domestic Data Coverage

Domestic data for lead scrap are developed by the USBM from voluntary canvass survey forms sent to the firms monthly and annually. The larger firms tend to be canvassed monthly, while the smaller ones tend to be canvassed annually. Of the 39 companies producing secondary lead, exclusive of copper base, to which a survey request was sent, 29 responded, representing 82% of the total refinery production of secondary lead. Production and consumption for the nonrespondents were estimated using prior-year levels adjusted for general industry trends.

Background

At yearend 1992, the secondary lead industry was composed of 16 companies that operated 23 battery breakers-smelters with capacities of between 10,000 and 120,000 mt/yr; 5 smaller operations with capacities between 6,000 and 10,000 mt/yr; and 18 small plants (less than 1,000 mt/yr) that produced mainly specialty alloys for solders, brass and bronze ingots, etc.

Annual Review

Domestic secondary production in 1992 was estimated to have nearly achieved 1990's alltime record as capacity utilization for the year was an optimum 88%. This was mainly because a major battery recycler in Alabama was permanently closed by the U.S. Environmental Protection Agency (EPA) early in the year.

Operations were indefinitely suspended at a smaller battery recycler in midyear in Tennessee, but this was offset by Refined Metals Corp.'s, Memphis, TN, plant, which had been shut down at the beginning of the year, coming back on-stream. During the year, several smaller nonbattery recyclers who mainly produced specialty alloys for such uses as solders, brass or bronze ingots, bearing metals, etc., closed permanently, a result of being overcome by very low to nonexistent margins and increasingly enforced environmental emissions and workplace standards.

A new, small, "just-in-time" battery recycler came partially on-stream in Ohio, but was not producing at yearend owing to financial and technical problems. However, at yearend, the secondary lead industry had an estimated production capacity of 1.04 Mmt, 1.0 Mmt of which resided with 15 battery recycling companies. These 15 companies operated 20 breakers and 22 smelter-refineries with capacities of 10,000 to more than 100,000 mt/yr, although two in Ohio and Tennessee were still shut down at yearend and several had curtailed operations. Also operating were five midlevel, nonbattery smelters-refineries, including Asarco's Omaha, NE, refinery, with furnace and kettle capacities of 6,000 to 10,000 mt/yr. In addition, 13 small specialty alloy producers were operating, 3 with capacities of 1,000 to 2,000 mt/yr; the other 10 had considerably smaller capacities.

Total production from the nonbattery plants in 1992 was 38,000 tons, much of which was from copper-base scrap and/or new scrap. In the first full year of operation, Doe Run Company's new secondary plant at Boss, MO (on the site of its former Buick primary smelter-refinery), produced at full capacity. However, overall, for 1992, the RSR Corp. (Dallas, TX) was the Nation's largest secondary lead producer. It outproduced both Doe Run's and Asarco's individual (primary and secondary) pig lead outputs.

Outlook

Primary and secondary lead production as well as consumption have been negatively impacted by numerous Federal and State laws targeted at specific areas to reduce the hazards of lead for more than a decade. The trend of increasing secondary share of production and consumption is expected to continue until optimum recycling is achieved. The year 2000 growth in scrap lead production is expected to average about 1.5% yearly.

TIN[6]

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 alloying metal with other metals. Metal is generally used as the starting point for most uses of tin. The major uses for tin are as follows: cans and containers, 32%; electrical, 22%; construction, 10%; and transportation, 11%; other uses account for the remaining 25%. Tinplating currently uses no scrap tin, but most other fabricated end-use items, especially solder and brass/bronze, use substantial quantities of tin scrap.

About 30% of the domestic supply of tin metal is metal recovered from both new and old tin scrap. In 1992, 13,700 tons of metal valued at an estimated $85 million was recovered from new and old tin scrap.

Old tin scrap is collected at hundreds of domestic scrap yards, at nine tinplate and can detinning plants, and at most municipal collection centers. New tin scrap is generated mainly in the tin mills at six steel plants, numerous brass and bronze plants, and numerous soldermaking plants.

Detinning facilities are unique to the tin scrap industry, in that no other major metal industry has such large-scale facilities to remove plated metal. Nine plants are spread across the country. Until about 1989 they processed almost solely new tinplate scrap that originated in the tin mills of steel plants and canmaking plants. Since 1989, with new technology that shreds used tin cans, some of the Nation's detinning facilities have the capability of also detinning old tin cans. Only in the detinning process does free tin metal see its way to the marketplace; all the alloy forms of tin are merely recycled within their own product-line industries and thus reappear as regenerated alloys. *(See tables 24, 25, 26, and 27.)*

Most tin scrap processing facilities are close to the tin-using industries and to densely populated areas. Most are in the

Midwest and Northeast.

Domestic Data Coverage

Domestic scrap data for tin are developed by the USBM from a voluntary survey of the U.S. tin scrap industry. The smaller side of this industry is covered by a canvass sent to five detinning companies monthly; all five respond or are estimated for. The larger side of the tin scrap industry, involving the alloys of tin, is covered largely by a canvass of the copper and lead scrap industries (tin's major coalloys) from which estimates are made for the tin content.

Background

Secondary tin was derived 30% from new scrap and 70% from old scrap. New tin scrap consists mostly of forms of tinplate (side scrap, flitters, cobbles, skeletal punch-outs from can-making etc), drosses from soldering skims, and plating residues and sludges from tinplating lines. Old tin scrap consists mostly of used brass/bronze items (often faucets, fixtures, etc.) and used soldered items (both electronic solders from computers, television and radio sets, etc. and plumbing solders from houses and office buildings); since about 1989 some used tin cans have been detinned, and the scrap tin recovered qualifies as old tin scrap.

The solder industry has traditionally consumed large amounts of tin scrap to make solder products. Tin scrap accounts for 38% of the total tin used for solder. The brass/bronze industry, although smaller than the solder industry, has also traditionally been a major consumer of tin scrap. Scrap accounts for 56% of the total tin used for brass/bronze.

The average life of tin in its end uses is estimated at 20 years. It is estimated that about 10% of the tin placed in use in any year is dissipated in that same year. Tin in such chemical products as wood preservatives, marine boat hull antifoulant paints, fungicides, tin oxides, and tin tetrachlorides sprayed on glass bottles is quickly dissipated. Some longer lasting tin products also release tin to the environment while in use. For example, tinned electrical copper cables lose tin through weathering or corrosion, whether overhead or underground. The tin in some other end uses is dissipated, even though the products are disposed of in a controlled way; an example would be the used tin cans collected by municipal trash departments and placed in landfills. Currently, about 13% of the domestic requirement for tin is satisfied by old scrap.

Technology.—Tin recycling processes vary according to the nature of the tin scrap. Tin-plated products such as tinned kitchen trays or tinned electrical copper cables or tinplate or tin cans typically are treated in a batch process at elevated temperatures with a sodium hydroxide solution for a considerable period of time. Typically, an electric current is applied in a reversal of the original plating process. The tinned product is made anodic, and electrodes in the batch are made cathodic. Positively charged tin ions leave the tinned product and travel through the electrolytic bath to the negatively charged electrode, where the tin is plated and then can be used as scrap tin for a variety of uses.

For tin alloys, generally there is no attempt to recover the tin as a separate element. Instead, during the alloy refining process the matt is analyzed periodically, and as needed, tin is added to bring the molten batch to the desired specifications.

Secondary tin generally is utilized in the various alloys of tin, especially brass/bronze and solder. These alloys often take the shape of a bar or ingot, but also sometimes appear as rod, wire, plate, pellets, or powder. Traditionally, the brass/bronze industry utilizes the largest percentage of scrap tin to total tin.

Economic Factors.—Scrap prices are generally available only within the industry. But, occasionally, publications such as AMM publish some alloy scrap prices and prices for baled old tin can scrap.

There is an active international market in some forms of tin scrap. Generally, the United States has been the world's leading generator of tin scrap, and in some years substantial amounts are exported.

Annual Review

Production.—MIDCO Inc., St. Louis, MO, announced the startup of its new tin smelter, designed to produce Grade A tin from secondary sources. The MIDCO brand, which was sanctioned by the LME, will be sold in ingot form. Expected production was 3,000 mt/yr. Before this year, MIDCO had been producing a tin/lead solder.

AMG Resources Corp., Pittsburgh, PA, the world's largest processor of tin-plated steel scrap and used tin cans, announced it would supply all used steel can scrap purchased by Weirton Steel Corp., Weirton, WV. Weirton ranks as one of the major domestic tinplate producers. The agreement was considered the first step in AMG's filling the majority of Weirton's overall scrap needs with AMG's processed cans. Although much of the steel can scrap that would be shipped to Weirton would be detinned material, some would still have the tin coating.

USX Corp. announced steps to increase its consumption of beverage can scrap to ensure recyclers that a viable market would continue to exist for recycled steel and bimetal cans. Previously, most of USX's can scrap purchases were melted at its Chicago, IL, and Gary, IN, plants. Henceforth, USX would accept can scrap at all its melt shops, adding its Braddock, PA, and Fairfield, AL, plants. Tube City Inc., which operated the scrap yards at all USX integrated plants, would handle the processing of all the can scrap, which totaled 70,000 tons in 1991. With completion this year of a continuous caster at USX's Mon Valley Works in Braddock, PA, the company would have converted completely to continuous casting. Because continuous casting generates considerably less internal scrap than ingot-cast steelmaking, used can

scrap from the Nation's solid waste stream will probably become increasingly important to USX and other steel producers.

Weirton announced it had joined a collaborative effort with Nippon Steel Corp., Japan, and the Sollac Div. of Usinor, France, to maximize the recycling of steel cans. All three firms are major tinplate producers. The companies intend to examine the various methods of separating steel cans from the refuse stream and recycling them back into the steelmaking process. They also planned to work together to develop a lighter weight steel can to increase the competitiveness of the 2-piece steel beer and soft drink can.

The Steel Can Recycling Institute, Pittsburgh, PA, funded by the major domestic tinplatemakers, announced that the recycling rate for steel beverage cans in 1991 was 46%, while the overall rate for steel cans was 34%. This compares to the following rates for competitive materials: aluminum beverage cans, 62%; glass containers, 31%; and plastic polyethylene terephthalate (PET) soft drink bottles, 36%.

World Review.—The United States, along with France, Germany, Japan, and the United Kingdom, generally lead the world in tin recycling activity and innovation. Environmental pressures in these countries for the past 20 years have acted as a powerful incentive. In contrast to the United States and Europe, Japanese industry does little or no detinning because they feel that tin coating on tinplate has become so thin in the past 20 years that detinning is not economical.

In Germany, 1992 marked the start of the Government's new controversial and more stringent packaging recycling law. The new quotas required under the law require business and industry to collect 30% of all aluminum sold as packaging material (based on weight) and to recycle 60% of that collected waste. They require collection of 40% of all tinplate sold, 65% of which must be recycled. The reason for the differential between tinplate and aluminum is that aluminum is combined more often with other materials, such as plastic and paper in beverage cartons or boxes and thus can be much more difficult to recycle. In July 1995, higher quotas are to be established—about 80% would have to be collected and about 90% of collected aluminum and tinplate will have to be recycled. Germany used 109,000 tons of tinplated cans and 7,000 tons of aluminum cans in 1991, a total of 4.3 billion cans. Germany was the first nation to require business and industry to collect and recycle materials used to package their products. The environmental group Bund für Umwelt und Naturschutz Deutschland began an intense campaign of its own calling for a ban on the use of tinplate and aluminum beverage cans, and a return to refillable glass bottles. The group argued that there was duplicity in the packaging industry's promotion of beverage can recycling and questioned the high recycling rate the industry has claimed. It targeted Viag AG, the large German container producer, for much of its attention.

In the Republic of South Africa, Iscor Ltd. organized a joint effort to clean up the nation's environment by recycling more used tin cans. The program was expected to increase the level of steel can recycling during the first year from 15,000 tons to 30,000 tons. This would represent 30% of the annual tin can production in South Africa. Organizers of the program set a 5-year goal of 50% tin can recycling. Driving the venture was National Metal Co., Iscor's scrap reclamation and trading subsidiary. Other partners in the venture were two major canmakers, Bevcan Co. and Crown, Cork & Seal Corp., plus a recycling firm, Collect-A-Can Co. National Metal was proceeding to establish a countrywide network of steel can delivery points. Collect-A-Can recovered cans through about 2,000 collection points. Cans were crushed, baled, and delivered to Iscor's steel works in Pretoria and Vanderbijlpark for use in their scrap charge.

AMG Resources, the large recycler of tinplate and used cans, began offering British smelters aluminum extracted from bimetallic beverage cans (these are tinplated cans with an aluminum easy-open end). AMG had been experimenting with ways of extracting the aluminum for the past year, and the process became commercially viable this year. The breakthrough meant that AMG could offer shredded steel scrap, tin, and shredded aluminum from its recycling operations in Hartlepool and Llanelli. AMG capacity in used can recycling was about 35,000 tons annually, with only a 50% utilization rate due to problems in finding feedstock. Bimetallic cans represent about 30% of the total cans recycled by AMG. Previously, nonferrous materials extracted from the bimetallic cans were unsalable because of contamination from plastic and other packaging materials. Now, with the introduction of air and magnetic separation systems at both Hartlepool and Llanelli, a salable 80% pure aluminum scrap was obtained.

In the United Kingdom, the British Steel Can Recycling Information Bureau (SCRIB) announced that the country's steel can recycling rate had reached 21% in 1991, with 1.2 billion steel cans recycled compared with 1.1 billion in 1990. SCRIB attributed much of the growth to the Save-A-Can bank program, which increased its number of collection points from 322 in early 1991 to more than 600 this year; a goal of 1,000 can banks was set for 1994. No data had yet been collected for 1992.

Current Research.—In Japan, a steel recycling research program for development of new technology to produce high-grade steel from 100% scrap was launched by the Research Institute of Innovative Technology for the Earth, a Government-industry foundation supported by the industrial Technology Agency of the Ministry of International Trade and Industry (MITI). Nine Japanese steel producers were slated to participate in the program, on which it was planned to spend about $77 million over the next 8 years. The Institute noted that increasingly, steel products have come to contain tin, copper, zinc, etc., making them more difficult to recycle,

and that this calls for a next-generation steelmaking technology. The project would focus on new technologies for separating copper, tin, zinc, etc., from scrap. Three steel plants would host the project: the Kimitsu Works of Nippon Steel Corp., the Keihin Works of NKK Corp., and the Chiba Works of Kawasaki Steel Corp.

Outlook

The near- and long-term outlook for tin recycling is positive, with modest growth of less than 1% annually. Tin consumption is expected to grow at about the same modest rate. Scrap is expected to grow from a current 17% of total metal consumed to about 18% by the year 2000. A major incentive is expected to be environmental legislation, mostly at the local and State level. If tin prices remain relatively high compared with prices of other major metals, the industry will have sufficient incentive to recycle this costly metal.

ZINC[7]

Zinc is the fourth most widely used metal after iron, aluminum, and copper. About three-fourths is used in metal form and one-fourth in compound form. More than 90% of the metal is used for galvanizing steel and for alloys; the remainder is used to produce dust, oxide, and various chemicals. Most metal products find widespread use in the automotive, construction, electrical, and machinery sectors of the economy. Compounds are similarly dispersed in distribution and use, but are mainly used in the agricultural, chemical, paint, pharmaceutical, and rubber sectors of the economy. Nearly one-third of the 1.2 Mmt of zinc consumed annually by domestic industries is secondary zinc. In 1992, about 366,000 tons of secondary zinc, valued at about $471 million, was recovered in basic forms—refined metal, alloys, dusts, and chemicals. Scrap containing about 82,000 tons of zinc and valued at $48 million was exported in 1992, whereas 43,000 tons of zinc in scrap, valued at $23 million, was imported.

Old zinc and brass scrap is collected at hundreds of domestic scrap yards, at more than 200 U.S. automobile and appliance shredding operations, and at numerous municipal collection centers. New zinc scrap is generated mainly in galvanizing plants, diecasting plants, brass mills, and manufacturing facilities when basic zinc materials are consumed. There are 4 primary and 11 secondary smelters that process scrap, drosses, skims, and/or steelworking electric arc furnace (EAF) dust into slab zinc, zinc alloys, and zinc dust. Seven other plants process skims, drosses, scrap, and residues into zinc sulfate and/or chloride chemicals. Secondary brass and bronze are recycled at more than 500 secondary smelters, foundries, and ingotmakers. A plant in Illinois produces American-process zinc oxide from oxidic secondary materials. Most secondary zinc plants are in the Eastern and Midwestern United States; one plant in Pennsylvania is, by far, the single largest processor of secondary zinc. Crude zinc concentrates extracted from EAF dust are produced at six plants. *(See tables 28 and 29.)*

Background

Sources of Secondary Zinc.—Recycled zinc was derived 70% from new scrap and 30% from old scrap. New zinc scrap consists mostly of drosses, skims, furnace dusts, and residues (from galvanizing and diecasting operations, brass mills, and chemical plants) and clippings from the processing (stamping, trimming, etc.) of galvanized steel sheet and strip, rolled zinc, and brass sheet. Old scrap, historically, has consisted almost entirely of diecastings, mainly from scrapped automobiles; brass products; and rolled zinc items, such as gutters, roofing, and engraving plates. Only in the past decade has any zinc been recovered from discarded rubber tires or from old galvanized steel scrap. Zinc recovery from the burning of tires for energy is small but growing, whereas recovery from both old and new galvanized steel scrap has increased dramatically.

New zinc-base scrap, as shown in tables 27-29, has remained essentially unchanged in quantity over the past 40 years despite a sharp drop in zinc used for diecastings; zinc recovery from new galvanized steel sheet scrap, generated mainly in automobile manufacture, has offset declines in scrap generation from diecasting and improved manufacturing processes. Old zinc scrap, on the other hand, has increased substantially in the past few years, owing to the additive effects of zinc recovery from old galvanized steel scrap generated mainly from the shredding of discarded automobiles and appliances.

Common types of zinc scrap have been categorized by the industry such that they are identifiable as to their derivation or source and minimum grade and quality requirements. Specifications for the various zinc scrap types were updated by the ISRI in 1991 and published by ISRI (1325 G St., NW, Washington, DC 20005) in "Scrap Specification Circular 1991."

The life cycles of zinc-containing products vary widely from days, for some chemical products, to more than 100 years for some rolled-zinc and brass products. The average life of zinc in end uses is estimated to be 14 years. Despite recent improvements in the recovery of old zinc, most zinc products are disposed of in landfills or are dissipated into the environment. About 10% of the zinc placed in use in any year is dissipated in that same year. The zinc in such products as fertilizers and animal feeds, oils, inks, pharmaceuticals, vitamins, welding fluxes, and fungicides is dispersed in a relatively short time to the environment and is not recoverable. Many longer lasting products also release and dispense zinc to the environment while in use. For example, galvanized surfaces lose zinc through weathering or corrosion, vehicle tires abrade, paint weathers, and sacrificial anodes are slowly consumed. The zinc in many other end products is dissipated or lost to recycling even though the products are disposed of in a controlled way (placed in landfills) because recovery is not economical, or in some cases, not

technologically feasible. Because zinc uses are largely dissipative, the net cumulative rise in total zinc in the overall pool in use in the United States is only 10% to 20% of annual zinc consumption.[8]

Currently about 10% of the domestic requirement for zinc is satisfied by old scrap. In earlier times, the recovery from old scrap was much smaller. This was illustrated in a recent USBM study[9] in which it was estimated that of the 73 Mmt of zinc placed in use in end products in the United States in the period 1850 to 1990, an estimated 23 Mmt (32%) was still in use at the end of 1990, 46 Mmt (63%) had been dissipated, and only 4 Mmt (5%) had been recovered by recycling.

Technology.—Because of wide differences in the character and content of zinc-bearing scrap, zinc recycling processes vary widely. Zinc-containing metals are generally separated from other materials initially by physical means such as magnetics, sink-float, and hand sorting. In the case of mixed nonferrous metal shredder scrap, zinc can be separated from higher melting metals such as copper and aluminum, by selective melting in a sweat furnace. Zinc in galvanized scrap is largely recovered in furnace dust when the scrap is charged into a steelmaking furnace; however, one commercial process has been developed to strip zinc from galvanized scrap with a caustic leach before recycling the substrate steel to the steelmaking process.

Clean new scrap, mainly brass and rolled zinc clippings and reject diecastings, generally only required remelting before reuse. Drosses, fragmentized diecastings, and mixed high-grade scrap typically are remelted, followed by zinc distillation with recovery as metal, dust, or oxide. Sometimes, high-purity drosses are simply melted and reacted with various fluxes to release the metallic content; often the recovered metal can be used directly as a galvanizing brightener or master alloy. Medium and low-grade skims, oxidic dust, ash, and residues generally undergo an intermediate reduction-distillation pyrometallurgical step to upgrade the zinc product before further treatment; or, they are leached with acid, alkaline, or ammoniacal solutions to extract zinc, which is subsequently recovered as a compound by precipitation-crystallization or as a salable chemical retained in solution. Almost all of the zinc in EAF dusts is first recovered in an upgraded, impure zinc oxide product; however, several commercial, EAF-dust-treatment plants are able to bypass the intermediate step and directly recover zinc metal. The upgraded zinc oxide pyrometallurgical product is almost always shipped to a primary pyrometallurgical zinc smelter for refinement to metal. For the most part, the zinc metals, alloys, dust, and chemicals recovered from secondary materials are comparable in quality to those derived from primary materials.

Recovery efficiency is very high from simple remelting but declines as the number of processing steps increases and, generally, as the zinc content of the scrap declines. Zinc recovery from most secondary processes range between 40% to 85%; however, oxide materials, slags, and residues resulting from initial processes may in turn be recycled, resulting in further zinc recovery.

Secondary Refined Products.—Zinc materials made from zinc-base scrap are slab zinc, alloys, dusts, and compounds. Brass scrap, on the other hand, typically is remelted and, with alloy adjustment, recast as brass. Zinc chloride and sulfate compounds are produced largely by acid leaching of zinc skims, drosses, and chemical residues. Impure zinc oxide products and zinc-bearing slags are sometimes used as trace element additives in fertilizers and animal feeds. Zinc in brass is the principal form of secondary recovery, although in the past few years secondary slab zinc has risen substantially because it has been the principal zinc product of EAF dust recycling.

Economic Factors.—Prices paid for scrap and secondary materials are generally negotiated, often on the basis of a daily or average LME price for zinc metal. Bids are required for U.S. Department of Defense scrap sales. Prices depend on factors such as geographic location, quantity available, quality, grade, the presence of other components or elements, and environmental difficulties in handling, transporting, or treating. In the case of EAF dust, the dust generator usually pays the dust processor a fee to recycle the material. Typically, there is a basic charge for dust with 20% zinc content; generators of dust with lower zinc content pay more, whereas generators of dust with higher zinc content pay less. Zinc and brass scrap prices are generally not available, although average daily, weekly, or monthly prices for a few specific common types are published in AMM, Metal Bulletin, and Metal Bulletin Monthly. Basic guidelines for scrap metal transactions (contracts, packing, weighing, shipping and receiving, rejections, downgrades, and claims) are available in the aforementioned ISRI publication.

Outlook

Driven by public concern for the environment and legislation intended to protect the environment, domestic and world secondary zinc recovery is expected to increase as a percentage of zinc consumption in the next decade. However, the prospect for recovery equivalent to more than 35% to 40% of consumption is relatively poor because of the dissipative nature and diversity of zinc uses. Galvanizing has been the major growth area for zinc, and greater secondary zinc recovery can be expected from this source in the future. Increased processing of low-zinc EAF dust, dust from other steelmaking processes, and energy-generating tire burning appear to be other sources for near-term gains in secondary zinc output. Increased zinc recovery from the recycling of carbon-zinc and alkaline batteries, and municipal incinerator dusts and residues are longer term possibilities. Secondary zinc recycling could dramatically increase after the year 2000 if substantial numbers

of electric cars, powered by zinc-air batteries, become a reality.

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[1]Prepared by J. F. Papp, physical scientist, Branch of Metals.

[2]Prepared by P. Plunkert, physical scientist, Branch of Metals.

[3]Murphy, J. E., and J. J. Lukasko. Vacuum Distillation of Magnesium and Zinc From Aluminum Scrap. Paper in Light Metals 1993, ed. by S. K. Das (122d TMS Annu. Meeting, Denver, CO, Feb. 21-25, 1993). TMS-AIME, Warrendale, PA, 1993, pp. 1061-1065.

[4]Prepared by J. L. W. Jolly and D. Edelstein, physical scientists, Branch of Metals.

[5]Prepared by J. F. Carlin, Jr., physical scientist, Branch of Metals.

[6]Prepared by J. F. Carlin, Jr., physical scientist, Branch of Metals.

[7]Prepared by J. H. Jolly, physical scientist, Branch of Metals.

[8]Jolly, J. H. Materials Flow of Zinc in the United States 1850-1990. BuMines OFR 72-92, 1992, 53 pp.

[9]Work cited in footnote 8.

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Roskill Information Services Ltd. Zinc 1990, 4th ed.
Zincscan.

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
			ALUMINUM[4]			
1988	1,077,000	1,045,000	2,122,000	2,614,000	2,536,000	5,150,000
1989	1,043,000	1,011,000	2,054,000	2,020,000	1,958,000	3,978,000
1990	1,034,000	1,359,000	2,393,000	1,688,000	2,218,000	3,906,000
1991[r]	969,000	1,317,000	2,286,000	1,270,000	1,727,000	2,997,000
1992	1,145,000	1,612,000	2,757,000	1,452,000	2,044,000	3,496,000
			COPPER[5]			
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[r]	773,841	536,732	1,310,573	2,101,141	1,457,340	3,558,481
1991[r]	682,289	518,401	1,200,690	1,644,529	1,249,508	2,894,037
1992	722,351	554,075	1,276,426	1,710,721	1,312,199	3,022,920
			LEAD[6]			
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[r]	54,970	829,654	884,624	38,538	581,645	620,183
1992	55,277	861,320	916,597	29,934	466,412	496,346
			NICKEL[7]			
1988[r]	—	—	49,371	—	—	680,249
1989[r]	—	—	42,565	—	—	566,462
1990[r]	—	—	46,079	—	—	408,449
1991[r]	—	—	40,304	—	—	328,704
1992	—	—	51,139	—	—	358,036
			TIN[8]			
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	5,114	7,982	13,096	41,534	64,827	106,361
1992	4,930	8,797	13,727	43,721	78,021	121,742
			ZINC[9]			
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	[r]381,000	179,273	[r]560,273
1991	233,000	[r]119,000	[10]353,000	271,114	[r]138,445	[r]409,559
1992	234,000	132,000	366,000	301,000	170,000	471,000

[r]Revised.

[1]Recycled metal is metal recovered from purchased new plus old scrap.

[2]New scrap is scrap that results from the manufacturing process, including metal and alloy production.

[3]Old scrap is scrap that results from consumer products.

[4]Quantity is the calculated metallic recovery from aluminum-base scrap, estimated for full industry coverage. Value is estimated based on average annual U.S. market price for primary aluminum metal.

[5]Recoverable copper values in scrap based on annual averages for refined copper.

[6]Transaction value estimated to be London Metal Exchange (LME) average cash value plus 6.5 cents/lb.

[7]Nickel scrap is nickel contained in ferrous and nonferrous scrap receipts. Value is estimated as average annual LME cash price of nickel cathode.

[8]Value estimated based upon Metals Week (MW) Tin Composite price. Reevaluation of the tin canvass in 1991 resulted in a substantial lowering of estimated old scrap.

[9]Value based on average annual U.S. zinc metal price published in MW; for 1988-90, the MW average prices were based on U.S. or North American Producers' High Grade zinc delivered prices and for 1991-92, the LME spot prices for Special High Grade zinc plus premiums based on market conditions.

[10]Data do not add to total shown because of independent rounding.

TABLE 2

SALIENT U.S. APPARENT SUPPLY AND RECYCLING STATISTICS FOR SELECTED METALS

Year	Quantity (metric tons)		Percent recycled	Value (thousand dollars)		Percent recycled
	Apparent supply[1]	Recycled metal[2]		Apparent supply[3]	Recycled metal	
			ALUMINUM[4]			
1988	6,450,000	2,122,000	32.90	15,654,000	5,150,000	32.90
1989	6,000,000	2,054,000	34.23	11,620,000	3,978,000	34.23
1990	6,298,000	2,393,000	38.00	10,280,000	3,906,000	38.00
1991[r]	6,012,000	2,286,000	38.02	7,881,000	2,997,000	38.02
1992	6,870,000	2,757,000	40.13	8,712,000	3,496,000	40.13
			COPPER[5]			
1988	3,002,257	1,306,891	43.5	8,008,791	3,486,250	43.5
1989	2,945,209	1,308,455	44.4	8,505,917	3,778,886	44.4
1990	[r]2,924,267	[r]1,310,573	44.8	[r]7,940,000	[r]3,558,481	44.8
1991	[r]2,730,612	[r]1,200,690	44.0	[r]6,581,624	[r]2,894,037	44.0
1992	2,900,542	1,276,426	44.0	6,869,264	3,022,920	44.0
			LEAD[6]			
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
1992	1,196,666	861,320	72.0	648,034	466,424	72.0
			NICKEL[7]			
1988[r]	164,996	49,371	29.92	2,273,367	680,249	29.92
1989[r]	148,788	42,565	28.61	1,980,096	566,462	28.61
1990[r]	158,990	46,079	28.98	1,409,303	408,449	28.98
1991[r]	143,681	40,304	28.05	1,171,806	328,704	28.05
1992	154,531	51,139	33.09	1,081,907	358,036	33.09
			TIN[8]			
1988	60,955	15,275	25	592,627	148,509	25
1989	47,285	14,340	30	542,076	196,436	36
1990	53,430	17,275	32	454,680	146,666	32
1991	39,606	13,096	33	316,779	106,361	34
1992	37,321	13,727	37	330,994	121,742	37
			ZINC[9]			
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	[r]1,240,000	341,000	27.5	[r]2,039,056	[r]560,273	27.5
1991	[r]1,165,000	353,000	[r]30.3	[r]1,355,361	[r]409,559	[r]30.3
1992	1,276,000	366,000	28.7	1,642,000	471,000	28.7

[r]Revised.

[1]Apparent supply is production plus net imports plus stock changes. Production is primary production plus recycled metal (see table 1, footnote 1). Net imports are imports minus exports. Apparent supply is calculated on a contained weight basis.

[2]Recycle is metal recovered from purchased scrap.

[3]Same as apparent supply defined above but calculated on a monetary value basis.

[4]Monetary 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.

[5]Copper recovered for consumption valued on average annual refined prices.

[6]Lead 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 London Metal Exchange (LME) average cash plus 6.5 cents/lb. Stock adjustments value based on actual proportion of stock change to secondary production.

[7]Value of apparent supply and recycle estimated as average annual LME cash price of nickel cathode.

[8]Value estimated based upon Metals Week (MW) Composite price.

[9]Value based on average annual U.S. zinc metal price published in MW; for 1988-90, the MW average prices were based on U.S. or North American Producers' High Grade zinc delivered prices and for 1991-92, the LME 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)

	1988	1989	1990	1991	1992
Primary production	3,944	4,030	4,048	4,121	4,042
Change in stocks:[1]					
Aluminum industry	+11	+61	+2	r+45	-100
LME stocks in U.S. warehouses	—	—	—	-168	-46
National Defense Stockpile	—	—	—	—	-55
Imports	1,620	1,470	1,514	1,490	1,725
Secondary recovery:[2]					
New scrap	1,077	1,043	1,034	r969	1,145
Old scrap	1,045	1,011	1,359	r1,317	1,612
Total supply	7,697	7,615	7,957	r7,774	8,323
Less total exports	1,247	1,615	1,659	1,762	1,453
Apparent aluminum supply available for domestic manufacturing	6,450	6,000	6,298	r6,012	6,870
Apparent consumption[3]	5,373	4,957	5,264	r5,043	5,725

rRevised.

[1]Positive figure indicates a decrease in stocks; negative figure indicates an increase in stocks.

[2]Metallic recovery from purchased, tolled, or imported new and old aluminum scrap expanded for full industry coverage.

[3]Apparent 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
1991r			
Secondary smelters	673,531	553,068	594,744
Intergrated aluminum companies	1,292,168	1,081,616	1,152,520
Independent mill fabricators	402,651	337,043	359,713
Foundries	77,500	64,496	69,464
Other consumers	10,476	10,476	10,476
Total	2,456,326	2,046,699	2,186,917
Estimated full industry coverage[2]	2,568,000	2,139,000	2,286,000
1992			
Secondary smelters	945,627	760,064	815,548
Integrated aluminum companies	1,365,751	1,139,971	1,215,115
Independent mill fabricators	553,318	473,818	505,679
Foundries	85,529	70,298	75,555
Other consumers	10,449	10,449	10,449
Total	2,960,674	2,454,600	2,622,346
Estimated full industry coverage[2]	3,113,000	2,580,000	2,757,000

rRevised.

[1]Excludes recovery from other than aluminum-base scrap.

[2]Rounded.

TABLE 5

U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF PURCHASED NEW AND OLD ALUMINUM SCRAP[1] AND SWEATED PIG IN 1992

(Metric tons)

Class of consumer and type of scrap	Stocks, Jan. 1	Net receipts[2]	Consumption	Stocks, Dec. 31
Secondary smelters:				
New scrap:				
Solids	r5,274	97,340	97,836	4,778
Borings and turnings	r6,618	105,144	107,435	4,327
Dross and skimmings	r2,852	59,497	59,793	2,556
Other[3]	r3,830	86,091	88,884	1,037
Total	r18,574	348,072	353,948	12,698
Old scrap:				
Castings, sheet, clippings	r14,648	437,927	439,286	13,289
Aluminum-copper radiators	r828	7,341	7,232	937
Aluminum cans[4]	r1,018	97,964	97,775	1,207
Other[5]	r456	45,503	45,592	367
Total[6]	r16,950	588,735	589,885	15,800
Sweated pig	r628	1,395	1,794	229
Total secondary smelters[6]	r36,152	938,202	945,627	28,727
Integrated aluminum companies, foundries, independent mill fabricators, other consumers:				
New scrap:				
Solids	r12,536	562,819	562,435	12,920
Borings and turnings	(7)	31,317	30,932	385
Dross and skimmings	r12	10,332	10,305	39
Other[3]	r8,269	234,145	235,121	7,293
Total	r20,817	838,613	838,793	20,637
Old scrap:				
Castings, sheet, clippings	r5,432	337,387	334,244	8,575
Aluminum-copper radiators	r12	3,773	3,424	361
Aluminum cans	r34,606	810,384	821,285	23,705
Other[5]	—	8,187	7,963	224
Total	r40,050	1,159,731	1,166,916	32,865
Sweated pig	1,197	8,409	9,338	268
Total integrated aluminum companies, etc.	r62,064	2,006,753	2,015,047	53,770
All scrap consumed:				
New scrap:				
Solids	r17,810	660,159	660,271	17,698
Borings and turnings	r6,618	136,461	138,367	4,712
Dross and skimmings	r2,864	69,829	70,098	2,595
Other[3]	r12,099	320,236	324,005	8,330
Total new scrap	r39,391	1,186,685	1,192,741	33,335
Old scrap:				
Castings, sheet, clippings	r20,080	775,314	773,530	21,864
Aluminum-copper radiators	r840	11,114	10,656	1,298
Aluminum cans	r35,624	908,348	919,060	24,912

See footnotes at end of table.

TABLE 5—Continued

U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF PURCHASED NEW AND OLD ALUMINUM SCRAP[1] AND SWEATED PIG IN 1992

(Metric tons)

Class of consumer and type of scrap	Stocks, Jan. 1	Net receipts[2]	Consumption	Stocks, Dec. 31
All scrap consumed—Continued:				
Old scrap—Continued:				
Other[5]	r456	53,690	53,555	591
Total old scrap[6]	r57,000	1,748,466	1,756,801	48,665
Sweated pig	1,825	9,804	11,132	497
Total of all scrap consumed[6]	r98,216	2,944,955	2,960,674	82,497

rRevised.

[1]Includes imported scrap. According to reporting companies, 3.87% of total receipts of aluminum-base scrap, or 112,286 metric tons, was received on toll arrangements.

[2]Includes inventory adjustment.

[3]Includes data on foil, can stock clippings, and other miscellaneous.

[4]Used beverage cans toll treated for primary producers are included in secondary smelter tabulation.

[5]Includes municipal wastes (includes litter) and fragmentized scrap (auto shredder).

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

[7]Revised to zero.

TABLE 6

PRODUCTION AND SHIPMENTS OF SECONDARY ALUMINUM ALLOYS BY INDEPENDENT SMELTERS IN THE UNITED STATES

(Metric tons)

	1991		1992	
	Production	Net shipments[1]	Production	Net shipments[1]
Die-cast alloys:				
13% Si, 360, etc. (0.6% Cu, maximum)	r60,126	r59,338	41,921	44,666
380 and variations	r299,071	r300,202	466,137	465,256
Sand and permanent mold:				
95/5 Al-Si, 356, etc. (0.6% Cu, maximum)	r10,207	r10,345	78,089	67,146
No. 12 and variations	W	W	W	W
No. 319 and variations	r46,045	r48,273	52,876	52,929
F-132 alloy and variations	13,770	r12,385	52,652	51,483
Al-Mg alloys	723	719	645	644
Al-Zn alloys	2,761	2,789	3,086	2,881
Al-Si alloys (0.6% to 2.0% Cu)	8,608	r8,413	10,680	10,705
Al-Cu alloys (1.5% Si, maximum)	1,195	1,249	1,664	1,588
Al-Si-Cu-Ni alloys	1,278	1,272	1,352	1,326
Other	r901	r1,017	1,684	1,647
Wrought alloys: Extrusion billets	67,922	r67,824	72,509	66,985
Miscellaneous:				
Steel deoxidation	6,690	r6,690	3,345	3,413
Pure (97.0% Al)	117	r96	59	69
Aluminum-base hardeners	100	r101	93	97
Other[2]	29,060	r27,491	34,262	33,433
Total	r548,574	r548,204	821,054	804,268
Less consumption of materials other than scrap:				
Primary aluminum	15,881	XX	65,351	XX
Primary silicon	r27,213	XX	35,573	XX
Other	1,888	XX	3,620	XX
Net metallic recovery from aluminum scrap and sweated pig consumed in production of secondary aluminum ingot[3]	r503,592	XX	716,510	XX

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Sand and permanent mold: Other." XX Not applicable.

[1]Includes inventory adjustment.

[2]Includes other die-cast alloys and other miscellaneous.

[3]No 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)
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.	—	—	—	—	—	—	—	—
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
1992:								
Belgium	—	—	—	—	567	337	567	337
Brazil	9	43	—	—	956	1,200	966	1,243
Canada	—	—	112	138	45,503	50,729	45,615	50,867
China	63	90	103	335	7,885	6,240	8,051	6,665
Finland	—	—	—	—	3,543	3,211	3,543	3,211
France	—	—	—	—	1,975	2,111	1,975	2,111
Germany	241	307	11	28	159	322	411	657
Hong Kong	1,136	913	—	—	7,710	5,558	8,845	6,471
Italy	—	—	—	—	533	533	533	533
Japan	37,088	41,826	58	55	102,689	103,037	139,835	144,919
Korea, Republic of	1,261	1,847	995	1,173	14,882	15,695	17,138	18,714
Mexico	9,514	12,020	79	81	16,417	16,307	26,010	28,409
Netherlands	—	—	2	4	522	594	524	598
Norway	—	—	—	—	—	—	—	—
Philippines	—	—	—	—	126	144	126	144
South Africa, Republic of	—	—	—	—	—	—	—	—
Taiwan	2,532	2,156	105	152	28,218	21,356	30,855	23,663
Thailand	1,019	763	44	143	929	683	1,992	1,590
U.S.S.R.[3]	—	—	—	—	—	—	—	—
United Kingdom	349	529	728	722	957	934	2,035	2,185

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)
1992—Continued:								
Other	1,204	$974	1,144	$1,203	3,872	$5,104	6,220	$7,281
Total[1]	54,416	61,468	3,381	4,034	237,443	234,095	295,239	299,598

[1]Data may not add to totals shown because of independent rounding.
[2]Less than 1/2 unit.
[3]Dissolved in Dec. 1991.

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)
1991:								
Australia	—	—	—	—	337	$331	337	$331
Bahamas	—	—	53	$54	1,425	229	1,479	282
Bermuda	—	—	44	37	14	8	57	45
Brazil	—	—	—	—	—	—	—	—
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	125	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
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
Total[1]	8,169	9,912	31,603	29,091	168,615	180,557	208,384	219,558
1992:								
Australia	—	—	—	—	19	12	19	12
Bahamas	—	—	—	—	205	84	205	84
Bermuda	—	—	10	4	—	—	10	4
Brazil	—	—	—	—	330	368	330	368
Canada	1,038	1,277	15,720	14,676	152,034	167,724	168,792	183,677
China	1,053	1,013	—	—	—	—	1,053	1,013
Colombia	—	—	89	78	268	274	357	352
Germany	2,987	3,486	—	—	1,829	2,067	4,816	5,554
Guatemala	—	—	46	23	602	339	648	362
Honduras	—	—	—	—	100	49	100	49
Jamaica	—	—	—	—	697	394	697	394
Japan	—	—	—	—	85	372	85	372
Mexico	303	99	21,375	19,059	21,954	18,839	43,632	37,997
Panama	2	1	1,307	1,132	986	954	2,295	2,087
South Africa, Republic of	—	—	—	—	20	7	20	7
Spain	—	—	—	—	63	174	63	174
Taiwan	288	261	—	—	—	—	288	261
U.S.S.R.[2]	932	619	—	—	4,987	4,189	5,919	4,808
Venezuela	2,584	2,769	4,780	3,339	13,357	10,356	20,721	16,464
Other	2,942	3,627	762	647	11,552	9,059	15,256	13,333
Total[1]	12,128	13,152	44,089	38,958	209,089	215,262	265,306	267,372

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

[2]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

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)

	1988	1989	1990	1991	1992
KIND OF SCRAP					
New scrap:					
Copper-base	764,490	737,088	750,707	r660,550	697,037
Aluminum-base	24,104	23,761	r23,092	r21,692	25,242
Nickel-base	118	45	42	47	72
Zinc-base	—	—	—	—	—
Total	788,712	760,894	r773,841	r682,289	722,351
Old scrap:					
Copper-base	498,797	530,499	502,326	495,397	522,639
Aluminum-base	19,271	16,957	r34,303	r22,921	31,372
Nickel-base	86	78	77	61	46
Zinc-base	25	27	26	22	18
Total	518,179	547,561	r536,732	r518,401	554,075
Grand total	1,306,891	1,308,455	r1,310,573	r1,200,690	1,276,426
FORM OF RECOVERY					
As unalloyed copper:					
At electrolytic plants	347,442	376,595	328,196	318,182	331,057
At other plants	109,036	112,687	121,705	107,905	111,482
Total	456,478	489,282	449,901	426,087	442,539
In brass and bronze	800,221	774,770	r800,771	r727,618	776,295
In alloy iron and steel	763	630	578	r567	1,495
In aluminum alloys	45,632	41,719	r56,489	r44,277	55,607
In other alloys	327	106	r114	r120	199
In chemical compounds	3,470	1,948	2,720	2,021	292
Total	850,413	819,173	r860,672	r774,603	[1]833,887
Grand total	1,306,891	1,308,455	r1,310,573	r1,200,690	1,276,426

rRevised.

[1]Data do 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]	
	1991	1992	1991	1992	1991	1992
Ingotmakers	37,598	32,350	90,767	100,884	128,365	133,234
Refineries[2]	111,452	107,161	306,309	326,010	417,761	433,171
Brass and wire rod mills	490,820	534,383	69,327	66,421	560,148	600,805
Foundries and manufacturers	r20,323	22,882	r27,327	29,324	r47,650	52,206
Chemical plants	r356	292	1,665	—	2,021	292
Total[1]	r660,550	697,068	r495,397	522,639	r1,155,945	1,219,708

rRevised.

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

[2]Electrolytically 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	1991	1992
UNALLOYED COPPER PRODUCTS		
Electrolytically refined copper	318,182	331,057
Fire-refined copper	99,575	102,166
Copper powder	7,794	8,826
Copper castings	536	490
Total[1]	426,087	442,539
ALLOYED COPPER PRODUCTS		
Brass and bronze ingots:		
Tin bronzes	15,240	14,006
Leaded red brass and semired brass	98,666	109,565
High-leaded tin bronze	7,965	9,223
Yellow brass	6,278	6,768
Manganese bronze	7,020	5,992
Aluminum bronze	7,433	7,504
Nickel silver	2,728	2,691
Silicon bronze and brass	5,415	6,135
Copper-base hardeners and master alloys	7,098	8,127
Miscellaneous	4,344	3,421
Total[1]	162,187	173,433
Brass mill and wire rod mill products	609,262	738,008
Brass and bronze castings	r42,394	44,060
Brass powder	238	283
Copper in chemical products	2,021	292
Grand total[1]	r1,242,190	1,398,616

rRevised.

[1]Data 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]							
1991	r129,453	r5,309	r9,096	r17,940	365	23	r162,187
1992	140,873	5,339	9,020	17,880	290	31	173,433
Secondary metal content of brass mill products:							
1991	r499,895	r295	r3,851	103,405	W	W	r609,262
1992	601,355	498	4,920	129,517	W	W	738,008
Secondary metal content of brass and bronze castings:							
1991	r36,528	r935	r1,597	r3,044	119	r170	r42,394
1992	38,806	1,004	1,441	2,367	114	327	44,060

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Total."

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

[2]About 96% from scrap and 4% from other than scrap in 1991 and in 1992.

TABLE 13

CONSUMPTION OF COPPER-BASE SCRAP IN 1992[1]

(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	11,204	10,493	12,622	10,985	9,580	11,305	7,534	11,077	12,984	12,754	9,990	7,308	127,836
Brass and wire rod mills	25,124	22,340	24,923	28,705	22,561	26,064	25,369	25,176	26,717	22,959	20,839	22,588	293,365
Foundries and other manufactures	2,257	2,257	2,257	2,257	2,257	2,257	2,257	2,257	2,257	2,257	2,257	2,257	27,084
No. 2 mixed heavy and light:													
Smelters, refiners, and ingotmakers	26,186	25,883	23,620	22,143	27,928	30,818	26,494	32,080	30,632	29,090	28,634	29,875	333,383
Brass and wire rod mills	3,598	6,026	4,473	2,211	3,419	3,228	3,255	3,516	3,507	3,001	3,779	3,475	43,488
Foundries and other manufactures	285	285	285	285	285	285	285	285	285	285	285	285	3,414
Total unalloyed scrap:													
Smelters, refiners, and ingotmakers	37,390	36,375	36,242	33,128	37,507	42,123	34,028	43,157	43,616	41,844	38,623	37,183	461,216
Brass mills	28,721	28,366	29,395	30,915	25,979	29,292	28,624	28,692	30,225	25,960	24,618	26,063	336,850
Foundries and other manufactures	2,542	2,542	2,542	2,542	2,542	2,542	2,542	2,542	2,542	2,542	2,542	2,542	30,504
Red brass:[2]													
Smelters, refiners, and ingotmakers	4,248	3,908	4,679	4,385	4,671	4,647	4,515	5,254	4,644	4,371	3,821	4,551	53,694
Brass mills	543	516	500	583	535	547	373	419	473	556	298	458	5,801
Foundries and other manufactures	888	888	888	888	888	888	888	888	888	888	888	888	10,656
Leaded yellow brass:													
Smelters, refiners, and ingotmakers	1,821	1,811	2,002	1,861	2,218	2,138	1,757	2,038	2,194	2,059	2,193	1,938	24,030
Brass mills	19,501	23,658	22,426	22,269	20,647	22,233	22,013	20,816	18,244	21,164	18,741	22,297	254,009
Foundries and other manufactures	124	124	124	124	124	124	124	124	124	124	124	124	1,488
Yellow and low brass:													
All plants	9,009	6,993	9,239	9,190	7,035	10,291	10,884	11,384	11,614	11,029	10,607	6,466	113,741
Cartridge cases and brass:													
All plants	4,768	4,419	4,074	4,776	4,435	4,594	3,755	4,198	4,355	4,885	3,554	3,806	51,619
Auto radiators:													
Smelters, refiners, and ingotmakers	6,492	5,659	6,284	6,352	5,902	6,538	5,162	5,646	5,951	5,777	5,579	5,151	70,493
Foundries and other manufacturers	553	553	553	553	553	553	553	553	553	553	553	553	6,636
Bronzes:													
Smelters, refiners, and ingotmakers	1,058	1,019	1,161	1,227	1,198	1,258	962	1,230	1,148	1,329	1,360	1,117	14,067
Brass mills	856	891	1,002	988	857	958	710	831	971	1,040	1,009	821	10,934
Nickel-copper alloys:													
All plants	1,279	1,157	1,443	1,202	1,224	1,114	983	1,265	1,507	1,364	1,087	1,083	14,708
Low grade and residues:													
Smelters, refiners, and other manufacturers	12,649	11,871	14,112	12,929	10,434	13,109	15,880	14,865	13,390	12,766	13,421	16,359	161,785

See footnotes at end of table.

TABLE 13—Continued

CONSUMPTION OF COPPER-BASE SCRAP IN 1992[1]

(Metric tons, gross weight)

Scrap type and processor	January	February	March	April	May	June	July	August	September	October	November	December	Total
Other alloy scrap:[3]													
Smelters, refiners, and ingotmakers	4,099	3,495	4,289	2,736	3,218	3,480	3,197	3,120	2,170	3,188	2,706	2,478	38,176
Brass mills and other manufacturers	687	731	649	667	683	692	699	727	667	766	611	761	8,340
Total alloyed scrap:													
Smelters, refiners, and ingotmakers	32,195	29,810	35,145	31,510	30,513	33,750	34,135	34,926	32,440	32,507	31,995	34,629	393,555
Brass mills	33,505	35,006	35,403	36,343	31,233	36,537	35,443	35,554	33,576	36,474	31,682	31,346	412,102
Foundries and other manufacturers	2,877	2,877	2,877	2,877	2,877	2,877	2,877	2,877	2,877	2,877	2,877	2,877	34,524
Total scrap:													
Smelters, refiners, and ingotmakers	69,585	66,185	71,387	64,638	68,020	75,873	68,163	78,082	76,056	74,350	70,618	71,811	854,771
Brass and wire rod mills	62,226	63,372	64,798	67,259	57,212	65,829	64,067	64,247	63,801	62,435	56,299	57,409	748,953
Foundries and other manufacturers	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	64,800

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

[2]Includes composition turnings, silicon bronze, zincy bronze, railroad car boxes, cocks and faucets, gilding metal, and commercial bronze.

[3]Includes refinery brass, beryllium copper, phosphor copper, and aluminum bronze.

TABLE 14

CONSUMPTION OF PURCHASED COPPER-BASE SCRAP[1] IN 1992

(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[e]	Old scrap[e]	
January	14,323	37,182	6,683	11,398	55,696	6,531	2,600	2,800	137,213
February	15,509	34,750	3,837	12,089	55,815	7,558	2,600	2,800	134,958
March	18,088	35,914	3,888	13,497	58,378	6,421	2,600	2,800	141,586
April	14,298	33,859	4,108	12,374	59,436	7,822	2,600	2,800	137,297
May	12,473	37,031	5,632	12,883	51,922	5,290	2,600	2,800	130,631
June	16,359	41,427	4,118	13,970	58,669	7,160	2,600	2,800	147,103
July	13,405	40,433	3,841	10,484	58,702	5,364	2,600	2,800	137,629
August	16,208	44,943	4,418	12,514	57,660	6,586	2,600	2,800	147,729
September	17,585	41,473	4,036	12,963	57,535	6,266	2,600	2,800	145,258
October	15,698	41,960	4,069	12,622	56,531	5,903	2,600	2,800	142,183
November	13,443	41,052	3,558	12,565	52,191	4,108	2,600	2,800	132,317
December	11,530	45,084	3,709	11,488	52,377	5,032	2,600	2,800	134,620
Year total	178,919	475,108	51,897	148,847	674,912	74,041	31,200	33,600	1,668,524

[e]Estimated.

[1]Consumption at brass and wire-rod mills assumed equal to receipts.

TABLE 15

CLOSING STOCKS OF COPPER-BASE SCRAP IN 1992

(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	7,091	6,266	5,040	3,925	5,837	6,231	9,270	9,310	7,957	7,121	6,956	9,644
No. 2 mixed heavy and light	14,815	13,524	14,201	14,214	12,260	10,785	16,106	14,875	15,181	15,120	13,261	8,476
Total unalloyed scrap	21,906	19,790	19,241	18,139	18,097	17,016	25,376	24,185	23,138	22,241	20,217	18,120
Alloyed scrap:												
Red brass[1]	2,118	1,779	2,008	2,148	2,057	2,787	2,953	2,367	2,210	2,220	2,571	2,223
Leaded yellow brass	987	885	902	1,223	1,118	1,384	1,731	1,500	1,376	1,476	1,082	1,246
Yellow and low brass[2]	755	767	819	951	899	778	964	1,316	1,243	1,389	1,434	1,301
Auto radiators	1,423	1,511	1,515	1,263	1,532	1,251	1,703	2,609	2,076	2,246	1,473	1,798
Bronzes	836	825	1,117	987	799	877	858	881	1,064	1,080	852	950
Nickel-copper alloys	233	240	225	209	276	244	220	317	333	311	242	272
Low grade and residues	10,587	11,162	10,051	9,675	10,998	12,991	12,101	10,260	9,482	9,869	9,335	9,082
Other alloy scrap[3]	4,119	3,074	1,548	1,850	2,088	1,851	2,305	1,991	2,108	1,761	1,613	1,748
Total alloy scrap	21,058	20,243	18,185	18,306	19,767	22,163	22,835	21,241	19,892	20,352	18,602	18,620
Total scrap	42,964	40,033	37,426	36,445	37,864	39,179	48,211	45,426	43,030	42,593	38,819	36,740
Brass and wire-rod mills:												
Unalloyed scrap	10,289	9,801	9,271	9,833	11,924	10,263	13,624	13,156	13,508	12,879	13,503	16,047
Alloyed scrap	23,044	21,361	21,877	23,484	22,996	24,458	26,235	24,503	28,497	27,313	24,975	30,265
Total scrap[4]	33,333	31,162	31,148	33,317	34,920	34,721	39,859	37,659	42,005	40,192	38,478	46,312
Foundries and other manufacturers:[5]												
Unalloyed scrap	3,004	3,004	3,004	3,004	3,004	3,004	3,004	3,004	3,004	3,004	3,004	3,004
Alloyed scrap	3,846	3,846	3,846	3,846	3,846	3,846	3,846	3,846	3,846	3,846	3,846	3,846
Total scrap	6,850	6,850	6,850	6,850	6,850	6,850	6,850	6,850	6,850	6,850	6,850	6,850
All plants:												
Unalloyed scrap	35,199	32,595	31,516	30,976	33,026	30,283	42,004	40,344	39,650	38,124	36,724	37,171
Alloyed scrap	47,948	45,450	43,908	45,635	46,609	50,467	52,917	49,589	52,236	51,511	47,423	52,729
Total scrap[4]	83,147	78,045	75,424	76,611	79,635	80,750	94,921	89,933	91,886	89,635	84,147	89,900

[1]Includes composition turnings, silicon bronze, zincy bronze, railroad car boxes, cocks and faucets, gilding metal and commercial bronze.
[2]Includes cartridge cases and brass.
[3]Includes refinery brass, beryllium copper, phosphor copper, and aluminum bronze.
[4]Data may not add to totals shown because of independent rounding.
[5]Stocks 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
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[r]	37,208	61,770	7,416	4,493	1,179	4,856	2,725	119,646	37,984	56,652
1992:										
Atlantic:										
Middle: New Jersey, New York, Pennsylvania	4,451	7,542	494	716	69	389	32	13,693	5,024	14,576
South: Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	7,047	2,876	263	279	189	351	15	11,019	12,244	4,065
Central:										
East North: Illinois, Indiana, Michigan, Ohio, Wisconsin	10,588	32,055	3,309	1,779	617	884	2,312	51,543	13,618	30,536
South: Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	3,432	11,485	235	136	2	208	183	15,682	6,457	2,713
West North: Iowa, Kansas, Minnesota, Missouri, Nebraska	1,478	4,963	1,515	337	12	806	75	9,185	2,336	3,263
Mountain and Pacific: Arizona, California, Colorado, Idaho, Montana, Oregon, Utah, Washington, Wyoming	1,286	7,123	938	584	57	849	125	10,962	403	9,090
New England: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island	544	727	768	197	252	331	13	2,832	725	475
Total[4]	28,826	66,769	7,522	4,027	1,198	3,816	2,756	114,915	40,807	64,719

[r]Revised.

[1]Includes silicon bronze and brass.

[2]Includes copper nickel and nickel bronze and brass.

[3]Includes special alloys.

[4]Data 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	Refiners		Dealers' buying (New York)		Alloy-ingot (New York)	
	No. 1 scrap	No. 1 scrap	No. 2 scrap	No. 2 scrap	Red brass turnings and borings	No. 115 brass (85-5-5-5)	Yellow brass (405)
1991:							
January	105.83	101.73	r93.18	82.00	69.00	124.50	122.75
February	105.80	102.26	r93.32	79.50	62.00	124.50	125.75
March	106.42	103.06	r94.48	90.47	62.90	124.50	125.75
April	106.85	103.37	r94.93	91.12	63.00	124.50	125.75
May	98.76	94.79	r87.09	78.50	61.90	123.70	121.48
June	96.78	92.46	r84.36	72.35	57.12	122.00	118.75
July	97.75	93.65	r85.37	81.36	66.00	122.00	118.75
August	99.09	96.38	r87.15	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	r88.22	84.22	58.00	122.00	118.75
December	99.44	92.30	r83.94	80.13	57.14	122.00	118.75
Average	101.89	98.21	r89.27	82.85	60.66	122.98	121.06
1992:							
January	94.08	90.87	82.43	76.23	60.55	122.00	118.75
February	98.11	94.33	85.58	81.58	58.00	122.00	118.75
March	99.63	96.41	87.06	83.05	58.91	122.00	118.75
April	98.49	95.28	86.35	82.35	59.00	122.00	118.75
May	98.76	95.29	87.20	83.20	59.00	122.00	118.75
June	101.98	98.00	89.97	85.88	59.00	122.00	118.75
July	108.85	104.09	96.61	92.60	59.00	123.70	121.48
August	108.18	103.49	96.44	92.56	59.00	124.50	122.75
September	102.89	98.42	91.43	87.43	57.02	124.50	122.75
October	96.33	91.49	84.65	80.83	52.55	122.23	119.11
November	91.74	87.49	80.55	76.39	53.37	122.00	118.75
December	92.95	88.43	82.07	78.07	50.14	122.00	118.75
Average	99.33	95.30	87.53	83.35	57.13	122.58	119.67

rRevised.

Source: American Metal Market.

TABLE 18

U.S. EXPORTS OF COPPER SCRAP, BY COUNTRY

Country	Unalloyed copper scrap				Copper-alloy scrap			
	1991		1992		1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Belgium	94	$122	99	$111	3,425	$9,484	3,066	$7,061
Brazil	362	706	172	356	1,272	1,274	652	665
Canada	32,988	40,400	26,864	26,119	15,123	24,696	17,603	27,479
China	22,873	10,260	23,870	19,054	22,709	22,636	53,030	41,254
Finland	—	—	—	—	2,083	518	—	—
France	—	—	—	—	219	315	51	196
Germany	519	900	216	232	2,422	4,402	1,051	1,400
Hong Kong	5,485	3,960	8,464	7,664	6,875	7,363	7,278	8,158
India	594	1,008	97	124	13,329	15,632	14,420	16,303
Indonesia	283	237	31	19	676	794	490	609
Italy	20	39	138	216	1,477	3,118	1,029	1,416
Japan	23,721	52,805	25,469	39,259	42,797	78,466	11,834	16,650
Korea, Republic of	29,488	53,864	12,422	19,468	42,397	66,412	21,756	25,801
Mexico	7,497	9,501	300	318	3,693	6,102	2,985	4,903
Netherlands	158	116	47	32	227	354	443	766
Singapore	846	851	1,057	1,099	1,757	2,138	730	779
Spain	20	5	—	—	290	251	49	44
Sweden	22	38	—	—	779	1,776	1,572	3,265
Taiwan	5,908	6,284	1,784	1,468	11,233	15,668	4,647	5,938
Thailand	—	—	36	65	469	725	941	1,340
Trinidad and Tobago	21	31	—	—	366	429	249	273
United Kingdom	82	145	35	25	870	1,228	703	907
Venezuela	—	—	4	11	395	208	407	205
Other	r337	r560	91	191	r394	r536	452	642
Total[1]	131,318	181,833	101,195	115,830	175,275	264,530	145,441	166,052

rRevised.

[1]Data 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[e 2] (metric tons)	Value[1] (thousands)
1991	28,751	$54,949	97,177	69,967	$161,356
1992:	29,616	57,876	62,560	45,043	105,051
Canada	2,506	5,542	15	11	60
Chile	93	149	780	562	931
Colombia	677	587	206	148	195
Costa Rica	553	987	1,448	1,043	2,706
Dominican Republic	592	1,031	927	667	1,467
Estonia[3]	—	—	107	77	866
France	—	—	280	202	699
Germany	570	473	172	124	124
Guatemala	344	174	517	372	489
Honduras	13	228	1,464	1,054	2,698
Hong Kong	572	493	292	210	210
Jamaica	—	—	378	272	775
Malaysia	63	75	331	238	1,055
Mexico	10,206	18,460	31,437	22,635	45,579
Netherlands	686	1,853	72	52	163
Netherlands Antilles	5	10	631	454	820
Nicaragua	338	308	679	489	656
Panama	818	1,384	672	484	1,190
Peru	148	196	572	412	426
Phillippines	—	—	382	275	557
Singapore	—	—	177	127	238
Spain	1,133	1,776	—	—	—
Sweden	—	—	1,115	803	3,147
Taiwan	—	—	271	195	537
Trinidad and Tobago	205	202	72	52	69
United Kingdom	359	774	2,616	1,884	4,663
Venezuela	2,019	1,980	5,876	4,231	8,892
Other	878	1,634	2,304	1,659	3,691
Total[4]	52,398	96,193	116,352	83,773	187,951

[e]Estimated.

[1]C.i.f. value at U.S. port.

[2]Under the Harmonized Tariff System that was implemented Jan. 1989, copper content is no longer available. Content is estimated to be 72% of gross weight.

[3]Formerly part of the U.S.S.R.

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

Source: Bureau of the Census.

TABLE 20

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, Dec. 31[1]
			New scrap	Old scrap	Total[1]	
1991						
Smelters, refiners, others:						
Soft lead[2]	1,385	20,283	—	21,162	21,162	506
Hard lead	767	6,159	—	6,561	6,561	365
Cable lead	1,161	W	—	24,915	24,915	W
Battery-lead	28,693	963,696	—	972,456	972,456	19,934
Mixed common babbitt	192	725	—	729	729	188
Solder and tinny lead	1,820	W	—	W	W	W
Type metals	90	W	—	W	W	129
Drosses and residues	1,184	W	68,001	W	68,001	1,695
Total[1]	35,293	1,101,985	68,001	1,044,076	1,112,076	25,202
1992						
Smelters, refiners, others:						
Soft lead[2]	506	20,373	—	20,522	20,522	357
Hard lead	365	W	—	9,048	9,048	W
Cable lead	W	11,028	—	W	W	789
Battery-lead	19,934	994,268	—	992,279	992,279	21,922
Mixed common babbitt	188	575	—	651	651	112
Solder and tinny lead	W	W	—	W	W	W
Type metals	129	8,351	—	8,268	8,268	211
Drosses and residues	1,695	68,813	67,169	573	67,742	2,766
Total	25,202	1,123,795	67,169	1,053,677	1,120,846	28,151

W Withheld to avoid disclosing company proprietary data; included in "Total."

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

[2]Includes remelt lead from cable sheathing plus other soft lead scrap processing.

TABLE 21

SECONDARY METAL RECOVERED[1] FROM LEAD AND TIN SCRAP IN THE UNITED STATES

(Metric tons)

	Lead	Tin	Antimony	Other	Total[2]
1991					
Refined pig lead[3]	421,907	—	—	—	421,907
Refined pig tin[4]	—	234	—	—	234
Lead and tin alloys:					
Antimonial lead	426,938	928	12,220	569	440,655
Lead-base babbitt	443	24	50	(5)	516
Solder	(6)	(6)	(6)	(6)	(6)
Type metal	863	44	121	4	1,031
Other alloys, including cable lead	19,519	2,697	65	9	22,288
Total[2]	447,763	3,693	12,454	582	464,491
Tin content of chemical products	—	34	—	—	34
Grand total[2]	869,672	3,961	12,454	582	886,666
1992					
Refined pig lead[3]	452,920	—	—	—	452,920
Refined pig tin[4]	—	137	—	—	137
Lead and tin alloys:					
Antimonial lead	424,535	704	11,353	W	436,592
Lead-base babbitt	375	78	41	—	494
Solder	(6)	(6)	—	—	(6)
Type metal	860	47	121	4	1,031
Other alloys, including cable lead	21,905	2,783	86	W	24,774
Total[2]	447,674	3,612	11,600	W	462,885
Tin content of chemical products	—	W	—	—	W
Grand total[2]	900,594	3,749	11,600	W	915,942

W Withheld to avoid disclosing company proprietary data.
[1]Most of the figures herein represent actual reported recovery of metal from scrap.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes remelt lead.
[4]Includes remelt tin.
[5]Included with "Antimony" to avoid disclosing company proprietary data.
[6]Included with "Other alloys, including cable lead" to avoid disclosing company proprietary data.

TABLE 22

LEAD RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1991	1992
KIND OF SCRAP		
New scrap:		
Lead-base	48,338	48,274
Copper-base	6,629	e7,000
Tin-base	3	3
Total	54,970	55,277
Old scrap:		
Battery-lead	756,227	784,269
All other lead-base	65,105	68,051
Copper-base	8,322	e9,000
Tin-base	—	—
Total	829,654	861,320
Grand total	884,624	916,597
FORM OF RECOVERY		
As soft lead	421,907	452,920
In antimonial lead	426,938	424,535
In other lead alloys	20,825	23,139
In copper-base alloys	14,951	e16,000
In tin-base alloys	3	3
Total	884,624	916,597
Value[1] thousands	$652,947	$709,283

eEstimated.
[1]Value based on average quoted price of common lead.

TABLE 23

U.S. EXPORTS AND IMPORTS OF LEAD SCRAP, BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
EXPORTS				
Scrap (gross weight):				
Antigua and Barbuda	8	$14	39	$14
Argentina	42	4	2	32
Austria	(1)	5	26	6
Bahamas	7	29	23	68
Belgium	185	621	135	384
Brazil	4,457	959	2,392	417
Canada	54,488	10,105	48,771	8,386
China	3,286	2,522	820	500
Colombia	—	—	471	105
France	274	83	168	69
Germany	1,011	278	269	117
Ghana	—	—	174	38
Hong Kong	1,431	918	109	37
India	1,706	1,093	1,379	292
Indonesia	4,764	1,023	126	20
Ireland	186	128	192	74
Israel	—	—	59	10
Italy	47	104	—	—
Japan	1,386	1,275	111	461
Jordan	350	35	—	—
Korea, Republic of	2,267	1,108	1,457	949
Malaysia	—	—	68	36
Mexico	5,399	1,895	2,381	833
Netherlands	211	120	30	27
Panama	17	14	(1)	4
Philippines	3,525	660	1,337	74
Singapore	(1)	10	3	104
South Africa, Republic of	274	77	23	5
Spain	2,583	481	314	42
Taiwan	2,290	1,397	572	584
Thailand	993	459	104	571
Trinidad and Tobago	96	20	—	—
United Kingdom	1,773	729	648	482
Venezuela	75	23	921	160
Other	130	384	88	265
Total[2]	93,262	26,574	63,212	15,165
IMPORTS				
Reclaimed scrap, including ash and residues (lead content):[3]				
Canada	117	28	216	54
Other	—	—	20	11
Total[2]	117	28	236	65

[1]Less than 1/2 unit.

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

[3]Also includes other lead-bearing materials containing greater than 10% by weight of copper, lead, or zinc (any one).

Source: Bureau of the Census.

TABLE 24

SECONDARY TIN RECOVERED FROM SCRAP PROCESSED AT DETINNING AND OTHER RECOVERY PLANTS IN THE UNITED STATES

		1991	1992
Tinplate scrap treated	metric tons	W	W
Tin recovered in the form of:			
Metal[1]	do.	234	137
Compounds (tin content)	do.	W	W
Total	do.	234	137
Weight of tin compounds produced	do.	W	W
Average quantity of tin recovered per metric ton of tinplate scrap used	kilograms	2.20	2.23
Average delivered cost of tinplate scrap	per metric ton	$104.30	$91.85

W Withheld to avoid disclosing company proprietary data.
[1]This data is felt to represent only 39% of actual industry activity due to nonreporting firms.

TABLE 25

TIN RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY FORM OF RECOVERY

(Metric tons unless otherwise specified)

Form of recovery		1991	1992
Tin metal[1]		234	137
Bronze and brass[e 2]		11,866	12,761
Lead and tin alloys:			
Antimonial lead		928	704
Babbitt		24	78
Type metal		44	47
Other alloys[3]		W	W
Total		996	829
Tin content of chemical products		W	W
Grand total		13,096	13,727
Value[e 4]	thousands	$74,778	$85,644

[e]Estimated. W Withheld to avoid disclosing company proprietary data; not included in "Total."
[1]Includes tin metal recovered at detinning and other plants. This data is felt to represent only 39% of actual industry activity due to nonreporting firms.
[2]Includes tin recovered from copper-, lead-, and tin-base scrap.
[3]Includes foil, solder, terne metal, and cable lead.
[4]Based on Metals Week composite price.

TABLE 26

U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF NEW AND OLD SCRAP AND TIN RECOVERED, BY TYPE OF SCRAP

(Metric tons)

Type of scrap	Gross weight of scrap						Tin recovered [e] [1]		
	Stocks, Jan. 1	Receipts	Consumption			Stocks, Dec. 31			
			New	Old	Total		New	Old	Total
1991									
Copper-base scrap	6,202	141,262	34,649	101,804	136,453	11,011	1,653	3,586	5,239
Brass mills[2]	2,810	20,185	20,185	—	20,185	—	406	—	406
Foundries and other plants	5,604	19,212	9,154	13,113	22,267	2,549	416	550	966
Total tin from copper-base scrap	XX	XX	XX	XX	XX	XX	2,475	4,136	6,611
Lead-base scrap	31,907	1,036,539	67,758	976,878	1,044,636	23,810	1,779	3,808	5,587
Tin-base scrap[3]	5	56	W	39	W	7	860	38	898
Grand total	XX	XX	XX	XX	XX	XX	5,114	7,982	13,096
1992									
Copper-base scrap	11,011	139,178	33,357	111,151	144,508	5,681	1,547	3,927	5,474
Brass mills[2]	—	19,912	19,912	—	19,912	—	500	—	500
Foundries and other plants	2,549	21,801	9,485	12,311	21,796	2,554	439	584	1,023
Total tin from copper-base scrap	XX	XX	XX	XX	XX	XX	2,486	4,511	6,997
Lead-base scrap	23,810	1,057,982	68,527	986,305	1,054,832	26,960	1,799	4,249	6,048
Tin-base scrap[3]	7	55	W	38	W	W	645	37	682
Grand total	XX	XX	XX	XX	XX	XX	4,930	8,797	13,727

[e]Estimated. W Withheld to avoid disclosing company proprietary data. XX Not applicable.

[1]Tin recovered from new and old copper-base scrap, brass mills, and foundries.

[2]Brass-mill stocks include home scrap, and purchased-scrap consumption is assumed equal to receipts; therefore, line does not balance.

[3]Includes tinplate and other scrap recovered at detinning plants; U.S. Bureau of Mines not at liberty to publish separately.

TABLE 27

STOCKS AND CONSUMPTION OF NEW AND OLD ZINC SCRAP IN THE UNITED STATES IN 1992, 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	214	3,818	—	3,699	3,699	333
Flue dust	W	11,428	5,571	5,558	11,129	W
Fragmentized diecastings	W	W	—	W	W	W
Galvanizer's dross	1,864	65,113	65,672	—	65,672	1,305
Old zinc[1]	59	1,189	—	1,167	1,167	81
Remelt die-cast slab	W	W	—	W	W	W
Remelt zinc[2]	W	W	156	—	156	W
Skimmings and ashes[3]	4,732	32,872	32,863	—	32,863	4,741
Steelmaking dust	—	W	W	W	W	W
Other[4]	7,723	104,860	35,776	71,904	107,680	5,046
Total	14,592	219,280	140,038	82,328	222,366	11,506

W Withheld to avoid disclosing company proprietary data; included in "Other."
[1]Includes engraver's plates and rod and die scrap.
[2]Includes new clippings.
[3]Includes sal skimmings and die-cast skimmings.
[4]Includes chemical residues and solutions and electrogalvanizing anodes.

TABLE 28

PRODUCTION OF ZINC PRODUCTS FROM ZINC-BASE SCRAP IN THE UNITED STATES

(Metric tons)

Product	1988	1989	1990	1991	1992
Electrogalvanizing anodes	—	W	W	W	W
Redistilled slab zinc	88,492	97,904	95,708	122,457	127,623
Remelt die-cast slab	907	4,167	5,144	W	W
Other metal alloys	317	272	257	W	W
Other zinc metal products	8,016	15,564	11,804	8,686	15,661
Secondary zinc in chemical products	55,972	57,575	56,135	65,746	73,277
Zinc dust	24,206	24,909	24,105	22,750	20,962

W Withheld to avoid disclosing company proprietary data; included in "Other zinc metal products."

TABLE 29

ZINC RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1991	1992
KIND OF SCRAP		
New scrap:		
Zinc-base	118,232	106,751
Copper-base	115,038	126,860
Magnesium-base	181	210
Total	233,451	233,821
Old scrap:		
Zinc-base	94,108	107,755
Copper-base	24,312	23,705
Aluminum-base	661	814
Magnesium-base	205	192
Total	119,286	132,466
Grand total	352,737	366,287
FORM OF RECOVERY		
Metal:		
Slab zinc	122,457	127,623
Zinc dust	22,750	20,962
Other[1]	7,084	8,880
Total	152,291	157,465
In zinc-base alloys	W	W
In brass and bronze	133,098	128,764
In other metal alloys	W	W
In chemical products:		
Zinc oxide (lead free)	34,394	37,717
Zinc sulfate	23,385	26,374
Zinc chloride	5,311	6,332
Miscellaneous	4,258	9,635
Total	200,446	208,822
Grand total	352,737	366,287

W Withheld to avoid disclosing company proprietary data; included in "Miscellaneous."
[1]Includes electrogalvanizing anodes and zinc content of slab made from remelt die-cast slab.

FIGURE 1
GENERAL RECYCLING MATERIAL INDUSTRY FLOW STRUCTURE

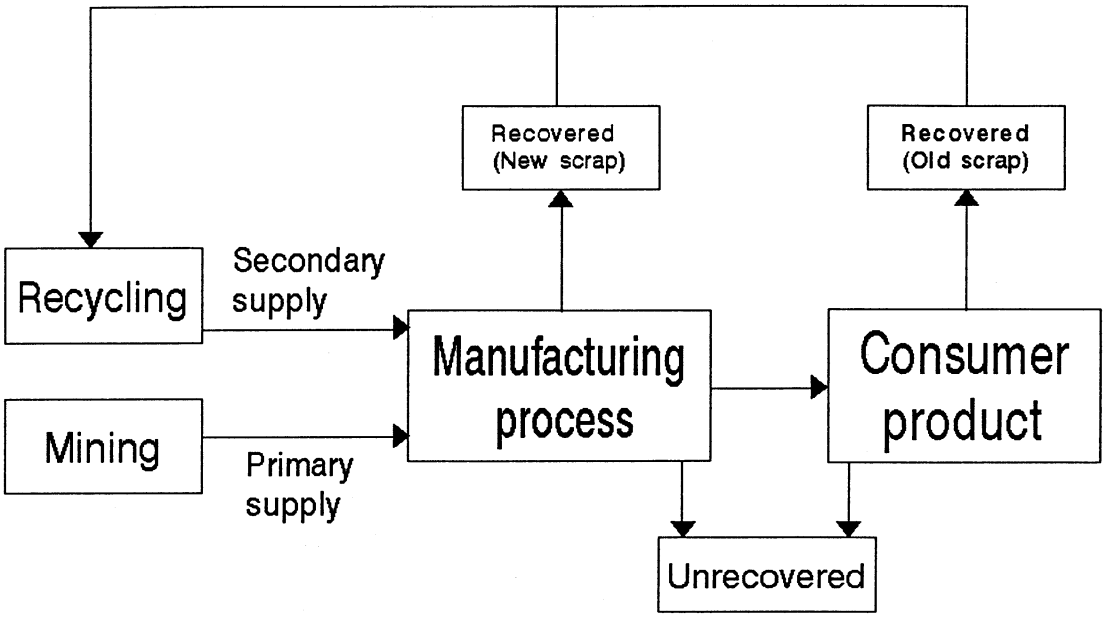


FIGURE 2
U.S. ALUMINUM CAN RECYCLING

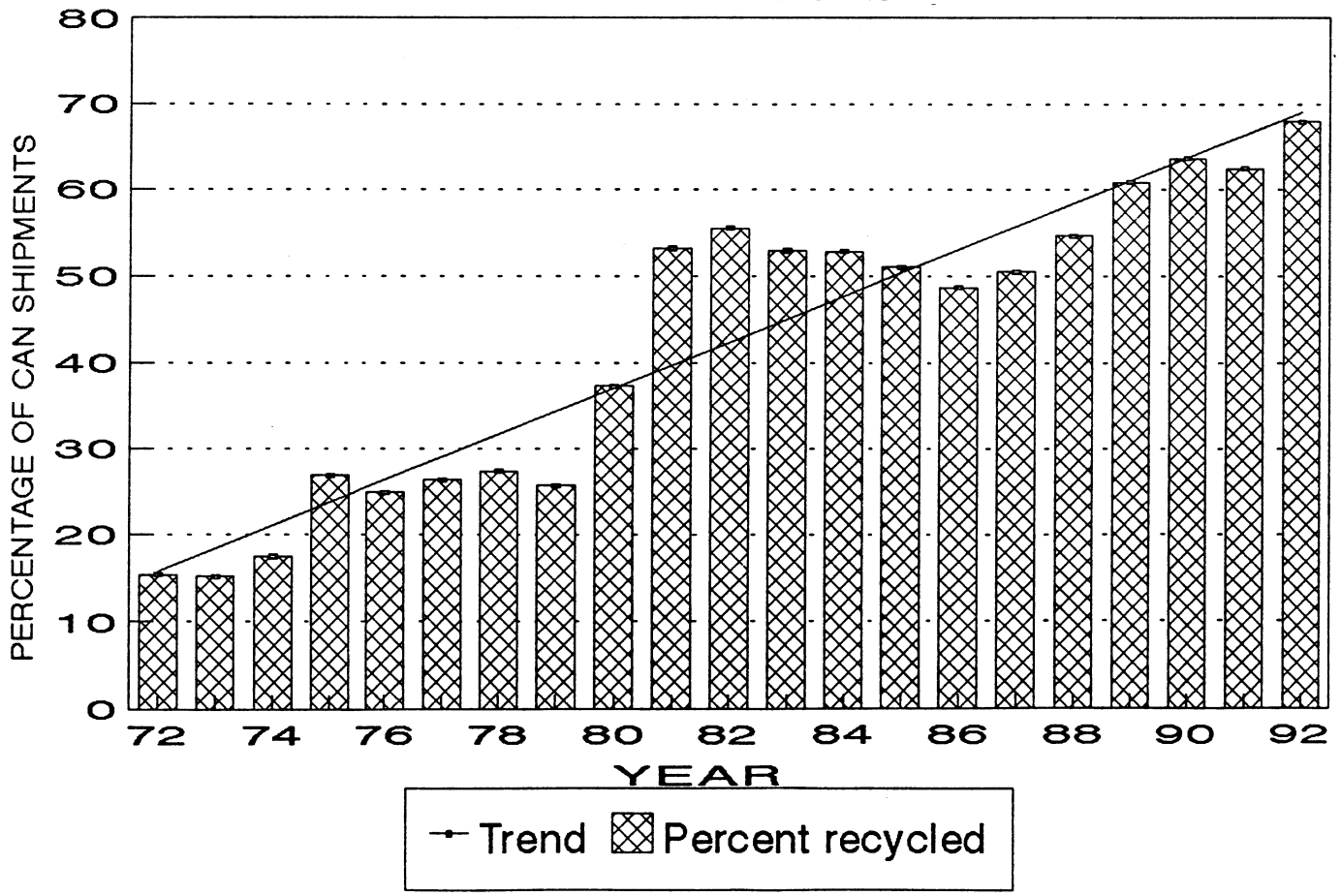
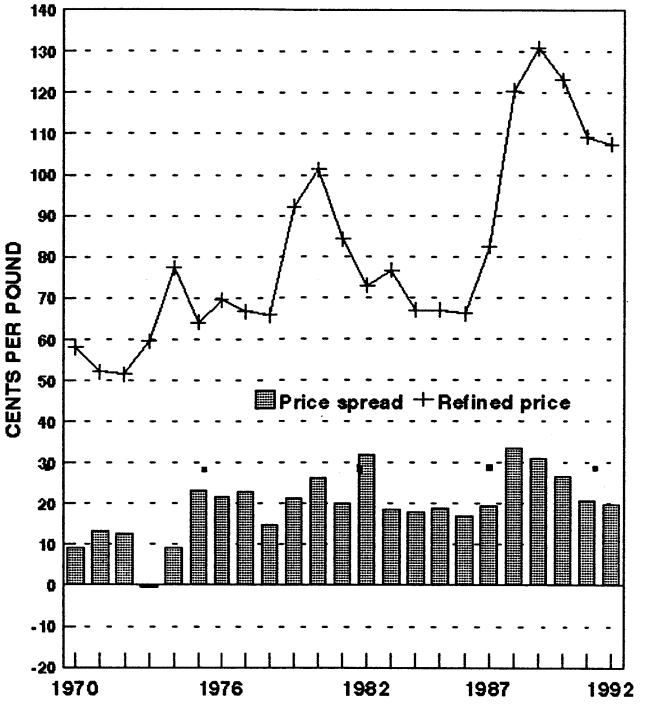


FIGURE 3

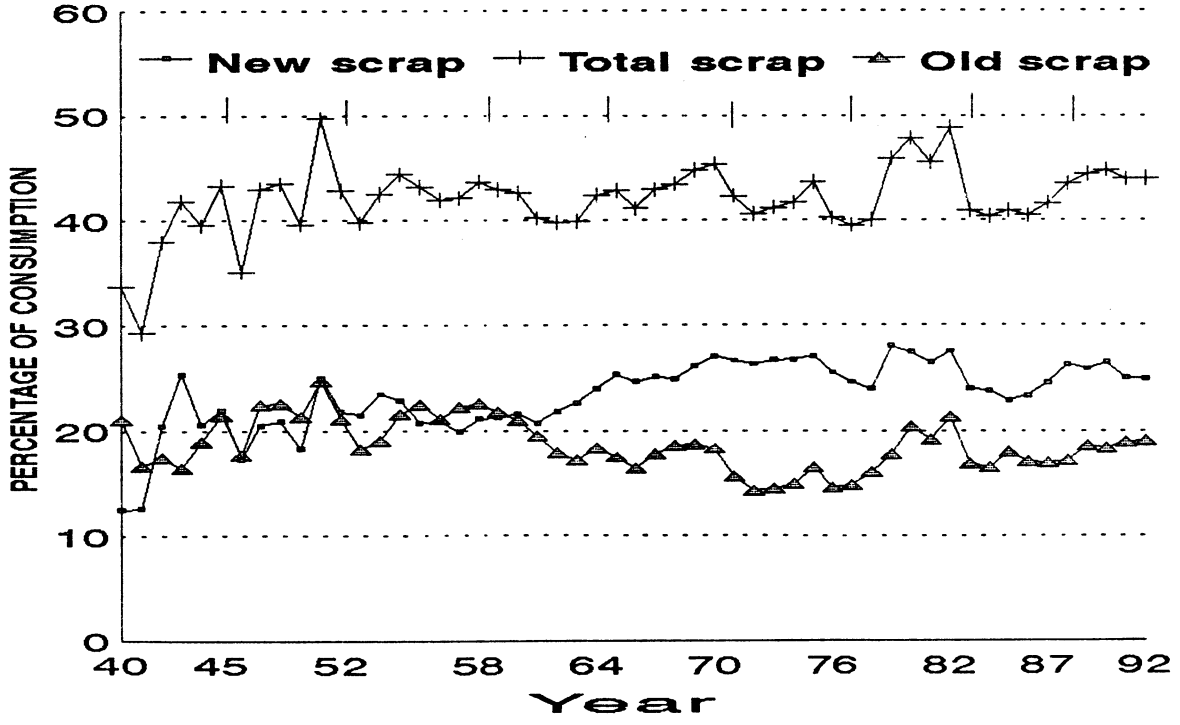
PRICE SPREAD BETWEEN NO. 2 SCRAP[1] AND U.S. PRODUCERS' REFINED COPPER PRICES



1/Refiner's buying price for No. 2 scrap.
Sources: American Metal Market (scrap) and Metals Week (refined).

FIGURE 4

PERCENT SCRAP IN U.S. COPPER CONSUMPTION[1]



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.

SALT

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 14 years of U.S. Bureau of Mines experience, has been the commodity specialist for salt since 1980. Domestic survey data were prepared by Christopher Lindsey, statistical assistant; and international data tables were prepared by Doug Rhoten, international data coordinator.

Sodium chloride, commonly known as salt, is a universal commodity that is known and used by virtually every person in the world. It is an important compound that has a multitude of applications with approximately 14,000 different reported uses. 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.

Beginning 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 Statute 339) and the United States was an original signatory party to the 1875 Treaty of the Meter (20 Statute 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. Therefore, all data in this report are in metric tons unless overwise noted. For comparison, 1 metric ton is equal to 2,204.62 pounds whereas 1 short ton is equal to 2,000 pounds. To convert metric tons to short tons, multiply the metric ton figure by 1.10231. To convert short tons to metric tons, divide by 1.10231.

As foreign trade of salt with the United States increases and foreign participation in U.S. salt companies continues, such as with the U.S. subsidiaries of Akzo Salt and Basic Chemicals International of the Netherlands and Sifto Canada of Canada, communicating information with an international standard of measurement becomes more important.

DOMESTIC DATA COVERAGE

Domestic production data for salt are developed by the U.S. Bureau of Mines (USBM) from an annual voluntary survey of U.S. salt-producing sites and of company operations. Of the 70 operations to which a survey request was sent, 68 responded, representing 97% of the total production shown in this report. Production for the nonrespondents was estimated on the basis of their prior response to the 1992 production estimate survey or brine production capabilities for chloralkali manufacture based on chlorine production capacities.

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.-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 also has been used to signify hospitality. The custom of presenting newlyweds wine, bread, and salt shows salt as a lifegiving 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 former 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 1.8-meter-wide by 61-meter-deep (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.

Uses and 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 22.7-kilogram (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.

There are reportedly about 14,000 different direct and indirect uses of salt. The USBM annually surveys 8 major categories comprising 29 separate end uses.

Chemical.—The greatest quantity of salt used in the chemical industry is by the chloralkali sector. Traditionally, the chloralkali sector included salt consumed for chlorine, coproduct sodium hydroxide (also known as caustic soda and lye), and synthetic soda ash. Since 1986, when the last synthetic soda ash plant closed because of high production costs and competition with less expensive natural soda ash, no synthetic soda ash has been manufactured in the United States. Aside from a few economic deposits of natural soda ash, several countries in the world continue to use salt for synthetic soda ash production.

Salt is used as the primary raw material in chlorine manufacture because it is an inexpensive and widely available source of chlorine ions. For sodium hydroxide production, salt is the main source of sodium ions. About 97% of the domestic chlorine and sodium hydroxide produced is obtained from the electrolysis of salt brine feedstock using three different cell technologies. The types of cells and percent chlorine manufactured by them are diaphragm, 75%; mercury, 16%; and membrane, 6%. It takes about 1.59 metric tons, (1.75 short tons) of salt to make 1.0 ton of chlorine and 1.1 tons of coproduct caustic soda. The electrolytic process ionizes the sodium chloride compound and selectively allows the ions to migrate through special membranes. Chlorine gas forms at the anode while sodium ions bond with water molecules at the cathode to form sodium hydroxide with hydrogen gas evolving.

Chlorine and caustic soda are considered to be the first generation of products made from salt. These two chemicals are further used to manufacture other materials, which are considered second generation products from salt.

Salt is also used as a feedstock by chemical establishments that make sodium chlorate (by the electrolysis of an acidified salt brine using hydrochloric acid adjusted to a pH of 6.5), metallic sodium (by the electrolysis of a molten salt mixture containing 33.2% sodium chloride and 66.8% calcium chloride, which is added to reduce the melting temperature of salt), and other downstream chemical operations. In powdered soaps and detergents, salt is used as a bulking agent and as a coagulant for colloidal dispersion after saponification. In pharmaceuticals, salt is a chemical reagent and is used as the electrolyte in saline solutions. It is also used as a cofeedstock with sulfuric acid to produce sodium sulfate and hydrochloric acid. This subsector is relatively small, representing only 10% of domestic salt sales for the entire chemical sector and only 5% of total domestic salt consumption.

Food Processing.—Every person uses some quantity of salt in his or her food. The salt is either added to the food by the food processor or by the consumer through free choice. Salt is added to food as a flavor enhancer, preservative, binder, fermentation control additive, texture aid, and color developer. This major category is subdivided into six applications, in descending order of salt consumption: meatpackers, canning, other food processing, baking, dairy, and

grain mill products.

In meatpacking, salt is added to processed meats to promote the color development in bacon, ham, and other processed meat products. As a preservative, salt inhibits the growth of bacteria, which would lead to spoilage of the product. Early pioneers used to store their perishables in salt barrels for protection and preservation. Salt acts as a binder in sausages to form a binding gel composed of meat, fat, and moisture. Salt also acts as a flavor enhancer and a tenderizer. In canning, salt is primarily added as a flavor enhancer and preservative. It also is used as a dehydrating agent, tenderizer, enzyme inhibitor, and as a carrier for other ingredients.

In the "other food processing" category, salt is used mainly as a seasoning agent. Other food processing includes miscellaneous establishments that make food for human consumption (i.e., potato chips, pretzels) and domestic pet consumption (i.e., dog and cat food). In baking, salt is added to control the rate of fermentation in bread dough. It also is used to strengthen the gluten (the elastic protein-water complex in certain doughs) and as a flavor enhancer, such as a topping on baked goods. In the dairy industry, salt is added to cheese as a fermentation control agent and as a color and texture control agent. The dairy subsector includes companies that manufacture creamery butter, natural and processed cheeses, condensed and evaporated milk, ice cream, frozen desserts, and specialty dairy products. The final food processing category is grain mill products, which consists of milling flour and rice and manufacturing cereal breakfast food and blended or prepared flour.

General Industrial.—The industrial uses of salt are diverse. They include, in descending order of salt usage, oil and gas exploration, metal processing, other industrial, pulp and paper, textiles and dyeing, tanning and leather treatment, and rubber manufacture.

In oil and gas exploration, salt is an important component of drilling fluids in well drilling. It is used to flocculate and to increase the density of the drilling fluid to overcome high down-well gas pressures. Whenever drilling activities encounter salt formations, salt is added to the drilling fluid to saturate the solution and minimize the dissolution within the salt strata. Salt is also used to increase the set rate of concrete in cemented casings. In metal processing, salt is used in concentrating uranium ore into uranium oxide (yellow cake). It is also used in processing aluminum, beryllium, copper, steel, and vanadium.

In the pulp and paper industry, salt is used to bleach wood pulp. It also is used to make sodium chlorate, which is added along with sulfuric acid and water to manufacture chlorine dioxide—an excellent oxygen-base bleaching chemical. Although the chlorine dioxide process originated in Germany after World War I, it is becoming more popular because of environmental pressures to reduce or eliminate chlorinated bleaching compounds. In textiles and dyeing, salt is used as a brine rinse to separate organic contaminants, to promote "salting out" of dyestuff precipitates, and to blend with concentrated dyes to standardize them. One of its main roles is to provide the positive ion charge to promote the absorption of negatively charged ions of dyes. In tanning and leather treatment, salt is added to animal hides to inhibit microbial activity on the underside of the hides and to replace some of the moisture in the hides. In rubber manufacture, salt is used to make neoprene rubber, white rubber, and buna rubber. Salt brine and sulfuric acid are used to coagulate an emulsified latex made from chlorinated butadiene.

Agricultural Industry.—Since prehistoric times, humankind has noticed that animals satisfied their salt hunger by locating salt springs, salt licks, or playa lake salt crusts. Barnyard and grazing livestock need supplementary salt rations to maintain proper nutrition. Veterinarians advocate adding loose salt in commercially mixed feeds or in block forms sold to farmers and ranchers. Salt also acts as an excellent carrier for trace elements not found in the vegetation consumed by grazing livestock. Sulfur, selenium, and other essential elements are commonly added to salt licks, or salt blocks, for free-choice feeding.

Water Treatment.—Approximately 1.2 trillion liters (325 billion gallons) of water is used daily in the United States for residential and commercial uses. Many areas of the United States have "hard" water, which contains excessive calcium and magnesium ions that contribute to the buildup of a scale or film of alkaline mineral deposits in household and industrial equipment. Commercial and residential water-softening units use salt to remove the ions causing water hardness. The sodium ions captured on a resin bed are exchanged for the calcium and magnesium ions. Periodically, the water-softening units must be recharged because the sodium ions become depleted. Salt is added and dissolved, and the brine replenishes the lost sodium ions.

Ice Control and Road Stabilization.—The second largest end use of salt is for highway deicing. Gabriel Daniel Fahrenheit, the developer of the Fahrenheit temperature scale (° F), discovered that salt mixed with ice (at a temperature below the freezing point) creates a solution with a lower freezing point than water by itself. The brine forms below the surface of the ice and snow and prevents the water from freezing into ice and bonding with the road surface. Therefore, salt causes snow and ice to melt. Salt is an inexpensive, widely available, and effective ice control agent. It does, however, become less effective as the temperature decreases below about -9.4° C to -6.7° C (15° F to 20° F). At lower temperatures, more salt would have to be applied to maintain higher brine concentrations to provide the same degree of melting. Most winter snow storms and ice storms occur between -3.9° C to 0° C (25° F and 32° F), a range in which salt is most effective.

In highway deicing, salt has been associated with corrosion to motor

vehicles, bridge decks, unprotected steel structures, and reinforcement bar and wire used in road construction. Surface runoff, vehicle spraying, and windblown actions also affect roadside vegetation, soil, and local surface and ground water supplies. Although there is evidence of environmental loading of salt during peak usage, the spring rains and thaws usually dilute the concentrations of sodium in the area.

Salt is also added to stabilize the soil and to provide firmness to the foundation on which highways are built. The salt acts to minimize the effects of shifting caused by changes in humidity and traffic load in the subsurface.

Distributors.—A tremendous amount of salt is marketed through various distributors, some of which specialize in certain markets such as agricultural and water-treatment services. In addition to these two categories, distributor sales include grocery wholesalers and/or retailers, institutional wholesalers, U.S. Government resale, and other wholesalers and retailers.

Other.—The other uses of salt include categories not discussed above.

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 42×10^{15} tons (46×10^{15} short tons) of sodium chloride, which is equivalent to 530 million cubic kilometers (4.5 million cubic miles) in volume or a cube measuring 795 kilometers (165 miles) on edge.

Domestic salt resources are found mainly in four large depositional basins, covering an area totaling about 0.2 million square hectacres (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 55×10^{12} tons (61×10^{12} short tons) and are being depleted at the rate of about 35 million tons (39 million short 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 rate 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 sea floor 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 914 meters (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 former 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 6,100 meters (20,000 feet), yet many outcrop at the surface. Most gulf coast salt mining operations are generally less than 300 meters (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 52% 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 desalinization, 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 485-kilometer (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.—The four types of salt that are produced each 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 1973. The data are compared with 1992 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 1992, U.S. salt imports were more than five 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. The non-MFN countries are Afghanistan, Albania, Azerbaijan, Byelarus, Cuba, Georgia, Kampuchea, Kazakhstan, Laos, North Korea, Romania, Tajikistan, Turkmenistan, Uzbekistan, and Vietnam.

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.

Environmental Issues.—The USBM has been actively assessing the environmental issues pertaining to the type and quantity of waste generated in the different steps from mining through postconsumption for many commodities. Some waste that traditionally may have been discarded after mining and processing may be recovered for reuse; other waste in the form of discarded consumer products may be recycled to reclaim various valuable raw materials. Several material flow studies have been completed by the USBM that trace the flow of a commodity from "cradle to grave." A material flow study on salt was conducted by this author.

Salt was selected as a commodity to study because it had a couple of associated environmental issues, such as the environmental effects from deicing

salt and salt used in water treatment. In addition, there were issues pertaining to some of the downstream uses, such as in PVC manufacture, that uses salt as feedstock. Cumulative historical data on salt consumption for highway deicing indicates that 243 million tons (268 million short tons) has been applied to the Nation's roads since 1940, when salt usage for this purpose first became significant. Although there are several site-specific studies that have been done to measure the concentration of salt in the soil and ground water from deicing runoff, there is no indication of any serious and permanent ill-effects from the use of about one-quarter billion tons of salt in the 50 years that salt has been used.

After analyzing all the categories that salt is used in, it is estimated that about three-fourths of the domestic salt consumed is released to the environment and unrecovered while about one-fourth is discharged to landfills, incinerated, or recycled as consumer products derived from salt, such as PVC plastic containers. For further information about the study, please refer to USBM Information Circular IC-9343, "The Material Flow of Salt."

Employment.—According to the Bureau of Labor Statistics, 1,285 people were employed in the mining and processing of rock salt in 1992. Of the 11 rock salt facilities surveyed, 784 personnel worked 1.42 million hours underground, 264 people worked 521,425 hours on surface duties, and 237 people worked 538,445 hours in the mills. There were 187 people who worked 396,078 hours in the office. Total employment in the domestic rock salt industry amounted to 1,472 individuals who worked a total of 2,880,794 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 curtained 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 according to a study done in 1989.

ANNUAL REVIEW

Strategic Considerations

Hunter Industrial Facilities Inc. continued its efforts to apply for permits to store hazardous waste in a salt dome near Dayton in Liberty County, TX. Construction of the $70 million underground repository had been delayed for more than 1 year already because of delays in obtaining the necessary permits. The Texas Water Commission that is involved in the permit process developed new regulations governing waste storage in salt domes. It held public hearings to hear concerns of local residents. Hunter and Secured Environmental Management Inc., a second company with a waste storage project slated for Boling, TX, had not learned of the decision by the commission by yearend regarding Hunter's effort to obtain its permits.[1]

The U.S. Department of Energy issued a Draft Environmental Impact Statement on the proposed plan for the final 250 million barrel segment of the 1 billion barrel Strategic Petroleum Reserve (SPR). Two new underground crude oil storage facilities are to be constructed from five salt dome candidates in Louisiana, Mississippi, and Texas: Cote Blanche in St. Mary Parish, LA; Weeks Island in Iberia Parish, LA; Richton in Perry County, MS; Big Hill in Jefferson County, TX; and Stratton Ridge in Brazoria County, TX. North American Salt Co. and Morton International presently operate rock salt mines in the first two domes, respectively.[2] The SPR has 750 million barrels of storage capacity distributed among five salt domes in Louisiana and Texas: Weeks Island, Bayou Choctaw, and West Hackberry, LA, and Bryan Mound and Big Hill, TX. Although comments would be accepted until December 29, 1992, no decision on which two sites would be made until May 1993.

Issues

A survey of chemicals used by the domestic pulp and paper industry was conducted by the American Forest and Paper Association. Its results showed a declining trend in chlorine consumption and a rising use of alternative bleaching agents. The association estimated that the industry's use of chlorine will decline 50% to 70% by 1995 from the level of the late 1980's. Production of sodium chlorate, an alternative bleaching chemical derived from salt, was estimated to grow from 650,000 tons in 1990 to 1.05 million tons by 1996, or about 62%.

The U.S. Environmental Protection Agency (EPA) continued its reassessment of the dioxin risk. EPA presently lists dioxins as "probable" carcinogens and not "known" carcinogens. Although its draft report showed that the danger to human beings from dioxin exposure is small, except for groups that live near or work in chemical plants that produce or dispose of dioxin, EPA also reported that the danger of dioxins to fish and other animals was greater than previously believed. The final report had not been published by yearend.[3]

In a separate investigation, a study was completed by the Institute of Paper Science and Technology and Batelle Laboratory for the Chlorine Institute.

The report studied the mechanisms of dioxin formation in pulp mills and found that dioxin could be reduced by pretreating the dioxin precursors in the wood. In addition, adsorbable organic halide levels in effluents could be reduced by 50% using an anaerobic-aerobic process.[4]

Production

The Retsof Mine in Livingston County, NY, owned by Akzo Salt Inc., reportedly is the largest room-and-pillar underground mine in the Western Hemisphere. Since production began in the 1880's, more than 100 million tons of rock salt has been extracted from the mine 335 meters (1,100 feet) below the surface, leaving behind more than 40,000 separate "rooms" comprising about 61 million cubic meters (80 million cubic yards) of space. These abandoned cavities are being considered as potential storage sites for waste incinerator ash. Akzo is evaluating a process that would allow industrial byproducts, such as incinerator ash, fly ash, and cement kiln dust, to be combined with a 10% mixture of portland cement and slurried using salt brine. The slurry would be discharged underground in the empty cavities where it would harden into a chemically and physically stabilized cementlike material suitable for mine backfilling. The backfilling would improve mine stability by reducing subsidence, and the salt brine in the slurry would reduce discharge of saline water into the Genesee River. Between 4,000 to 8,000 tons of ash is expected to be processed and slurried daily. Aside from providing Akzo with additional revenue and a more uniform income flow to offset any occasional poor-seasonal salt sales, the proposed project also would reduce the future quantity of industrial byproducts landfilled, thereby lessening the impact on the environment. There also is the possibility that certain ferrous metals, which comprise about 20% of the municipal waste incinerator ash by weight, could be magnetically separated from the ash and recycled.[5]

According to the USBM survey for 1992, 28 companies operated 67 salt-producing plants in 14 States, as shown in figure 1. Nine of the companies and 11 of the plants produced more than 1 million tons each and accounted for 92% and 56%, respectively, of the U.S. total. Several companies and plants produced more than one type of salt. In 1992, 12 companies (15 operations) produced solar-evaporated salt; 5 companies (17 operations), vacuum pan salt; 10 companies (14 operations), rock salt; and 15 companies (31 operations), salt brine. *(See tables 1, 3, 4, and 5 and figure 1.)*

The five leading States in terms of total salt sold or used were Louisiana, 35%; Texas, 23%; New York, 14%; and Kansas, 5%. 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 table 6.)*

U.S. salt production accounted for about 20% of total world production. Production and trade of salt increased slightly compared with the previous year. World production of all types of salt decreased slightly. The depressed market for chlorine and environmental problems associated with emissions of chlorinated compounds may affect the short-term status of the world chloralkali industry, which is the largest single consumer of salt.

Consumption and Uses

The Transportation Research Board, which is a committee under the National Research Council of the National Academy of Science, issued a report that compared salt and calcium magnesium acetate (CMA) as highway deicing agents. The report was completed for the Federal Highway Administration at a cost of $212,230. The committee concluded that rock salt remained the more effective and practical deicer at a lower cost per ton. The full range of relative costs was measured of the alternative deicer's affect on road structures, motor vehicles, bridges, drinking water, and vegetation. The large-scale use of CMA as a general replacement for salt was determined to be unlikely and unwarranted.[6]

More than 37.8 million tons of domestic and imported salt was consumed in the United States in 1992, based on the annual survey of the U.S. salt producers. Some of the data submitted by one of the major domestic producers appeared to understate sales to the ice control sector and overstate sales to the "miscellaneous" category. The reported percent distribution of salt by major end use was chemicals, 44%; ice control, 21%; distributors, 11%; food and agricultural, 7%; industrial, 7%; primary water treatment, 1%; and other combined with exports, 9%. 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 7 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 chloralkali manufacturers now purchase 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 7 and 8.)*

Using Bureau of the Census data, the chlorine and caustic soda industry consumed about 17.8 million tons (19.6 million short 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 15.1 million tons, as noted in table 7. The difference

between the calculated and reported quantities was the amount of salt unreported to the USBM from imports or captive brine production of chloralkali 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 9. *(See table 9.)*

There are approximately 18 domestic companies that operate 38 chlorine-producing plants that used only salt as feedstock. Estimates were made on the chlorine production capacity for individual plants. 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 89% of nominal capacity and 94% of effective capacity in 1992. Because these capacities include chlorine produced from nonsalt sources; i.e., from the electrolysis of magnesium chloride and the oxidation of hydrochloric acid, these data may differ from other reported chlorine capacity utilization information.

Stocks

Total yearend stocks reported by producers were 2.5 million tons. Most of these inventories were rock salt and solar salt. 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 USBM. 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 10. *(See tables 10 and 11.)*

Foreign Trade

Under the Harmonized Tariff Schedule nomenclature, imports only have one category known as "Salt (including table and denatured 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. Figure 2 shows the quantity and customs value for salt imports and exports in 1992 and the location of the customs districts within the Nation. The United States is divided into three regions so that each region has at least three salt producers for each type of salt. Three are required to avoid disclosure of company proprietary data. Figures 3 and 4 show the distribution by region for domestic salt sales and consumption. *(See figures 2, 3, and 4.)*

Based on Bureau of Census statistics, the United States imported 5.39 million tons (5.95 million short tons) in 1992, or about 5.4 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 4.48 million tons (4.93 million short tons) was imported; however, PIERS data include only ocean freight and do 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, North American Salt Co. and Western Salt Co. imported 52% of the total imports. Six companies that manufacture chlorine, which was the single largest domestic salt market, consumed 25% of total imports, which were primarily solar salt. These companies were Atochem North America, Brunswick Pulp and Paper Co., Georgia Pacific Corp., LCP Chemical & Plastics Inc., Occidental Chemical Corp., and Weyerhaeuser Co. The salt and chloralkali producers imported 77% of total imports; the remainder were to many small direct buyers. Five domestic salt-producing companies exported 79% of the 315,946 tons (348,270 short tons) exported in 1992, according to PIERS. Tables 12 through 15 list the import and export statistics reported by the Bureau of Census for 1991 and 1992. *(See tables 12, 13, 14, and 15.)*

World Review

Table 16 lists world salt production statistics for 101 countries based on reported and estimated information. The unification of the two Germany's and the dissolution of the former U.S.S.R. and Yugoslavia in 1992 have modified the list of nations surveyed. World production decreased 4% in 1992 compared with that of the previous year. The decline was because of stagnant economic conditions in many world industries that consume salt, reduction in salt brine usage for worldwide chlorine manufacture, and the changes brought about in the political, social, and economic situations in the former U.S.S.R. and Yugoslavia that affected salt consumption. *(See table 16.)*

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 28 companies and 67 plants by 1992.

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.

Capacity.—Each type of salt produced in the world has unique mining, processing, and marketing characteristics that determine the criteria for deriving rated capacities. 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 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, the production capacities for domestic rock salt operations in 1992 was 15.78 million tons (17.39 million short tons).

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. In 1992, total domestic solar salt production capacity was 3.95 million tons (4.35 million short tons).

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. The total production capacity of the domestic vacuum pan salt producers in 1992 was 4.30 million tons (4.74 million short tons).

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, brine production capacity is assumed to be equal to the quantity of brine produced annually. Although data cannot be published for individual companies, the aggregate domestic brine production capacity in 1992 was 17.57 million tons (19.37 million short tons), which was the total quantity of salt brine produced.

Australia.—A 2.5-million-ton-per-year solar salt facility is planned for construction south of Onslow on the east coat of the Exmouth Gulf in Western Australia. The A$85 million project by Gulf Holdings Pty. Ltd. will create about 60 permanent jobs when the plant is in operation. The company has obtained environmental clearance and State Government endorsement for the solar salt works. The majority of the output will be sold to Asian industrial and chemical markets.[7]

China.—Construction is nearing completion on a solar salt facility along the northern area of the Fulandian Bay in Dalian, China. The project is slated to be completed in 1994 and is expected to produce 200,000 tons of salt annually.[8]

United Kingdom.—The U.S.-based D. George Harris and Associates Inc., which owns North American Salt Co., Great Salt Lake Minerals and Chemicals Corp., Carey Salt Co., and Sifto Salt of Canada, acquired the rock salt mine of Imperial Chemical Industries (ICI) at Winsford in Cheshire, England, in February 1992. The mine has been in operation since 1844 and supplies about two-thirds of the deicing salt used in the United Kingdom. The purchase also includes ICI's white salt business at Weston Point, Runcorn, Cheshire. The majority of this salt is used by the domestic chemical and animal feed markets. The salt company will operate as Salt Union Ltd., the historic name that was first used in 1888.

OUTLOOK

Because salt is the primary feedstock used to make a multitude of consumer products, the outlook for salt in the 1990's is optimistic. The privatizing of former state-owned salt operations in Eastern Europe and the commercializing of certain salt mines in the newly formed republics of the former U.S.S.R. will probably affect competition within those regions.

As many developing nations strive for self determination, salt will be one of the

first natural resources developed for trade because of its virtual universal existence. The United States is usually viewed as one of the first markets to be considered as a trading partner because of its large import-to-export ratio (5:1). Although the statistics show that the United States is import reliant, the majority of imported salt is under the control of the U.S. salt industry that imports through its foreign subsidiaries in Canada and in the Caribbean. Consolidations and restructuring within the U.S. salt industry during the past several years have strengthened it into a competitive North American enterprise operating in the Western Hemisphere.

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[2]Federal Register. Strategic Petroleum Reserve; Availability of Draft Environmental Impact Statement on the Expansion of the Strategic Petroleum Reserve. V. 57, No. 222, Tuesday, Nov. 17, 1992, p. 54227-54228.

[3]Chemical Week. Dioxin Data Indicate Threat May Be Greater Than Believed. V. 151, No. 16, p. 17.

[4]Chlorine Institute Annual Report 1992, p. 5.

[5]Akzo: Mine Ideal for Ash Storage. Genesee Country Express, Aug. 20, 1992, p. A2.

[6]Transportation Research Board. Highway Deicing: Comparing Salt and Calcium Magnesium Acetate. 1992, 172 pp.

[7]Industrial Minerals (London). World of Minerals. Plans for New Solar Salt Project. Nov. 1992, No. 302, p. 9.

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TABLE 1
SALIENT SALT STATISTICS

(Thousand metric tons and thousand dollars)

	1988	1989	1990	1991	1992
United States:					
Production[1]	35,534	35,632	36,794	36,316	36,016
Sold or used by producers[1]	35,326	35,250	36,916	35,902	34,784
Value	$699,323	$776,846	$826,659	$801,507	$802,563
Exports	802	1,422	2,266	1,777	992
Value	$10,858	$20,211	$32,944	r$29,875	$32,193
Imports for consumption	4,966	5,519	5,969	6,188	5,394
Value	$77,357	$74,474	$88,419	$87,380	$87,714
Consumption, apparent[2]	39,490	39,347	40,619	40,313	39,186
World: Production	r185,542	r192,473	r184,062	r192,281	e184,854

eEstimated. rRevised.
[1]Excludes Puerto Rico.
[2]Sold or used plus imports minus exports.

TABLE 2

U.S. SALT SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons)

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
WORLD PRODUCTION										
Production:										
United States	40,186	42,114	37,839	39,736	38,938	38,898	42,018	37,633	35,289	34,169
Rest of world[e]	114,473	124,115	123,828	120,931	118,102	129,350	131,351	131,245	136,127	130,096
Total[e 1]	154,660	166,229	161,667	160,667	157,040	168,248	173,369	168,878	171,415	164,265
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY										
Components of U.S. supply										
Domestic sources	40,186	42,114	37,839	39,736	38,938	38,898	42,018	37,633	35,289	34,169
Sold or used[2]	39,834	42,217	37,222	40,089	39,383	38,890	41,543	36,607	35,296	34,377
Imports	2,909	3,046	2,917	3,948	4,109	4,881	4,785	4,775	3,918	4,945
Industry stocks, Jan. 1[3]	—	—	—	—	—	—	—	—	—	—
Total U.S. supply[1]	42,744	45,263	40,138	44,037	43,491	43,771	46,328	41,381	39,214	39,322
Distribution of U.S. supply										
Industry stocks, Dec. 31[3]	—	—	—	—	—	—	—	—	—	—
Exports	552	473	1,208	914	914	704	632	754	949	908
Industrial demand[1]	42,191	44,790	38,930	43,124	42,577	43,067	45,696	40,627	38,265	38,414
U.S. DEMAND PATTERN[4]										
Agriculture	1,890	1,799	1,689	1,746	1,656	1,679	1,739	1,664	1,622	1,421
Alkalies and chlorine	25,713	25,945	21,912	23,560	22,780	22,236	24,460	22,447	20,613	17,373
Deicing	6,628	8,265	8,020	9,247	9,449	9,698	10,104	6,782	7,491	9,833
Food products	2,677	2,694	2,480	2,509	2,500	2,554	2,292	2,148	1,999	2,134
Metal production	207	229	240	310	318	314	323	247	267	267
Other chemicals	1,272	1,573	926	1,051	1,018	1,051	1,109	925	1,028	785
Paper products	190	150	156	193	201	200	176	209	224	190
Petroleum	195	220	237	283	327	409	499	643	759	939
Textiles and dyeing	182	186	163	185	178	165	171	161	200	150
Water treatment	740	933	821	653	737	807	869	785	913	731
Other[5]	2,646	3,019	2,952	3,316	3,284	3,179	3,201	2,971	3,406	3,587
Undistributed[6]	(149)	(223)	(667)	71	128	774	755	1,646	(255)	1,005
Total U.S. primary demand[1]	42,191	44,790	38,930	43,124	42,577	43,067	45,696	40,627	38,265	38,414
VALUES[7]										
Average annual value (dollars per ton):										
Salt in brine (short tons)	3.57	3.69	3.91	3.80	3.91	4.24	4.51	6.50	5.91	6.21
Constant 1992 dollars	10.45	9.94	9.61	8.78	8.46	8.50	8.32	10.96	9.06	8.96
Salt in brine (metric tons)	3.94	4.07	4.31	4.19	4.31	4.67	4.97	7.17	6.51	6.85
Constant 1992 dollars	11.53	10.96	10.59	9.69	9.32	9.36	9.17	12.09	9.98	9.88
Rock salt (short tons)	6.19	7.14	8.94	7.82	8.94	10.10	10.00	14.65	13.76	13.89
Constant 1992 dollars	18.12	19.23	21.97	18.08	19.34	20.25	18.46	24.70	21.08	20.04
Rock salt (metric tons)	6.82	7.87	9.85	8.62	9.85	11.13	11.02	16.15	15.17	15.31
Constant 1992 dollars	19.96	21.19	24.20	19.93	21.30	22.32	20.34	27.23	23.25	22.09
Solar salt (short tons)	8.99	9.30	14.21	14.36	14.21	14.67	12.16	15.65	18.35	17.89
Constant 1992 dollars	26.32	25.04	34.92	33.20	30.73	29.41	22.44	26.39	28.12	25.81
Solar salt (metric tons)	9.91	10.25	15.66	15.83	15.66	16.17	13.40	17.25	20.23	19.72
Constant 1992 dollars	29.01	27.60	38.48	36.59	33.87	32.42	24.73	29.09	31.00	28.45
Vacuum pan salt (short tons)	29.65	34.50	43.01	50.73	52.01	58.86	61.64	76.44	79.68	86.72
Constant 1992 dollars	86.80	92.90	105.69	117.27	112.49	118.01	113.78	128.89	122.10	125.11
Vacuum pan salt (metric tons)	32.68	38.03	47.41	55.92	57.33	64.88	67.95	84.26	87.83	95.59
Constant 1992 dollars	95.67	102.40	116.50	129.27	123.99	130.08	125.42	142.08	134.45	137.91

See footnotes at end of table.

TABLE 2—Continued

U.S. SALT SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons)

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
WORLD PRODUCTION										
Production:										
United States	29,913	35,544	35,577	33,822	33,514	35,534	35,632	36,794	36,316	36,016
Rest of world[e]	128,935	137,055	137,359	140,913	145,210	r150,008	r156,841	r147,268	r155,965	e148,838
Total[e 1]	158,847	172,599	172,936	174,735	178,725	r185,542	r192,473	r184,062	r192,281	e184,854
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY										
Components of U.S. supply										
Domestic sources	29,913	35,544	35,577	33,822	33,514	35,534	35,632	36,794	36,316	36,016
Sold or used[2]	31,364	35,584	36,348	33,260	33,106	35,326	35,250	36,916	35,902	34,784
Imports	5,440	6,845	5,631	6,046	5,185	4,966	5,519	5,969	6,188	5,394
Industry stocks, Jan. 1[3]	—	—	—	—	—	—	—	—	—	—
Total U.S. supply[1]	36,804	42,429	41,979	39,307	38,291	40,292	40,769	42,885	42,090	40,178
Distribution of U.S. supply										
Industry stocks, Dec. 31[3]	—	—	—	—	—	—	—	—	—	—
Exports	469	744	820	1,057	491	802	1,422	2,266	1,777	992
Industrial demand[1]	36,335	41,685	41,159	38,250	37,801	39,490	39,347	40,619	40,313	39,186
U.S. DEMAND PATTERN[4]										
Agriculture	1,456	1,562	1,559	1,498	1,592	1,657	1,746	2,105	2,005	1,984
Alkalies and chlorine	18,361	18,273	18,539	17,221	16,289	18,115	17,037	17,402	18,940	15,078
Deicing	6,250	9,726	10,142	9,563	8,961	10,092	10,397	10,253	r9,360	7,814
Food products	2,079	1,973	1,913	1,969	2,112	2,075	2,154	2,282	2,162	2,164
Metal production	220	296	347	276	282	339	363	314	293	217
Other chemicals	864	1,141	697	742	689	695	1,068	1,856	1,073	1,655
Paper products	249	306	282	279	351	341	338	257	237	230
Petroleum	833	789	875	569	542	743	653	719	554	1,208
Textiles and dyeing	155	173	169	205	215	208	212	206	232	271
Water treatment	721	1,767	1,307	1,409	1,320	1,373	1,349	1,468	r1,321	1,335
Other[5]	3,673	3,799	3,068	2,779	3,696	3,452	4,423	4,017	4,381	5,822
Undistributed[6]	1,475	1,880	2,261	1,741	1,752	399	(393)	(259)	(r246)	1,407
Total U.S. primary demand[1]	36,335	41,685	41,159	38,250	37,801	39,490	39,347	40,619	40,313	39,186
VALUES[7]										
Average annual value (dollars per ton):										
Salt in brine (short tons)	5.22	5.05	6.14	5.15	4.93	3.58	5.67	4.86	4.94	3.95
Constant 1992 dollars	7.24	6.71	7.86	6.43	5.96	4.17	6.32	5.20	5.10	3.95
Salt in brine (metric tons)	5.75	5.57	6.77	5.68	5.43	3.95	6.25	5.36	5.45	4.35
Constant 1992 dollars	7.97	7.40	8.67	7.09	6.56	4.60	6.97	5.74	5.63	4.35
Rock salt (short tons)	13.43	13.78	15.15	14.51	14.34	14.46	16.38	16.80	r17.46	17.81
Constant 1992 dollars	18.62	18.31	19.40	18.10	17.34	16.83	18.27	17.99	18.04	17.81
Rock salt (metric tons)	14.80	15.19	16.70	15.99	15.81	15.94	18.06	18.52	19.25	19.63
Constant 1992 dollars	20.52	20.18	21.39	19.95	19.11	18.55	20.14	19.83	19.89	19.63
Solar salt (short tons)	21.47	19.67	23.10	23.76	25.40	26.59	27.88	31.60	25.20	29.54
Constant 1992 dollars	29.77	26.13	29.58	29.64	30.71	30.94	31.09	33.84	26.04	29.54
Solar salt (metric tons)	23.67	21.68	25.46	26.19	28.00	29.31	30.73	34.83	27.78	32.56
Constant 1992 dollars	32.82	28.80	32.61	32.68	33.85	34.11	34.27	37.30	28.71	32.56
Vacuum pan salt (short tons)	87.39	92.78	92.66	91.27	94.21	97.71	92.73	100.32	104.10	102.09
Constant 1992 dollars	121.16	123.26	118.67	113.88	113.90	113.70	103.42	107.43	107.57	102.09
Vacuum pan salt (metric tons)	96.33	102.27	102.14	100.61	103.85	107.71	102.22	110.58	114.75	112.53
Constant 1992 dollars	133.56	135.87	130.81	125.53	125.55	125.33	114.01	118.42	118.58	112.53

See footnotes at end of table.

TABLE 2—Continued
U.S. SALT SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons)

[e]Estimated. [r]Revised.
[1]Data may not add to totals shown because of independent rounding.
[2]Represents 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.
[3]The 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.
[4]Includes imports for consumption.
[5]Includes 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 are included.
[6]Represents 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.
[7]Values 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.

Source: U.S. Bureau of Mines.

TABLE 3
SALT PRODUCTION IN THE UNITED STATES

(Thousand metric tons)

	Vacuum pans and open pans	Solar	Rock	Brine	Total[1]
1988	3,469	3,065	11,567	17,434	35,534
1989	3,606	2,849	12,682	16,496	35,632
1990	3,662	2,985	12,772	17,374	36,794
1991	3,654	2,813	11,188	18,660	36,316
1992	3,811	3,221	11,411	17,574	36,016

[1]Data may not add to total shown because of independent rounding

TABLE 4
SALT PRODUCED IN THE UNITED STATES, BY TYPE AND PRODUCT FORM

(Thousand metric tons)

Product form	Vacuum pans and open pans	Solar	Rock	Brine	Total[1]
1991					
Bulk	625	2,062	10,608	18,660	31,955
Compressed pellets	931	86	XX	XX	1,017
Packaged	1,803	594	551	XX	2,947
Pressed blocks	296	71	30	XX	396
Total[1]	3,654	2,813	11,188	18,660	36,316
1992					
Bulk	727	1,874	10,942	17,574	31,117
Compressed pellets	962	233	XX	XX	1,195
Packaged	1,825	986	428	XX	3,240
Pressed blocks	298	127	40	XX	464
Total[1]	3,811	3,221	11,411	17,574	36,016

XX Not applicable.
[1]Data may not add to totals shown because of independent rounding.

TABLE 5

SALT SOLD OR USED[1] IN THE UNITED STATES, BY TYPE AND PRODUCT FORM

(Thousand metric 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
1991										
Bulk	609	31,856	1,977	35,514	10,469	178,467	18,640	101,475	31,694	347,312
Compressed pellets	926	115,333	54	5,453	NA	XX	XX	XX	981	120,786
Packaged:										
Less than 5-pound units	288	NA	—	NA	49	NA	XX	XX	337	XX
More than 5-pound units	1,507	NA	487	NA	516	NA	XX	XX	2,510	XX
Total[2]	1,795	234,974	487	28,983	565	33,862	XX	XX	2,848	297,819
Pressed blocks:										
For livestock	138	NA	46	NA	5	NA	XX	XX	190	XX
For water treatment	155	NA	10	NA	24	NA	XX	XX	190	XX
Total[2]	293	28,133	56	4,691	30	2,764	XX	XX	379	35,588
Grand total[2]	3,623	410,296	2,575	74,641	11,064	215,093	18,640	101,475	35,902	801,507
1992										
Bulk	696	34,710	1,500	24,787	10,369	181,644	17,571	76,428	30,136	317,569
Compressed pellets	954	119,124	153	11,869	NA	XX	XX	XX	1,108	130,993
Packaged:										
Less than 5-pound units	99	NA	—	NA	—	NA	XX	XX	99	XX
More than 5-pound units	1,735	NA	787	NA	503	NA	XX	XX	3,025	XX
Total[2]	1,833	238,217	787	42,798	503	31,835	XX	XX	3,124	312,850
Pressed blocks:										
For livestock	93	NA	73	NA	5	NA	XX	XX	171	XX
For water treatment	187	NA	26	NA	33	NA	XX	XX	246	XX
Total[2]	279	29,452	99	8,122	38	3,577	XX	XX	416	41,151
Grand total[2]	3,763	421,503	2,539	87,576	10,911	217,056	17,571	76,428	34,784	802,563

NA Not available. XX Not applicable.

[1]As 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.

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

TABLE 6

SALT SOLD OR USED[1] BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1991		1992	
	Quantity	Value	Quantity	Value
Kansas[2]	2,101	97,713	1,852	98,620
Louisiana	13,240	130,587	12,054	112,334
New York	4,534	173,837	4,703	164,729
Texas	8,106	73,117	7,985	76,125
Utah	1,203	29,959	1,368	44,498
Other Eastern States[3]	4,651	233,167	4,977	245,638
Other Western States[4]	2,067	63,127	1,846	60,619
Total	35,902	801,507	34,784	802,563
Puerto Rico[e]	41	1,500	45	1,500

[e]Estimated.
[1]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.
[2]Quantity and value of brine included with "Other Western States."
[3]Includes Alabama, Michigan, Ohio, and West Virginia.
[4]Includes Arizona, California, Kansas (brine only), Nevada, New Mexico, and Oklahoma.
[5]Data may not add to totals shown because of independent rounding.

TABLE 7

DISTRIBUTION OF DOMESTIC AND IMPORTED[1] SALT BY PRODUCERS IN THE UNITED STATES, BY END USE AND TYPE

(Thousand metric tons)

End use	Standard industrial classification	Vacuum pans and open pans		Solar		Rock		Salt in brine		Grand total[2]	
		1991	1992	1991	1992	1991	1992	1991	1992	1991	1992
Chemical:											
Chloralkali producers	2812	73	17	161	25	805	466	17,901	14,569	18,940	15,078
Other chemical	28 (excludes 2812, 2899)	457	318	287	320	312	923	17	94	1,073	1,655
Total[2]		530	335	449	346	1,117	1,389	17,919	14,664	20,014	16,733
Food-processing industry:											
Meat packers	201	196	214	48	64	126	112	—	—	370	389
Dairy	202	110	111	5	6	15	3	1	2	132	122
Canning	2091, 203	132	137	46	43	74	72	2	1	255	252
Baking	205	132	148	2	3	9	10	—	—	142	161
Grain mill products	204 (excludes 2047)	80	86	1	9	13	13	(3)	—	93	108
Other food processing	206-208, 2047, 2099	181	208	47	44	44	32	—	(3)	272	283
Total[2]		831	904	150	168	281	240	3	3	1,265	1,315
General industrial:											
Textiles and dyeing	22	157	197	47	44	24	25	5	5	232	271
Metal processing	33, 34, 35, 37	15	12	35	34	243	171	(3)	(3)	293	217
Rubber	2822,30 (excludes 3079)	2	1	1	(3)	3	3	132	31	138	34
Oil	13, 29	28	21	278	245	96	75	152	867	554	1,208
Pulp and paper	26	20	17	170	158	41	48	6	7	237	230
Tanning and/or leather	311	10	11	27	21	39	35	—	—	76	67
Other industrial	9621	107	111	59	122	92	344	5	5	263	581
Total[2]		338	369	617	623	537	701	302	915	1,794	2,609
Agricultural:											
Feed retailers and/or dealers-mixers	434	301	230	328	337	467	454	(3)	(3)	1,097	1,020
Feed manufacturers	2048	53	64	86	89	196	239	(3)	(3)	335	392
Direct-buying end user	02	5	5	7	6	15	8	—	—	27	19
Total[2]		358	298	422	432	679	701	(3)	(3)	1,459	1,431
Water treatment:											
Government (Federal, State, local)	2899	15	15	84	110	200	201	3	5	302	331
Commercial or other	2899	8	8	78	53	41	36	2	7	129	104
Total[2]		24	23	163	162	240	238	5	13	432	435
Ice control and/or stabilization:											
Government (Federal, State, local)	9621	4	4	197	157	8,577	7,278	2	1	8,779	7,440
Commercial or other	5159	5	5	35	37	541	331	—	—	582	374
Total[2]		9	9	232	194	9,117	7,609	2	1	9,360	7,814

See footnotes at end of table.

TABLE 7—Continued

DISTRIBUTION OF DOMESTIC AND IMPORTED[1] SALT BY PRODUCERS IN THE UNITED STATES, BY END USE AND TYPE

(Thousand metric tons)

End use	Standard industrial classification	Vacuum pans and open pans		Solar		Rock		Salt in brine		Grand total[2]	
		1991	1992	1991	1992	1991	1992	1991	1992	1991	1992
Distributors:											
Agricultural distribution	5159	281	282	131	113	134	158	—	—	546	553
Grocery wholesalers and/or retailers	514, 54	557	537	231	237	109	75	—	—	897	849
Institutional wholesalers and end users	58, 70	29	32	10	17	23	16	(3)	1	62	66
Water-conditioning distribution	7399	241	229	471	521	171	145	6	5	889	899
U.S. Government resale	9199	5	5	3	5	1	2	—	—	9	12
Other wholesalers and/or retailers	5251	680	809	429	438	698	454	(3)	(3)	1,807	1,701
Total[2]		1,794	1,894	1,275	1,331	1,135	850	6	5	4,210	4,081
Other n.e.s.[4]		186	273	375	186	1,033	2,838	445	165	2,039	3,462
Grand total[2]		4,071	4,104	3,682	3,442	14,139	14,567	18,682	15,766	40,574	37,879

[1]The 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 13, 14, and 15.

[2]Data may not add to totals shown because of independent rounding. Because data include 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 1, 2, 5, and 8, which are derived from plant reports at salt production locations. Data may differ from totals shown in table 8 because of changes in inventory and/or incomplete data reporting.

[3]Less than 1/2 unit.

[4]Includes exports.

TABLE 8

DISTRIBUTION OF DOMESTIC AND IMPORTED EVAPORATED AND ROCK SALT[1] IN THE UNITED STATES, BY DESTINATION

(Thousand metric tons)

Destination	1991				1992			
	Evaporated		Rock	Total[2]	Evaporated		Rock	Total[2]
	Vacuum pans and open pans	Solar			Vacuum pans and open pans	Solar		
Alabama	54	(3)	224	279	55	1	137	193
Alaska	1	15	(3)	16	1	10	(3)	11
Arizona	7	79	(3)	86	8	85	2	95
Arkansas	38	2	60	100	34	2	57	93
California	161	760	9	930	161	679	2	842
Colorado	16	132	27	176	15	147	24	187
Connecticut	9	13	155	177	9	9	151	169
Delaware	3	26	2	31	3	10	3	15
District of Columbia	1	6	(3)	7	1	1	7	9
Florida	77	97	46	220	68	114	37	220
Georgia	160	47	61	268	158	34	66	259
Hawaii	2	4	—	5	2	3	—	5
Idaho	7	64	4	74	7	53	2	62
Illinois	341	103	1,388	1,832	324	119	1,296	1,739
Indiana	191	62	692	945	185	65	591	841
Iowa	166	68	380	614	153	78	309	541
Kansas	83	17	409	509	83	30	236	348
Kentucky	52	2	367	420	57	2	93	152
Louisiana	48	2	543	593	43	2	1,442	1,486
Maine	29	15	204	248	33	20	175	228
Maryland	73	86	112	272	68	80	195	343
Massachusetts	33	17	333	383	32	6	279	318
Michigan	228	16	1,112	1,356	230	19	1,259	1,509
Minnesota	133	158	415	707	132	171	376	679
Mississippi	22	1	177	200	22	(3)	141	162
Missouri	121	25	711	857	138	31	262	431
Montana	2	45	(3)	47	2	44	5	51
Nebraska	83	27	147	257	84	24	208	317
Nevada	1	217	W	218	2	239	W	240
New Hampshire	4	5	88	97	5	4	200	209
New Jersey	116	106	214	436	118	102	193	413
New Mexico	6	53	1	60	7	64	1	72
New York	221	51	1,787	2,059	190	52	2,067	2,308
North Carolina	245	75	38	358	279	51	46	376
North Dakota	17	24	14	54	8	22	9	39
Ohio	342	28	1,386	1,756	347	30	1,442	1,819
Oklahoma	31	14	66	111	29	16	52	97
Oregon	16	45	1	63	15	45	1	61
Pennsylvania	181	105	886	1,173	194	103	728	1,025
Rhode Island	5	5	55	65	7	7	35	50
South Carolina	44	10	8	62	47	10	9	66
South Dakota	34	33	34	102	32	77	32	141

See footnotes at end of table.

TABLE 8—Continued

DISTRIBUTION OF DOMESTIC AND IMPORTED EVAPORATED AND ROCK SALT[1] IN THE UNITED STATES, BY DESTINATION

(Thousand metric tons)

Destination	1991				1992			
	Evaporated		Rock	Total[2]	Evaporated		Rock	Total[2]
	Vacuum pans and open pans	Solar			Vacuum pans and open pans	Solar		
Tennessee	68	1	336	405	73	1	271	345
Texas	169	147	235	551	164	117	298	580
Utah	5	220	W	225	5	206	W	211
Vermont	5	1	161	167	6	1	227	234
Virginia	77	34	70	181	86	32	46	164
Washington	17	258	1	276	20	240	(3)	260
West Virginia	13	3	214	230	13	3	148	163
Wisconsin	218	85	539	842	221	93	1,016	1,330
Wyoming	(3)	24	1	25	(3)	27	1	28
Other[4]	94	249	425	768	127	64	389	581
Total[2 5]	4,071	3,682	14,139	21,892	4,104	3,442	14,567	22,114

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

[1]Each salt type includes domestic and imported quantities. Brine is excluded because brine usually is not shipped out of State.

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

[3]Less than 1/2 unit.

[4]Includes 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.

[5]Because 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 1, 2, and 5, which are derived from plant reports at salt production locations. Data may differ from totals shown in table 7 because of changes in inventory and/or incomplete data reporting.

TABLE 9

CHLORINE AND SODIUM HYDROXIDE PRODUCTION IN THE UNITED STATES

(Thousand metric tons)

	Bureau of the Census		The Chlorine Institute	
	Chlorine gas, 100%	Sodium hydroxide liquid, 100%	Chlorine gas, 100%	Sodium hydroxide liquid, 100%
1988	10,212,615	9,555,641	10,520,880	11,123,752
1989	r10,353,643	r10,404,167	10,803,494	11,345,994
1990	r10,713,283	r10,913,260	10,747,326	11,302,760
1991	r10,361,207	r10,626,018	10,423,461	11,023,463
1992	10,166,054	10,976,410	10,574,495	11,188,840

rRevised.

Sources: Bureau of the Census and The Chlorine Institute.

TABLE 10
SALT YEAREND PRICES

	1991	1992
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. 240, No. 27, Dec. 30, 1991, p. 31; and v. 242, No. 26, Dec. 28, 1992, p. 29.

TABLE 11
AVERAGE VALUES[1 2] OF SALT, BY PRODUCT FORM AND TYPE

(Dollars per metric ton)

Product form	Vacuum pans and open pans	Solar	Rock	Brine
1991				
Bulk	52.34	17.97	17.05	5.45
Compressed pellets	124.52	100.18	XX	XX
Packaged	130.88	59.49	59.91	XX
Average[3]	114.75	27.78	19.25	5.45
Pressed blocks	96.01	83.40	92.33	XX
1992				
Bulk	49.88	16.53	17.52	4.35
Compressed pellets	124.83	77.42	XX	XX
Packaged	129.93	54.35	63.23	XX
Average[3]	112.53	32.56	19.63	4.35
Pressed blocks	105.40	82.13	93.88	XX

XX Not applicable.
[1]Net selling value, f.o.b. plant, excluding container costs.
[2]Average values calculated using unrounded totals.
[3]Salt 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 5.

TABLE 12

U.S. EXPORTS OF SALT, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1991		1992	
	Quantity	Value	Quantity	Value
Argentina	(1)	16	(1)	19
Australia	2	183	(1)	41
Bahamas	4	181	2	162
Bahrain	—	—	1	318
Belize	—	—	(1)	12
Bolivia	(1)	96	—	—
Brazil	(1)	3	(1)	10
Canada	1,288	17,762	718	19,562
Chile	(1)	194	(1)	6
Costa Rica	1	16	(1)	21
Dominican Republic	(1)	84	(1)	69
El Salvador	1	140	1	99
France	5	142	(1)	36
Germany	2	39	2	28
Guatemala	1	118	3	240
Honduras	(1)	3	(1)	34
Hong Kong	(1)	18	(1)	4
Ireland	10	136	(1)	6
Jamaica	9	184	6	158
Japan	13	248	35	913
Korea, Republic of	120	1,441	84	2,173
Mexico	270	4,871	110	4,487
Netherlands	6	77	(1)	36
Netherlands Antilles	(1)	67	(1)	91
Panama	1	89	1	107
Saudi Arabia	14	1,771	13	1,865
Taiwan	1	92	1	89
Trinidad and Tobago	1	3	(1)	6
United Arab Emirates	—	—	(1)	149
United Kingdom	19	704	8	831
Venezuela	—	—	(1)	3
Other	10	1,197	8	618
Total[2]	1,777	29,875	992	32,193

[1]Less than 1/2 unit.

[2]Data may not add to totals shown due to independent rounding.

Source: Bureau of the Census.

TABLE 13
U.S. IMPORTS FOR CONSUMPTION OF SALT

(Thousand metric tons and thousand dollars)

Year	Salt in brine[1]		In bags, sacks, barrels, or other packages		Bulk	
	Quantity	Value	Quantity	Value	Quantity	Value
1988	2	125	71	6,682	4,893	70,550
1989	(2)	(2)	(2)	(2)	5,519	74,474
1990	(2)	(2)	(2)	(2)	5,969	88,419
1991	(2)	(2)	(2)	(2)	6,188	87,380
1992	(2)	(2)	(2)	(2)	5,394	87,714

[1]Anhydrous salt content.
[2]Included in bulk because categories were merged under HTS code No. 2501.00.0000 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 14
U.S. IMPORTS FOR CONSUMPTION OF SALT, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1991		1992	
	Quantity	Value	Quantity	Value
Bahamas	648	8,769	534	7,589
Brazil	40	1,342	36	420
Canada	2,799	43,042	2,505	42,798
Chile	321	2,869	203	3,226
France	329	447	154	572
Germany	1	965	3	739
Italy	34	416	24	311
Korea, Republic of	163	428	57	346
Mexico	1,424	18,927	1,416	21,008
Netherlands	286	7,870	325	7,616
Netherlands Antilles	99	1,778	124	2,345
Spain	5	25	9	23
United Kingdom	(1)	79	(1)	112
Other	40	423	3	609
Total[2]	6,188	87,380	5,394	87,714

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 15

U.S. IMPORTS FOR CONSUMPTION OF SALT, BY CUSTOMS DISTRICT

(Thousand metric tons and thousand dollars)

Customs district	1991		1992	
	Quantity	Value	Quantity	Value
Anchorage, AK	34	160	16	599
Baltimore, MD	215	3,015	287	4,873
Boston, MA	182	2,624	168	2,977
Buffalo, NY	7	570	117	1,428
Chicago, IL	118	2,768	111	2,300
Charleston, SC	336	5,598	347	6,291
Cleveland, OH	289	5,080	176	3,246
Columbia Snake, OR	424	4,742	437	5,553
Dallas-Fort Worth, TX	(1)	63	1	88
Detroit, MI	1,117	15,251	804	13,804
Duluth, MN	151	2,047	210	2,872
Great Falls, MT	(1)	19	—	—
Honolulu, HI	—	—	(1)	3
Houston, TX	(1)	34	(1)	48
Laredo, TX	(1)	2	—	—
Los Angeles, CA	153	2,621	93	1,445
Miami, FL	(1)	73	12	65
Milwaukee, WI	543	9,426	603	10,299
Minneapolis, MN	19	300	(1)	9
New Orleans, LA	164	2,320	161	2,200
New York, NY	683	4,031	339	3,357
Norfolk, VA	77	976	44	640
Ogdensburg, NY	43	835	1	80
Pembina, ND	5	153	12	293
Philadelphia, PA	233	3,079	112	1,713
Portland, ME	312	4,602	286	5,348
Providence, RI	49	518	52	659
St. Albans, VT	(1)	23	(1)	43
St. Louis, MO	(1)	3	(1)	2
San Diego, CA	5	63	(1)	72
San Francisco, CA	(1)	4	2	44
San Juan, PR	15	239	7	411
Savannah, GA	242	5,287	220	3,979
Seattle, WA	472	6,228	507	8,090
Tampa, FL	170	2,513	181	2,666
Wilmington, NC	127	2,111	86	2,216
Total[2]	6,188	87,380	5,394	87,714

[1]Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 16
SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Afghanistan[e]	10	10	10	12	12
Albania[e]	70	80	[3]85	80	50
Algeria	237	229	[r]222	[r]211	210
Angola[e]	70	70	70	70	70
Argentina:					
Rock salt[e]	1	1	1	1	1
Other salt	1,246	1,185	[e]1,200	[e]1,200	1,100
Australia (marine salt and brine salt)	7,165	7,069	7,227	7,791	8,000
Austria:					
Rock salt	1	1	1	1	1
Evaporated salt	413	396	386	[e]380	380
Other salt	256	251	288	[r]280	280
Bahamas	616	858	[r]828	[r]1,096	1,000
Bangladesh[4]	409	415	[r]350	[e]300	320
Benin[e]	([5])	([5])	([5])	([5])	([5])
Bosnia and Herzegovina:[6]					
Rock salt	—	—	—	—	50
Brine salt	—	—	—	—	100
Botswana	—	—	—	[r]3	200
Brazil:					
Rock salt	1,336	1,298	1,033	[r]4,510	4,500
Marine salt	3,020	2,355	[r]4,170	[r]3,703	3,700
Bulgaria	103	78	166	[e]150	150
Burkina Faso[e]	7	7	7	7	7
Burma[7]	246	262	[e]260	[e]260	260
Cambodia[e]	40	40	40	40	40
Canada	10,687	11,057	11,097	[r]11,993	11,154
Cape Verde[e]	[3]3	3	4	4	4
Chile	1,043	904	1,834	[r]1,676	1,700
China[e]	22,000	28,000	20,000	[r]24,100	25,000
Colombia:					
Rock salt	209	190	209	[r]219	220
Marine salt	473	470	478	[r]482	480
Costa Rica (marine salt)[e]	28	30	40	[r]50	50
Croatia (marine salt)[6]	—	—	—	—	20
Cuba	201	206	[e]200	[e]200	185
Czechoslovakia	350	344	[r]227	[r]207	200
Denmark (sales)	[r]548	[r]552	[r]522	[e]520	520
Dominican Republic	38	30	11	[e]12	12
Egypt	922	1,162	989	[r]891	890
El Salvador	3	5	8	[r]15	15
Ethiopia:[e 4]					
Rock salt	15	10	10	[r]9	10
Marine salt	120	100	100	[r]85	80

See footnotes at end of table.

TABLE 16—Continued

SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
France:					
Rock salt	1,145	910	790	e800	700
Brine salt[e]	1,100	1,100	1,000	1,000	1,100
Marine salt[e]	1,650	1,132	1,298	1,200	1,200
Salt in solution[e]	3,675	4,322	3,362	3,500	3,600
Germany:					
Marine salt:					
Eastern states	r2,032	r2,079	r2,000	—	—
Western states	r946	r941	r785	—	—
Total	r2,978	r3,020	r e2,785	r e2,278	1,775
Rock salt and other:					
Eastern states	r3,253	r3,144	e2,450	—	—
Western states	r11,630	r10,997	r10,808	—	—
Total	r14,883	r14,141	r e13,258	r e13,747	11,350
Ghana[e]	50	50	50	50	50
Greece	r181	r148	r150	r e150	125
Guatemala	42	63	109	e100	100
Honduras[e]	30	30	r30	r30	30
Iceland[e]	2	3	3	3	4
India:					
Rock salt	4	3	3	3	3
Marine salt	9,200	9,600	9,500	9,500	9,500
Indonesia[e]	600	600	600	610	630
Iran[e]	815	990	848	r901	900
Iraq[e]	3300	300	250	120	250
Israel	361	475	426	r1,115	1,100
Italy:					
Rock salt and brine salt	3,609	3,501	r3,252	e3,550	3,600
Marine salt[e 9]	680	450	450	450	500
Jamaica	15	16	12	r15	14
Japan	1,363	1,367	1,377	e1,380	1,370
Jordan	r38	r57	r55	r57	57
Kenya (crude salt)	95	103	102	e102	102
Korea, North[e]	570	570	580	580	590
Korea, Republic of	1,020	830	r617	r696	700
Kuwait	40	32	e30	—	30
Laos[e]	30	38	8	8	8
Lebanon[e]	3	3	3	3	3
Leeward and Windward Islands[e]	50	r5	r5	r5	1
Libya[e]	12	12	12	12	12
Madagascar[e]	30	30	30	30	30
Mali[e]	5	35	5	5	5
Malta (marine salt)[e]	(3)	(3)	(3)	(3)	(3)
Mauritania[e]	r6	r6	r6	r6	6
Mauritius[e]	6	6	6	6	6
Mexico	6,788	6,942	7,135	7,595	7,600

See footnotes at end of table.

TABLE 16—Continued

SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Mongolia[e]	16	16	17	17	17
Morocco	133	89	125	[r]109	108
Mozambique[e]	38	40	40	40	40
Namibia (Marine salt)	[r]149	142	[r]157	[r]141	135
Nepal[10]	6	7	7	[e]7	7
Netherlands	3,693	3,756	3,653	[r]3,417	3,500
Netherlands Antilles[e]	350	350	350	350	350
New Zealand[e]	45	76	80	80	80
Nicaragua[e]	15	15	15	15	15
Niger[e]	[3]3	[3]3	[r]3	3	3
Pakistan:[4]					
Rock salt	406	721	763	[r]769	750
Other	266	250	14	[r]12	30
Panama[e]	9	8	9	[r]5	5
Peru[e]	[3]126	200	200	200	200
Philippines	492	489	490	[r]493	450
Poland:					
Rock salt	1,247	[r]995	556	[e]500	500
Other	4,932	[r]3,675	3,499	[e]3,400	3,400
Portugal:					
Rock salt	536	584	523	[r]524	525
Marine salt[e]	[3]139	150	125	125	125
Romania[e]	5,400	[3]6,771	6,500	6,500	6,000
Russia[11]	—	—	—	—	[3]3,600
Senegal[e]	75	97	92	[r]102	100
Serbia and Monenegro[6]	—	—	—	—	30
Sierra Leone[e]	200	200	200	200	200
Somalia[e]	2	[r]2	[r]2	[r]1	1
South Africa, Republic of	678	692	728	665	[3]702
Spain:					
Rock salt	2,455	[r]2,496	[r]2,519	[r]2,500	2,500
Marine salt and other evaporated salt[e]	[r]1,425	[r]594	[r]858	[r]900	900
Sri Lanka	107	150	53	53	53
Sudan	[r e]50	91	68	[e]75	75
Switzerland	309	243	254	[e]250	250
Syria	127	138	127	[e]127	127
Taiwan	111	170	83	195	21
Tanzania	20	20	39	[r]64	64
Thailand:					
Rock salt	6	15	119	125	120
Other[e]	165	165	100	100	100
Tunisia	485	480	402	[r]441	400
Turkey	[r]1,358	1,739	[e]1,600	[r]1,440	1,500
Uganda[e]	5	5	5	5	5
U.S.S.R.[12]	14,800	15,000	14,700	[e]14,000	3,000
Ukraine[11]	—	—	—	—	4,400

See footnotes at end of table.

TABLE 16—Continued

SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
United Kingdom:					
Rock salt	[13]877	1,184	1,102	[r]1,635	1,600
Brine salt[14]	1,426	1,344	1,341	[r]1,319	1,400
Other salt[14]	3,827	4,228	3,991	[r]3,874	3,600
United States including Puerto Rico:					
United States:					
Rock salt	10,702	12,645	13,055	11,064	[3]10,911
Solar salt	2,374	2,498	2,484	2,575	[3]2,539
Vacuum pan salt	3,467	3,599	3,655	3,623	[3]3,763
Brine	17,782	16,509	17,724	18,640	[3]17,571
Puerto Rico[e]	36	41	41	41	[3]45
Venezuela[e]	500	[r]365	[r]439	[r]430	440
Vietnam[e]	300	320	340	350	350
Yemen[e]	225	230	[3]220	225	225
Yugoslavia:[15]					
Rock salt	127	134	100	[e]100	—
Brine salt	200	184	204	[e]220	—
Marine salt	58	60	71	[e]70	—
Total	[r]185,542	[r]192,473	[r]184,062	[r]192,281	184,854

[e]Estimated. [r]Revised.

[1]Table includes data available through July 19, 1993.

[2]Salt 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.

[3]Reported figure.

[4]Year ending June 30 of that stated.

[5]Less than 1/2 unit.

[6]Formerly part of Yugoslavia.

[7]Brine salt production as reported by the Burmese Government in metric tons, was as follows: 1988—59,768; 1989—60,229; 1990—49,670; 1991—46,835 (revised); and 1992—43,488.

[8]Year begining Mar. 21 of that stated.

[9]Does not include production from Sardinia and Sicily, estimated at 200,000 metric tons annually.

[10]Year ending July 15 of that stated.

[11]Formerly part of the U.S.S.R.

[12]Dissolved in Dec. 1991. In addition to the former republics of the U.S.S.R. listed in this table, it is believed that Armenia, Azerbaijan, and Turkmenistan also produce salt; however, information is inadequate to formulate reliable estimates of individual country production.

[13]Great Britain only.

[14]Data 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.

[15]Dissolved in Apr. 1992.

FIGURE 1
U.S. SALT PRODUCTION LOCATIONS, 1992

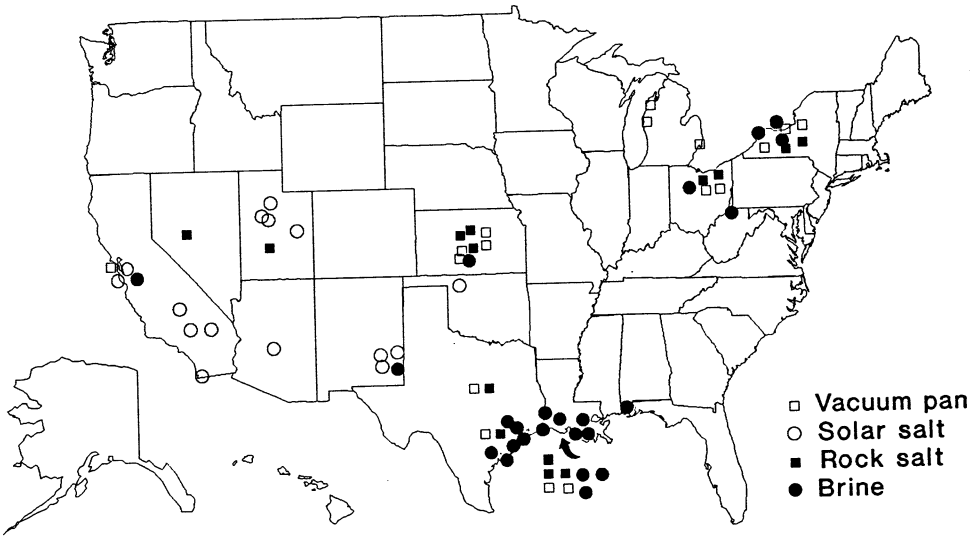
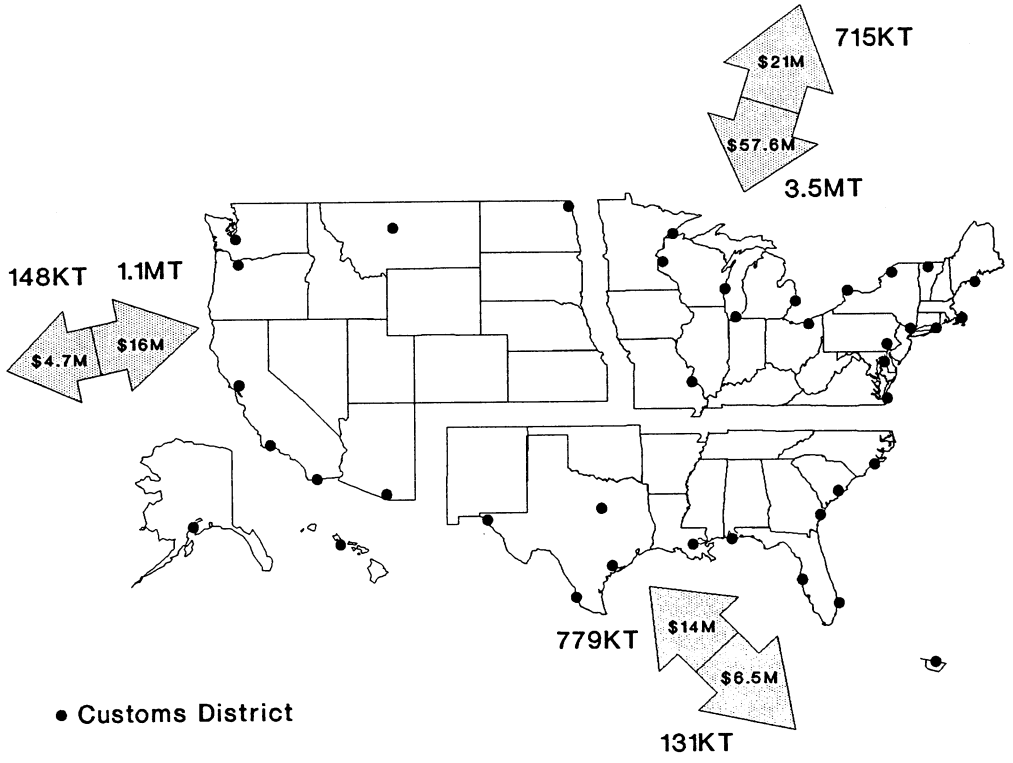


FIGURE 2
U.S. SALT IMPORTS AND EXPORTS, BY REGION, IN 1992

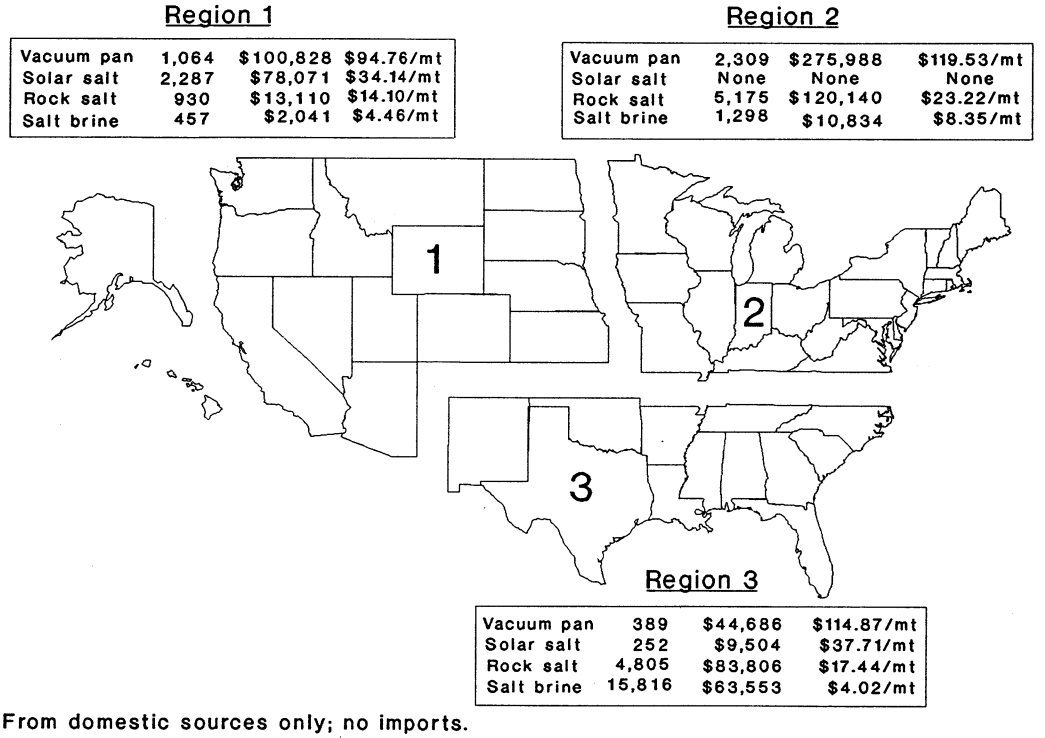


Source: U.S. Bureau of the Census.

FIGURE 3

U.S. SALT SALES, BY REGION, IN 1992[1]

(Thousand metric tons and thousand dollars)

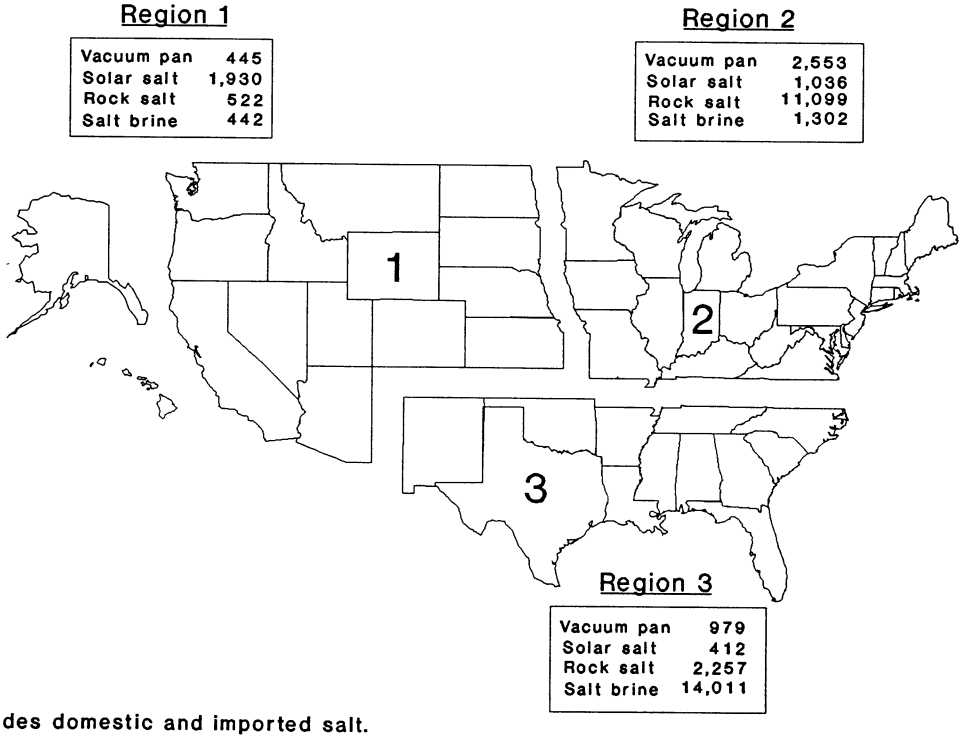


[1]From domestic sources only; no imports.

FIGURE 4

U.S. CONSUMPTION OF SALT, BY REGION, IN 1992[1]

(Thousand metric tons)



[1]Includes domestic and imported salt.

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 industry. 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.

Complying with the provisions of the Metric Conversion Act of 1975 and the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418), beginning with this issue of the Annual Report for Construction Sand and Gravel the U.S. Bureau of Mines (USBM) will publish its statistical information on construction sand and gravel in U.S. customary units as well as metric units. Initially, the reporting in dual units will be applied to the totals only, with increased emphasis on metric units in successive years.

A total of 919 million short tons [834 million metric tons (Mmt)] of construction sand and gravel was produced in the United States in 1992, a 17.8% increase compared with the estimated total of 1991, but only a 0.6% increase over the actual total of 1990. This tonnage represents the third year since 1988 of production of more than 900 million short tons of construction sand and gravel, an indication of continuing strong demand for construction aggregates in the United States. *(See table 1.)*

Foreign trade of construction sand and gravel remained relatively minor in 1992. Exports increased 37.4% to 1.6 million tons (1.4 Mmt), while value decreased 5.7% to $18 million.

Imports decreased slightly to 1.4 million tons (1.3 Mmt), while the value decreased 7.1% to $15.5 million. Domestic apparent consumption of construction sand and gravel was 919 million tons (834 Mmt).

The major issues of concern to the construction sand and gravel industry are: the implementation of the Clean Air Act Amendments of 1990 and its complex legal and technical provisions; the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, Section 404, dealing with "wetlands" and the associated "no net loss of wetlands" policy; the Storm Water Pollution Prevention Program; the Occupational Safety and Health Administration's (OSHA) Hazard Communication Standards regulating the use of products containing more than 0.1% crystalline silica; and the provisions of the Federal Endangered Species Act.

The removal of nonasbestiform Anthophyllite, Tremolite, and Actinolite (AT&A) from the scope of the present Occupational Safety Health Advisors standards for regulating occupational exposure to asbestos in 1992 eliminated one of the major areas of concern for the construction aggregates industries.

DOMESTIC DATA COVERAGE

Domestic production data for construction sand and gravel are developed by the USBM 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 new 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 Survey.

Of the 8,237 construction sand and gravel operations surveyed, 5,999 operations with 8,424 pits were active. Of these, 4,994 operations with 7,342 pits representing 83.3% of the total number of operations reported to the USBM survey. Their total production of 809 million short tons (734 Mmt) represents 88% of the total U.S. construction sand and gravel output. Of the 4,994 reporting operations, 586 operations with 1,123 pits did not report a breakdown by end uses. Their production, about 124.7 million tons (113 Mmt), is included in table 6 under "Unspecified uses, actual." The nonrespondents' production was estimated using employment data and/or adjusted prior-years production reports. The estimated production of 1,005 operations representing 12% of the total U.S. output of construction sand and gravel is included in table 6 under "Unspecified uses, estimated." A total of 946 operations were idle in 1992.

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.

Uses and 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 1992, there were 4,213 companies producing construction sand and gravel from 5,999 operations with 8,424 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 number of products, but most of the tonnage comes from large operations. For example, the 18 operations reporting more than 2.0 million tons each in 1992 represented only 0.2% of the total number of operations, but produced 6.7% of the total tonnage, while 81 operations reporting between 1 and 2 million tons each, representing only 1.4% of the total number of operations, produced 12.2% of the total tonnage. In 1992, most of the construction sand and gravel was produced by operations reporting between 200,000 and 1,000,0000 tons each—1,191 operations or 20% of the total produced 52.1% of the total tonnage.

The leading companies producing construction sand and gravel, in descending order of tonnage, based on the 1992 survey, were CalMat Co. of Los Angeles, CA; Beazer U.S.A. Inc./Hanson PLC of Walnut Creek, CA; CSR America, Inc. of Atlanta, GA; APAC Inc., of Atlanta, GA, a subsidiary of Ashland Oil of Russell, KY; and Western Mobile, Inc., of Fort Collins, CO, a subsidiary of Redland PLC of Groby, Leicester, United Kingdom. The top 5 companies operated 203 pits and produced 10.1% of the U.S. total. Three 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 lakebeds 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, bucket wheel 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 $3.63 in 1992. However, the unit price in constant 1982 dollars fluctuated between $2.64 and $2.71 per ton for the same period. 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, 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 also may 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

A total of 919 million short tons (834 Mmt) of construction sand and gravel was produced in the United States in 1992, a 17.8% increase compared with the estimated total of 1991, but only a 0.6% increase over the actual total of 1990. This tonnage represents the third year since 1988 of production of more than 900 million short tons of construction sand and gravel, an indication of continuous strong demand for construction aggregates in the United States. *(See table 1.)*

Legislation

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&A 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&A presents the same type or magnitude of health effect as asbestos or that employees would be at significant risk because nonasbestiform AT&A were not regulated in the asbestos standards. The nonasbestiform varieties will be regulated according to limits set for "particulates not otherwise regulated." The latest administrative stay of enforcement of the revised standards was also removed by OSHA effective May 29, 1992.

The U.S. Environmental Protection Agency (EPA) issued final general stormwater permits to regulate discharges resulting from industrial and construction activities that disturb five or more acres. Facilities that must be covered by a stormwater permit include many mining operations where water comes into contact with raw materials or wastes. All facilities covered by a general permit must prepare and implement a site-specific stormwater pollution-prevention plan. To assist industry in complying with the stormwater requirements, the EPA has developed guidance manuals on sampling and on pollution prevention management practices.

The removal of nonasbestiform AT&A 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.

Issues

The new complex legal and technical provisions of the comprehensive amendments of 1990 to the Clean Air Act and the implementing regulations for these provisions constitute a major area of concern to the crushed stone industry. One major emphasis of the amendments is expanded authority given to EPA and the States to enforce the new law and assess increased penalties. EPA is now authorized to issue administrative orders with penalties of up to $200,000 for noncompliance, and its field inspectors can issue citations for minor violations with penalties of up to $5,000 per day for each violation. The law also includes provisions for new Federal permits to be issued by the State agencies that include source specific emission limitations and related monitoring, recordkeeping, and reporting requirements. Complying with the new provisions of the Clean Air Act Amendments will constitute a major challenge to all crushed stone producers.

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 reintroduced in the 103d 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.

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

U.S. production of construction sand and gravel increased 17.8% in 1992 to 919 million tons (834 Mmt) compared with the estimated total of 1991, and only 0.6% compared with that of 1990, the year when the previous full annual survey was conducted. *(See table 1.)*

Of the four major geographic regions, the West again led the Nation in the production of construction sand and gravel with 331 million tons (300 Mmt), or 36% of the U.S. total, followed by the Midwest with 295 million tons (267 Mmt), or 32% of the total; the South with 189 million tons (171 Mmt), or 20.6%; and the Northeast with 104 million tons (95 Mmt), or 11.4%. Compared with that of 1991, production by major geographic regions increased 29.3% in the Northeast, 20.8% in the Midwest, 16.2% in the West, and 10.8% in the South. *(See table 2.)*

Of the nine geographic regions, the East North Central led the Nation in the production of construction sand and gravel with 189 million tons (171 Mmt), or 20.6% of the U.S. total, followed by the Pacific with 185 million tons (168 Mmt), or 20.2%; and the Mountain with 146 million tons (132 Mmt), or 15.8% of the total. *(See table 2.)* Compared with that of 1991, production increased in all regions, with the largest increases recorded in New England, 30.7%, the Mountain, 29.2%, and Middle Atlantic, 28.5%, and the smallest increases in the East North Central, 17.3%, and East South Central, 7.1%.

A review of the production by size of operation indicates that 45.6% of the construction sand and gravel produced in 1992 came from 1,872 operations reporting between 100,000 and 499,999 tons per year; 21.7% came from 289 operations reporting between 500,000 and 999,999 tons per year; and 18.9% came from 99 operations reporting more than 1,000,000 tons per year. A total of 5,999 operations were active in 1992. *(See table 8.)*

The estimated production by quarters for 1992 indicates 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. *(See table 3.)* Estimated production by each quarter of 1992 was also available for most of the States. *(See table 5.)*

Construction sand and gravel was produced in 1992 in every State. The 10 leading States, in descending order of tonnage, were California, Michigan, Ohio, Texas, Washington, Minnesota, Illinois, Arizona, New York, and Colorado. Their combined production represented 50.3% of the national total. Compared with that of 1991, production increased in 37 States, including 9 of the top 10 States. *(See table 4.)*

Limited information about the production of construction sand and gravel in foreign countries may be found in the USBM "Minerals Yearbook, Volume III, 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.

Significantly fewer changes in ownership, acquisitions, and mergers occurred in the construction sand and gravel industry in 1992 compared with prior years. Granite Construction Co. of Watsonville, CA, acquired from Tarmac America of Herndon, VA, 13 sand and gravel and crushed stone operations located in southern California. The transaction also included 10 ready-mixed concrete plants and 5 asphalt operations.

CalMat Co. of Los Angeles, CA, acquired in the second half of 1992 the Jamieson Co. of Pleasanton, CA, a major producer of construction aggregates in the San Francisco Bay area. This is the first time that CalMat will own and operate a sand and gravel plant in the northern part of the State.

Consumption and Uses

Construction sand and gravel reported by producers to the USBM is actually material that was "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. Because no consumption surveys are conducted by the USBM, the "sold or used" tonnage is assumed to represent the amount produced for domestic consumption and export. Because some of the construction sand and gravel producers did not report a breakdown by end use, their total production is reported under "Unspecified uses, actual." The estimated production of nonrespondents is reported under "Unspecified uses, estimated."

Of the 919 million tons of construction sand and gravel produced in 1992, 235 million tons (213 Mmt) or 25.6% of the total was unspecified uses. Of the remaining 684 million tons (621 Mmt), 38.8% was used as concrete aggregates; 28.4% for road base and coverings and road stabilization; 14.1% as asphaltic concrete aggregates and other bituminous mixtures; 13% as construction fill; 1.7% for concrete products such as blocks, bricks, pipes, etc.; 1.4% for plaster and gunite sands: and the remainder for snow and ice control, railroad balast, roofing granules, filtration, and other miscellaneous uses. *(See table 6.)*

To provide a more acurate estimation of the consumption patterns for construction sand and gravel, the "Unspecified uses" are not included in the above percentages. It is recommended that in any marketing or use pattern analysis the quantities included in "Unspecified uses" be distributed among the reported uses by applying the above percentages.

A review of consumption by major geographic regions indicates that most of the sand and gravel for concrete aggregates, including concrete sand, was used in the West, with 31.9%; the South, with 31.5%; and the Midwest, with 21.7%, with high levels of construction activity. Most of the sand and gravel for road base and coverings was used in the West, 44.4%, and the Midwest, 39.2%, while most of the sand and gravel used for asphaltic concrete aggregates and other bituminous mixtures was used in the West, 43.6%, and the Midwest, 31.5%.

(See table 7.)

Additional information regarding production and/or consumption of construction sand and gravel by major uses in each State and the State districts is published in the USBM Annual Reports State chapters, Volume II of the Minerals Yearbook.

Transportation

Information regarding the method of transportation of construction sand and gravel from the pit or processing plant to the first point of sale or use is now available for each geographic region. Total U.S. reports regarding the method of transportation were provided by the producers for 643 million tons (583 Mmt) or 69.9% of the total U.S. production of construction sand and gravel. Of this total, 72.8% was transported by truck, 4% by waterway, and 1.1% by rail. A significant amount of construction sand and gravel produced, about 21.6%, was not transported and used at the production site. *(See table 11.)* Because most producers either did not keep records or did not report shipping distances or cost per ton per mile, no transportation cost data were available.

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 1992 average unit prices increased only 1.7% to $3.63 per ton. By uses, the unit prices varied from a high of $5.32 for filtration sand to a low of $2.16 for fill. The largest increases in unit prices by uses were recorded for plaster and gunite sands, 22%; road stabilization cement, 21.7%; and railroad ballast, 19.4%. Average unit prices declined for filtration sands, 12.2%; fill, 9.2%; and snow and ice control sand, 2.3%. *(See table 6.)*

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 only about 1% of the domestic consumption.

Exports.—Exports of construction sand increased 118.5% to 959,000 tons (870,000 Mmt), compared with that of 1991, while the value decreased 3.1% to $12.6 million. Mexico was the major destination, receiving about 54.3% of the total, followed by Canada with 34.2%. Exports of construction gravel declined 13.4% to 606,000 tons (550,000 Mmt), while the value decreased 11.2% to $5.4 million. Canada was the major destination receiving about 83.7% of the total. *(See table 12.)*

Imports.—Imports decreased slightly to 1.4 million tons (1.3 Mmt), while the value decreased 7.1% to $15.5 million. Canada was the major source of imported construction sand and gravel with 71.7% of the total, followed by the Bahamas with 15%. *(See table 13.)*

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 NAA and the National Stone Association established in 1990 the Aggregates Foundation for Technology, Research, and Education (AFTRE). The main purpose of the foundation was to establish and provide the funding for a new Aggregates Research Center (CAR). On August 25, 1992, the formal ceremonies establishing CAR took place at the University of Texas at Austin. The center will be operated jointly by the University of Texas at Austin and Texas A&M University and financed by the AFTRE. The center's mission is to conduct scientific and technical research related to aggregates; coordinate technology transfer activities; establish a central information clearinghouse on aggregates technology; and develop undergraduate and graduate engineering courses and continuing education programs related to aggregates research.

A technical advisory committee overviewing the center's activity identified six priority areas of research that include the following: fine aggregates properties and their influence on end products; uses for fines resulting from the processing of aggregates; performance-related tests for aggregates; proper use of aggregates in asphaltic concrete to minimize rutting; prevention of alkali-silica and alkali-carbonate reactivity of aggregates in portland cement concrete; and nature and effects of coatings on aggregates.

Nineteen ninety-two was the last year of the 5-year Strategic Highway Research Program (SHRP) created by the U.S. Congress through the Surface Transportation and Uniform Relocation Assistance Act of 1987. SHRP's mission was 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 performance of asphalt-concrete mixtures, a new set of specifications called Superpave is being finalized by SHRP. Superpave specifications use performance-based criteria and take into account environmental factors and traffic volumes and loads, a dramatic departure from earlier mixture specifications.[5] SHRP also continues to refine and improve its asphalt binder specifications that will produce a superior-quality asphalt and address the rutting, low-temperature cracking, fatigue cracking, aging, and loss of adhesion problems.

SHRP's concrete program is in the final stage of developing new engineering guidelines, materials tests, and specifications that will produce consistently a more durable concrete for use in highway construction work. SHRP's program identified materials and the processes needed to produce a very early high strength concrete that requires only 4 hours of curing time, and therefore speeds the construction process and reduces the interruptions of the traffic flow.

Alkali-Silica Reactivity (ASR) of concrete is a major cause of deterioration in highway structures and pavements. SHRP's research found that lithium hydroxide introduced into concrete can prevent or inhibit ASR. Laboratory evaluations also showed that lithium hydroxide alone, or in combination with class-F fly ash, is very effective in inhibiting expansion even in concrete made with highly reactive aggregates.

SHRP's structure program is developing guidelines for evaluation, protection, and rehabilitation of structures. The presence of chloride in concrete is the number-one cause of distress in highway structures. Unprotected reinforcing steel used in concrete structures is highly susceptible to chloride-induced corrosion. Several of SHRP's research projects are exploring new ways of evaluating structures and preventing corrosion.

As the U.S. highway system ages and traffic volumes and weights continue to increase, roadway maintenance expenditures have become the fastest growing portion of highway budgets. The performance of materials, methods, and equipment used in highway maintenance and repair continued to be investigated by SHRP's highway operation program. Field tests to evaluate materials and procedures for pavement repair are being conducted by cooperative States under different climatic and installation conditions. Twenty-two such test sites have been built. The performance of the test sites will be monitored by the Federal Highway Administration (FHWA).

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. Eight hundred of the LTPP test sections contain common types of pavement in use throughout the United States, general pavement studies, and 340 other sites have been specially constructed to study certain engineering factors in pavement design. The collected data will provide vitally needed technical information regarding improved design techniques to highway agencies and pavement design organizations. Since its inception, the LTPP program has been international in scope. Fifteen countries are participating in the program, conducting research and forwarding data to SHRP.

In July 1992, responsibility for the ongoing LTPP research and data collection effort was assumed by the FHWA, while the Transportation Research Board has assumed responsibility for maintaining the LTPP data base.

A low-cost dewatering technique for fine-grained slurries usually produced in the processing of crushed stone has been developed by the USBM. The technique consists of injecting a polymer into the line carrying the slurry and dewatering the resulting flocs on a static, hydrosieve screen. The key to successful dewatering is the formation of strong flocs that will not break apart as the floc moves down the screen. To produce strong flocs, the mixing time and the turbulent conditions in the flow line to the screens must be optimized. This is accomplished by varying the feed rate and the length of pipe carrying the slurry and the polymer mixture to the screens.[6] The initial field tests were conducted at a Birmingham, AL, limestone quarry. The waste slurry consisted of fine-grained calcium-magnesium carbonate. The testing program included an evaluation of the parameters for polymer concentration, mixing time, and effect of turbulence during the mixing. Field test results showed that 50% solids were produced using 1.4 pounds of polymer per ton of solids treated, at a cost of $0.50 per pound of polymer.

Just a few years ago, plant automation was considered to be something that can be implemented only in large crushed stone and sand and gravel operations. Today, plant automation has become a necessity essentially for operations of any size. The principal advantages of plant automation are improved product quality; lower unit cost for the final product; reduced plant wear; and improvements in health and safety of the operators. The current requirements to limit dust and noise exposure, for example, in many cases, can be best handled by automating high-exposure tasks and removing workers from potentially high-exposure areas. These factors also apply to retrofitted plants.[7]

Looking at plant automation and the future, two emerging technologies will have a significant impact on this industry: "smart sensors" and "expert systems." Smart sensors will play an important role in more efficient, more flexible automation processes, while expert systems will be used for diagnosis of plant problems and early prediction of impending failures. Some basic research in the areas of adaptive learning networks (ALN's), fuzzy logic, and neural networks, the underlying technologies for smart sensors, as well as research in the development of expert system to diagnose equipment failures are being conducted by the USBM.

Technology

The Metric Conversion Act of 1975 declared a national policy of coordinating the increasing use of the metric system in the United States and provided for the establishment of a U.S. Metric Board to coordinate the voluntary conversion to the metric system. It was followed by the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418) that declared the metric system of measurement "the preferred system of

weights and measures for United States trade and commerce." The act stipulates that each agency of the Federal Government, by a date prior to the end of fiscal year 1992, will use the metric system of measurements in its procurements, grants, and other business-related activities. The only allowed exceptions are for circumstance that will demonstrate that the use of the metric system is impractical or is likely to cause significant inefficiencies or loss of markets to U.S. firms.[8]

MSHA and the FHWA, two Federal Government agencies working closely with the crushed stone and sand and gravel industries, developed plans and schedules for their conversion to the metric system that were published for public comments during 1991. Although the MSHA metrication plan is scheduled to be completed in 18 months in place by July 1993, the FHWA metrication schedule expands over a longer period of time and is scheduled to be completed by September 30, 1996.

The USBM is also in the process of completing the conversion to the metric system of all its publications. Beginning with this issue of the Annual Report for Construction Sand and Gravel, the statistical information on construction sand and gravel will be published in metric units as well as U.S. customary units. Initially, the reporting in dual units will be applied to the totals only, with increased emphasis on metric units in successive years.

The participants of the 1992 European Concrete Study Tour sponsored by the American Association of State Highway and Transportation Officials, the FHWA, and the American Concrete Pavement Associations observed highways and met with experts in Austria, Belgium, France, Germany, and the Netherlands. They also attended presentations made by experts from Italy, Portugal, Spain, and Switzerland concerning portland cement concrete pavements in their countries. The group of 21 American highway and pavement experts concluded that "the new and recently built portland cement concrete highways observed were built with a common philosophy—worry more about design, materials, and construction excellence, and less about cost. The European highways featured well-conceived, durable concrete slabs placed on thick, well-drained bases, resulting in superior pavement structures. The pavements were built with the best technology available, much of which has been developed in the United States. The European nations are building their portland cement concrete highways for the future with 30- to 40-year designed service life, compared with our 20 years. The European highways carry a large volume of trucks, with allowable axle weight substantially above those in the U.S."[9]

Jointed plain concrete pavements (JPCP) are constructed most often in Europe, and their design has been improved over time through effective research. Continuous reinforced concrete pavements (CRCP) have been built in several countries, most commonly Belgium and France. The new and rehabilitation designers in most countries are developed by teams of experts and placed in "pavement design catalogs" for use by design engineers. Emphasis is on the design of the total pavement system, not just the thickness of the concrete slab.

Warranties for pavement construction work are used in Europe. For concrete pavements, warranties range from 4 to 9 years. Two-layer slab construction is common in some countries for safety, noise, and economic reasons. A hard, high-quality aggregate is used in the upper 4 to 7 centimeters (1.6 to 2.8 inches) of the slab. Two-layer paving equipment is available to place this pavement in one pass.

Rehabilitation of pavements is performed at a higher level of condition than in the United States Designer CRCP and JPCP overlays are common on old concrete pavements, which are often cracked and seated or picked up and crushed and used as base. Jointed, steel-fiber-reinforced concrete and AC pavements have been used successfully in Belgium.

Recycling of pavements is on the rise in Europe, with total recycling of concrete and other construction materials required by law in Austria. Recycled concrete that includes up to 10% recycled asphalt concrete materials is used routinely in Austria. Concrete durability problems do not exist in Europe because high-strength concrete is used. Reduction of pavement-tire noise levels is an important environmental issue in Europe.

Recycling of construction materials, especially concrete and asphalt pavements, as well as construction debris is increasing throughout the United States as well as most industrialized countries. Construction and demolition debris (C&D) is bulky, difficult to handle, and expensive to move and dispose of. C&D represent 5% to 15% by weight of the wastestream, and for economic as well as environmental reasons, are becoming a subject of increased interest for expanded recycling programs. The reuse and recycling of C&D can make a significant contribution to aggregates conservation and also reduced landfill requirements. The European Demolition Association, which represents more than 1,000 European demolition and recycling companies in Western Europe, recently conducted a survey of its members. The purpose of the survey was to determine the present status and practices in recycling and the future requirements of its members related to the expected growth of this industry. The review of the information provided by the survey indicated that: recycled material produced from concrete or mixed debris can be used as aggregates in new concrete; there is a need to create a larger market for recycled material by establishing national or preferably European specifications; and despite significant differences between the European Community countries, the volume of recycled C&D is expected to grow faster than in the past.[10] A similar report reviewing the status of recycling of construction materials in Canada was published by the Ontario Ministry of Natural Resources.[11]

More and more specialized software programs that increase efficiency and productivity of crushed stone and sand and gravel operations are now available, covering operations from mine planning to drilling and blasting, conveying,

dispatching, and equipment management. Many of these software systems can be combined for overall computer management of aggregates operations. The programs can assist quarry and plant operators in increasing output by providing accurate, up-to-the-minute information, some of it not available in the past.[12]

OUTLOOK

The demand for construction sand and gravel in 1993 is expected to be about 940 million tons, a 2.5% increase compared with that of 1992. Gradual increases in demand for construction aggregates are anticipated after 1993 as well, based on increased volume of work on the infrastructure that is being financed by the Intermodal Surface Transportation Efficiency Act of 1991, some State highway projects, and the recovery of the U.S. economy. It is estimated that the demand for construction sand and gravel will reach 975 million tons in 1995. The projected increases will be influenced by construction activity, primarily in the public construction sector.

Construction sand and gravel f.o.b. prices are not expected to increase significantly, even if the demand for construction aggregates rise over the 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

		1988	1989	1990	1991	1992
Sold or used by producers:						
Quantity[1]	thousand short tons	923,400	e897,300	r913,500	e780,300	919,300
Quantity	thousand metric tons[2]	837,695	814,017	r828,713	707,876	833,975
Value[1]	thousand dollars	$3,126,000	e$3,249,100	r$3,267,500	e$2,805,500	$3,341,300
Exports	value, thousand dollars	$11,048	$13,591	$11,880	$19,044	$17,963
Imports	do.	$3,163	$6,618	$22,912	$16,638	$15,463

eEstimated. rRevised.

[1]Hawaii and Puerto Rico excluded from all sand and gravel statistics.

[2]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

TABLE 2
CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY GEOGRAPHIC REGION

Geographic region	1991e				1992			
	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	28,400	4	$111,100	4	37,127	4	$154,535	5
Middle Atlantic	52,300	7	231,200	8	67,209	7	305,016	9
Midwest:								
East North Central	161,100	21	520,600	19	188,929	21	617,291	18
West North Central	82,700	11	216,900	8	105,658	11	291,706	9
South:								
South Atlantic	64,600	8	248,900	9	70,661	8	265,300	8
East South Central	37,000	5	127,000	5	39,635	4	145,651	4
West South Central	69,400	9	238,100	8	79,096	9	278,891	8
West:								
Mountain	112,700	14	377,600	13	145,620	16	506,920	15
Pacific	172,100	22	734,100	26	185,315	20	775,973	23
Total[1]	780,300	100	2,805,500	100	919,300	100	3,341,300	100
Total[2 3]	707,876	XX	2,805,500	XX	833,975	XX	3,341,300	XX

eEstimated. XX Not applicable.

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

[2]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[3]Total quantity and total value in thousand metric tons and thousand dollars.

TABLE 3

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1992, BY GEOGRAPHIC REGION AND QUARTER[1]

Geographic region	Quantity[2] (thousand short tons)					Value (thousands)	Number of companies[4]
	1st quarter	2d quarter	3d quarter	4th quarter	Total[3]		
Northeast:							
New England	3,500	9,600	12,000	9,500	34,600	$137,700	25
Middle Atlantic	5,400	14,500	18,000	12,200	50,100	227,300	33
Midwest:							
East North Central	16,500	43,800	54,800	44,700	159,800	528,600	55
West North Central	11,300	29,200	31,800	21,600	93,900	249,200	44
South:							
South Atlantic	14,000	17,000	18,300	16,400	65,700	251,500	50
East South Central	6,700	10,600	11,700	10,000	39,100	136,600	21
West South Central	15,600	17,900	20,800	16,300	70,700	246,400	17
West:							
Mountain	24,500	41,100	41,600	34,300	141,500	483,500	34
Pacific[5]	26,600	38,700	41,700	33,500	140,400	628,000	29
Total[5]	124,000	222,600	250,600	198,600	[6]809,100	[6]2,927,800	XX
Total[7 8]	112,500	201,900	227,300	180,200	[6]734,000	2,927,800	XX

XX Not applicable.

[1]As published in the "Crushed Stone and Sand and Gravel in the First Quarter of 1993," Mineral Industry Survey, based on estimated 1991 totals.

[2]Most of the 1992 data have been revised owing to adjustments of quarterly data to agree with 1992 totals.

[3]Data may not add to totals shown because of independent rounding and differences between projected totals by States and by regions.

[4]Number of companies reporting for the quarterly survey.

[5]Does not include Alaska and Hawaii.

[6]Includes Alaska and Hawaii.

[7]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[8]Total quantity and total value in thousand metric tons and thousand dollars.

TABLE 4

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1991[e]			1992		
	Quantity (thousand short tons)	Value (thousands)	Unit value	Quantity (thousand short tons)	Value (thousands)	Unit value
Alabama	12,700	$45,700	$3.60	12,294	$42,038	$3.42
Alaska	14,000	39,200	r2.80	15,006	43,335	2.89
Arizona	22,500	79,400	r3.53	33,842	123,517	3.65
Arkansas	8,300	31,100	r3.75	10,908	39,627	3.63
California	101,900	489,100	r4.80	112,888	522,108	4.63
Colorado	26,400	88,200	r3.34	29,455	105,281	3.57
Connecticut	5,400	24,800	r4.59	6,025	30,107	5.00
Delaware	1,600	5,100	3.19	2,488	8,574	3.45
Florida	16,000	51,400	r3.21	23,266	66,141	2.84
Georgia	4,700	14,500	r3.09	4,860	15,581	3.21
Hawaii	400	2,300	r5.75	—	—	—
Idaho	11,600	31,300	r2.70	14,906	40,728	2.73
Illinois	26,300	90,400	r3.44	35,695	123,720	3.47
Indiana	18,100	60,400	r3.34	28,862	95,889	3.32
Iowa	17,400	55,800	r3.21	16,825	58,382	3.47
Kansas	9,600	22,100	r2.30	11,979	27,289	2.28
Kentucky	7,700	27,200	r3.53	7,396	24,412	3.30
Louisiana	13,300	48,900	r3.68	12,644	48,698	3.85
Maine	3,900	14,800	r3.79	6,703	26,932	4.02
Maryland	13,000	72,800	r5.60	11,988	69,297	5.78
Massachusetts	10,100	39,400	r3.90	12,033	48,671	4.04
Michigan	44,800	132,200	r2.95	47,994	143,107	2.98
Minnesota	24,500	58,800	r2.40	37,604	98,673	2.62
Mississippi	9,900	33,000	r3.33	11,467	44,124	3.85
Missouri	7,400	20,100	2.72	9,024	26,457	2.93
Montana	4,800	13,700	r2.85	11,109	31,375	2.82
Nebraska	10,100	27,300	r2.70	13,206	38,108	2.89
Nevada	20,300	69,000	r3.40	24,273	93,585	3.86
New Hampshire	4,700	16,200	r3.45	6,436	25,570	3.97
New Jersey	10,300	47,900	r4.65	16,416	79,993	4.87
New Mexico	9,200	35,900	r3.90	11,210	46,176	4.12
New York	23,700	95,500	r4.03	31,458	130,379	4.14
North Carolina	9,900	35,000	r3.54	10,233	42,717	4.17
North Dakota	5,000	12,000	r2.40	8,740	20,609	2.36
Ohio	42,300	160,100	r3.78	47,260	177,508	3.76
Oklahoma	9,000	22,300	r2.48	9,904	24,204	2.44
Oregon	15,600	62,800	r4.03	16,488	69,536	4.22
Pennsylvania	18,300	87,800	r4.80	19,334	94,643	4.90
Rhode Island	1,300	6,000	r4.62	2,455	11,964	4.87
South Carolina	6,600	18,900	r2.86	6,896	19,923	2.89
South Dakota	8,700	20,800	r2.39	8,279	22,187	2.68
Tennessee	6,700	21,100	r3.15	8,478	35,077	4.14
Texas	38,800	135,800	r3.50	45,640	166,362	3.65
Utah	14,400	48,200	r3.35	17,678	54,819	3.10
Vermont	3,000	9,900	r3.30	3,474	11,291	3.25
Virginia	9,700	36,900	r3.80	9,545	37,336	3.91

See footnotes at end of table.

TABLE 4—Continued

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1991e			1992		
	Quantity (thousand short tons)	Value (thousands)	Unit value	Quantity (thousand short tons)	Value (thousands)	Unit value
Washington	40,200	$140,700	r$3.50	40,933	$140,994	$3.44
West Virginia	3,100	14,300	r4.61	1,385	5,730	4.14
Wisconsin	29,600	77,500	r2.62	29,118	77,066	2.65
Wyoming	3,500	11,900	r3.40	3,147	11,438	3.63
Total[1]	780,300	2,805,500	3.60	919,300	3,341,300	3.63
Total[2 3]	707,876	2,805,500	3.96	833,975	3,341,300	4.01

eEstimated. rRevised.

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

[2]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[3]Total quantity and total value in thousand metric tons and thousand dollars.

TABLE 5

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1992, BY STATE AND QUARTER[1]

State	Quantity[2] (thousand short tons)					Value (thousands)	Number of companies[4]
	1st quarter	2d quarter	3d quarter	4th quarter	Total[3]		
Alabama	2,500	3,600	3,400	2,800	12,300	$45,100	9
Alaska[5]	—	—	—	—	13,000	37,200	—
Arizona	5,500	7,800	7,100	6,200	26,500	95,400	8
Arkansas	1,800	1,900	2,400	1,800	8,000	30,600	4
California	16,800	25,700	26,400	20,300	89,100	436,600	14
Colorado	4,900	12,300	13,600	10,100	41,000	139,800	9
Connecticut	700	1,600	2,300	1,800	6,400	30,000	6
Delaware	600	1,100	1,700	1,600	5,000	16,300	5
Florida	3,800	4,100	4,000	3,700	15,600	51,200	9
Georgia	1,200	1,300	1,200	1,000	4,700	14,800	9
Hawaii[5]	—	—	—	—	300	1,800	—
Idaho	2,600	2,900	3,400	4,700	13,600	37,400	4
Illinois	2,800	8,300	9,400	7,600	28,100	98,600	8
Indiana	2,800	5,600	6,800	5,000	20,200	68,700	13
Iowa	1,500	6,000	5,600	3,600	16,700	54,600	7
Kansas	1,600	2,700	2,900	2,400	9,600	22,600	8
Kentucky	1,300	2,500	3,000	2,700	9,500	34,200	5
Louisiana	3,000	3,700	3,500	3,100	13,300	49,900	5
Maine	300	1,100	1,600	1,500	4,500	17,400	4
Maryland	2,000	2,800	3,100	2,900	10,800	61,700	8
Massachusetts	1,500	3,300	4,600	3,500	12,900	51,300	6
Michigan	3,000	11,800	14,600	12,800	42,300	127,300	10
Minnesota	2,600	9,500	10,600	6,700	29,500	72,300	13
Mississippi	1,700	2,200	2,900	2,400	9,200	31,300	6
Missouri	1,300	2,500	3,100	2,100	9,000	24,900	6
Montana[5]	—	—	—	—	7,900	23,000	—
Nebraska	1,800	4,000	3,600	2,400	11,700	32,300	7
Nevada	3,700	6,200	6,000	5,400	21,300	73,900	7
New Hampshire	600	2,000	1,900	1,400	5,900	20,800	4
New Jersey	1,700	3,200	4,000	3,000	11,900	56,400	5
New Mexico	2,800	3,900	3,800	2,600	13,100	52,100	3
New York	2,000	5,300	7,700	5,300	20,300	83,400	12
North Carolina	2,300	2,300	2,600	2,300	9,400	33,900	5
North Dakota[5]	—	—	—	—	5,300	13,000	—
Ohio	4,400	9,700	14,900	12,400	41,400	159,800	17
Oklahoma	2,300	2,600	2,900	2,300	10,100	25,600	6
Oregon	2,000	3,200	4,600	5,400	15,300	62,900	4
Pennsylvania	1,700	5,600	6,500	4,100	17,900	87,500	15
Rhode Island[5]	—	—	—	—	1,300	6,100	—
South Carolina	1,700	2,000	1,900	1,700	7,300	21,300	6
South Dakota	700	3,300	4,700	3,500	12,100	29,500	5
Tennessee	1,200	2,400	2,400	2,100	8,100	26,000	6
Texas	8,400	9,700	12,100	9,100	39,300	140,300	8
Utah	1,700	4,500	5,900	3,000	15,100	51,500	3
Vermont	300	1,100	1,400	800	3,600	12,100	4
Virginia	2,100	2,600	2,900	2,600	10,200	39,600	7

See footnotes at end of table.

TABLE 5—Continued

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1992, BY STATE AND QUARTER[1]

State	Quantity[2] (thousand short tons)					Value (thousands)	Number of companies[4]
	1st quarter	2d quarter	3d quarter	4th quarter	Total[3]		
Washington	7,600	8,900	10,700	8,800	36,000	$128,500	10
West Virginia	300	700	1,000	700	2,700	12,700	4
Wisconsin	2,900	8,400	9,200	7,300	27,800	74,200	13
Wyoming	800	700	800	700	3,000	10,400	3
Total	XX	XX	XX	XX	809,100	2,927,800	XX
Total[6 7]	XX	XX	XX	XX	734,000	2,927,800	XX

XX Not applicable.

[1]As published in the "Crushed Stone and Sand and Gravel in the First Quarter of 1993," Mineral Industry Survey, based on estimated 1991 totals.

[2]Most of the 1992 data have been revised owing to adjustments of quarterly data to agree with 1992 totals.

[3]Data may not add to totals shown because of independent rounding, and differences between projected totals by States.

[4]Number of companies reporting for the quarterly survey.

[5]Due to a low number of reporting companies, no production estimates by quarters were generated.

[6]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[7]Total quantity and total value in thousand metric tons and thousand dollars.

TABLE 6

CONSTRUCTION SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES IN 1992, BY MAJOR USE

Use	Quantity (thousand short tons)	Value (thousands)	Value per ton
Concrete aggregates (including concrete sand)	265,930	$1,083,966	$4.08
Plaster and gunite sands	9,662	51,411	5.32
Concrete products (blocks, bricks, pipe, decorative, etc.)	12,040	49,532	4.11
Asphaltic concrete aggregates and other bituminous mixtures	96,702	419,732	4.34
Road base and coverings	189,216	587,399	3.10
Road stabilization (cement)	3,380	11,774	3.48
Road stabilization (lime)	1,466	5,146	3.51
Fill	88,722	191,726	2.16
Snow and ice control	6,955	23,225	3.34
Railroad ballast	1,002	4,944	4.93
Filtration	2,435	11,777	4.84
Other	6,541	29,794	4.55
Unspecified:[1]			
Actual	124,656	470,532	3.77
Estimated	110,546	400,324	3.62
Total[2]	919,300	3,341,300	3.63
Total[3 4]	833,975	3,341,300	4.01

[1]Includes production reported without a breakdown by use and estimates for nonrespondents.

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

[3]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[4]Total quantity and total value in thousand metric tons and thousand dollars.

TABLE 7

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1992, BY GEOGRAPHIC REGION AND MAJOR USE

(Thousand short tons and thousand dollars)

Geographic region	Concrete aggregates (including concrete sand)		Plaster and gunite sands		Concrete products (blocks, bricks, pipe decorative, etc.)		Asphaltic concrete aggregates and other bituminous mixtures		Road base and coverings[1]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Northeast:										
New England	8,637	45,093	102	659	252	1,293	4,586	23,391	5,868	19,101
Middle Atlantic	20,582	109,737	512	3,094	1,329	6,528	6,023	31,909	12,029	44,891
Midwest:										
East North Central	44,284	148,126	581	2,275	3,024	10,889	21,062	75,453	43,042	142,104
West North Central	23,957	75,917	641	2,373	1,256	4,256	9,388	31,078	33,052	76,935
South:										
South Atlantic	27,251	111,461	1,145	5,180	2,438	8,739	3,394	12,721	4,029	14,046
East South Central	17,358	63,195	127	463	870	3,951	5,764	25,244	4,730	13,289
West South Central	39,042	154,015	648	3,134	525	1,825	4,308	19,628	5,098	16,429
West:										
Mountain	27,376	114,538	2,241	14,745	1,369	6,281	15,885	67,635	39,858	109,859
Pacific	57,441	261,883	3,665	19,486	977	5,770	26,291	132,672	46,355	167,666
Total[2]	265,930	1,083,966	9,662	51,411	12,040	49,532	96,702	419,731	194,062	604,319
Total[3 4]	241,248	1,083,966	8,765	51,411	10,923	49,532	87,727	419,731	176,050	604,319

	Fill		Snow and ice control		Railroad ballast		Other uses[5]		Total[2]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Northeast:										
New England	4,316	10,115	1,733	5,560	67	184	11,566	49,139	37,127	154,535
Middle Atlantic	4,745	12,510	1,835	7,238	75	265	20,077	88,844	67,209	305,016
Midwest:										
East North Central	21,184	47,743	1,416	3,592	171	831	54,164	186,278	188,929	617,291
West North Central	7,014	13,390	825	2,401	102	511	29,424	84,844	105,658	291,706
South:										
South Atlantic	10,402	20,045	W	W	W	W	21,957	92,912	70,661	265,300
East South Central	2,180	4,905	W	W	W	W	8,581	34,370	39,635	145,651
West South Central	9,922	16,643	W	W	W	W	19,481	66,957	79,096	278,891
West:										
Mountain	10,868	21,153	482	1,768	251	1,390	47,291	169,551	145,620	506,920
Pacific	18,092	45,224	550	2,209	309	1,531	31,634	139,533	185,315	775,973
Total[2]	88,721	191,727	6,955	23,225	1,002	4,944	244,178	912,427	[6]919,300	[6]3,341,300
Total[3 4]	80,486	191,727	6,309	23,225	909	4,944	221,515	912,427	833,975	3,341,300

W Withheld to avoid disclosing company proprietary data; included in "Total."

[1]Includes sand and gravel used in road and other stabilization (cement and lime).

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

[3]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[4]Total quantity and total value in thousand metric tons and thousand dollars.

[5]Includes sand and gravel used in filtration, and production reported without a breakdown by use and estimates for nonrespondents.

[6]Rounded.

TABLE 8

CONSTRUCTION SAND AND GRAVEL PRODUCTION IN THE UNITED STATES IN 1992, BY REGION AND SIZE OF OPERATION

Size range (short tons)	Northeast				Midwest			
	Number of operations	Percent of total	Quantity (thousand short tons)	Percent of total	Number of operations	Percent of total	Quantity (thousand short tons)	Percent of total
Less than 25,000	444	40.3	4,163	4.0	620	28.6	6,995	2.4
25,000 to 49,999	169	15.3	6,158	5.9	362	16.7	13,472	4.6
50,000 to 99,999	179	16.2	13,071	12.5	397	18.3	28,325	9.6
100,000 to 199,999	164	14.9	23,406	22.4	384	17.7	55,006	18.7
200,000 to 299,999	78	7.1	18,655	17.9	150	6.9	35,957	12.2
300,000 to 399,999	26	2.4	8,917	8.5	91	4.2	31,300	10.6
400,000 to 499,999	16	1.5	7,325	7.0	56	2.6	24,945	8.5
500,000 to 599,999	10	.9	5,534	5.3	32	1.5	17,292	5.9
600,000 to 699,999	6	.5	3,874	3.7	18	.8	11,508	3.9
700,000 to 799,999	4	.4	2,941	2.8	15	.7	11,073	3.8
800,000 to 899,999	1	W	W	W	8	W	W	W
900,000 to 999,999	1	.1	997	1.0	8	.4	7,440	2.5
1,000,000 to 1,499,999	2	W	W	W	17	.8	20,229	6.9
1,500,000 to 1,999,999	1	W	W	W	8	.4	14,083	4.8
2,000,000 to 2,499,999	2	W	W	W	2	W	W	W
2,500,000 to 4,999,999	—	—	—	—	—	—	—	—
5,000,000 and over	—	—	—	—	1	—	6,029	2.0
Total[1]	1,103	100.0	104,336	100.0	2,169	100.0	294,587	100.0
Total thousand metric tons[2]	1,103	XX	94,652	XX	2,169	XX	267,245	XX

See footnotes at end of table.

TABLE 8—Continued

CONSTRUCTION SAND AND GRAVEL PRODUCTION IN THE UNITED STATES IN 1992, BY REGION AND SIZE OF OPERATION

Size range (short tons)	South				West				U.S. total[1]			
	Number of operations	Percent of total	Quantity (thousand short tons)	Percent of total	Number of operations	Percent of total	Quantity (thousand short tons)	Percent of total	Number of operations	Percent of total	Quantity (thousand short tons)	Percent of total
Less than 25,000	283	25.8	3,020	1.6	450	27.6	4,358	1.3	1,800	30.0	18,536	2.0
25,000 to 49,999	141	12.9	5,173	2.7	225	13.8	8,221	2.5	897	15.0	33,025	3.6
50,000 to 99,999	187	17.1	13,370	7.1	279	17.1	20,001	6.0	1,042	17.4	74,767	8.1
100,000 to 199,999	181	16.5	26,029	13.7	241	14.8	35,363	10.7	970	16.2	139,805	15.2
200,000 to 299,999	105	9.6	25,282	13.3	134	8.2	32,954	9.9	467	7.8	112,848	12.3
300,000 to 399,999	63	5.8	21,239	11.2	80	5.0	27,489	8.3	261	4.4	88,946	9.7
400,000 to 499,999	42	3.8	18,769	9.9	60	3.7	26,661	8.0	174	2.9	77,700	8.4
500,000 to 599,999	20	1.8	10,876	5.7	35	2.1	18,842	5.7	97	1.6	52,544	5.7
600,000 to 699,999	21	1.9	13,357	7.1	18	1.1	11,695	3.5	63	1.1	40,433	4.4
700,000 to 799,999	20	1.8	14,884	7.9	15	.9	11,276	3.4	54	.9	40,174	4.4
800,000 to 899,999	12	1.1	10,104	5.3	20	1.2	16,803	5.1	41	.7	34,465	3.7
900,000 to 999,999	3	.3	2,891	1.5	22	1.3	20,678	6.2	34	.6	32,006	3.5
1,000,000 to 1,499,999	10	W	W	W	23	1.4	28,711	8.7	52	.9	62,692	6.8
1,500,000 to 1,999,999	5	W	W	W	15	.9	25,896	7.8	29	.5	49,724	5.4
2,000,000 to 2,499,999	1	.1	2,387	1.3	3	.2	6,731	2.0	8	.1	17,739	1.9
2,500,000 to 4,999,999	1	W	W	W	7	.4	22,874	6.9	8	.1	25,436	2.8
5,000,000 and over	—	—	—	—	1	.1	12,382	3.7	2	—	18,411	2.0
Total[1]	1,095	100.0	189,392	100.0	1,628	100.0	330,935	100.0	5,999	100.0	[3]919,300	100.0
Total thousand metric tons[2]	1,095	XX	171,814	XX	1,628	XX	300,219	XX	5,999	XX	833,975	XX

W Withheld to avoid disclosing company proprietary data; included with "Total." XX Not applicable.

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

[2]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[3]Rounded.

TABLE 9

NUMBER OF CONSTRUCTION SAND AND GRAVEL OPERATIONS AND PROCESSING PLANTS IN THE UNITED STATES IN 1992, BY GEOGRAPHIC REGION

Geographic region	Mining operations on land				Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable	Number plants or unspecified		
Northeast:						
New England	179	145	40	52	2	418
Middle Atlantic	227	309	46	66	37	685
Midwest:						
East North Central	406	345	86	152	91	1,080
West North Central	267	421	42	103	256	1,089
South:						
South Atlantic	127	47	8	101	137	420
East South Central	108	15	6	22	69	220
West South Central	175	58	20	102	100	455
West:						
Mountain	291	492	121	58	16	978
Pacific[1]	329	186	63	49	23	650
Total	2,109	2,018	432	705	731	5,995

[1]An undetermined number of operations leased from the Bureau of Land Management in Alaska are counted as one operation.

TABLE 10

NUMBER OF CONSTRUCTION SAND AND GRAVEL OPERATIONS AND PROCESSING PLANTS IN THE UNITED STATES IN 1992, BY STATE

State	Mining operations on land				Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable	Number plants or unspecified		
Alabama	33	7	—	12	23	75
Alaska[1]	6	4	—	1	2	13
Arizona	54	58	25	10	1	148
Arkansas	39	13	3	6	9	70
California	185	86	40	13	13	337
Colorado	59	107	48	13	8	235
Connecticut	28	15	9	4	2	58
Delaware	4	1	—	2	2	9
Florida	12	2	—	7	40	61
Georgia	10	—	—	6	28	44
Hawaii	—	—	—	—	—	—
Idaho	30	78	7	10	1	126
Illinois	54	33	17	14	31	149
Indiana	61	33	17	13	25	149
Iowa	55	45	3	22	39	164
Kansas	17	30	3	27	58	135
Kentucky	11	—	3	1	7	22
Louisiana	27	4	1	8	39	79
Maine	40	50	5	18	—	113
Maryland	25	7	5	25	3	65
Massachusetts	69	11	9	10	—	99
Michigan	108	118	15	72	10	323
Minnesota	92	148	18	22	4	284
Mississippi	36	2	2	8	27	75
Missouri	36	17	2	3	36	94
Montana	37	53	5	5	2	102
Nebraska	25	30	1	4	118	178
Nevada	21	54	9	11	1	96
New Hampshire	20	23	6	4	—	53
New Jersey	29	5	6	2	17	59
New Mexico	38	48	8	2	1	97
New York	127	264	31	52	9	483
North Carolina	31	18	1	36	37	123
North Dakota	18	58	8	1	—	85
Ohio	118	30	16	40	23	227
Oklahoma	25	14	2	24	32	97
Oregon	53	19	7	6	5	90
Pennsylvania	71	40	9	12	11	143
Rhode Island	8	—	6	1	—	15
South Carolina	14	8	1	13	13	49
South Dakota	24	93	7	24	1	149
Tennessee	28	6	1	1	12	48
Texas	84	27	14	64	20	209
Utah	39	58	14	5	—	116

See footnote at end of table.

TABLE 10—Continued

NUMBER OF CONSTRUCTION SAND AND GRAVEL OPERATIONS AND PROCESSING PLANTS IN THE UNITED STATES IN 1992, BY STATE

State	Mining operations on land				Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable	Number plants or unspecified		
Vermont	14	46	5	15	—	80
Virginia	24	11	1	12	13	61
Washington	85	77	16	29	3	210
West Virginia	7	—	—	—	1	8
Wisconsin	65	131	21	13	2	232
Wyoming	13	36	5	2	2	58
Total	2,109	2,018	432	705	731	5,995

[1]An undetermined number of operations leased from the Bureau of Land Management in Alaska are counted as one operation.

TABLE 11

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1992, BY REGION AND METHOD OF TRANSPORTATION

(Thousand short tons)

Geographic region	Truck	Rail	Water	Other	Not transported	Not specified	Total[1]
Northeast:							
New England	21,281	247	—	—	5,395	10,204	37,127
Middle Atlantic	36,063	9	2,602	69	6,662	21,805	67,209
Midwest:							
East North Central	86,979	332	4,791	792	28,350	67,685	188,929
West North Central	52,399	329	3,787	7	9,977	39,158	105,658
South:							
South Atlantic	37,546	841	3,025	66	5,789	23,394	70,661
East South Central	21,146	640	4,298	—	4,439	9,112	39,635
West South Central	41,799	3,336	101	61	12,950	20,850	79,096
West:							
Mountain	77,078	128	—	1,539	15,502	51,374	145,620
Pacific	93,527	1,112	6,987	848	50,059	32,782	185,315
Total[1]	467,800	7,000	25,600	3,400	139,100	276,400	919,300
Total thousand metric tons[2]	424,381	6,350	23,224	3,084	126,189	250,746	833,975

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

[2]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

TABLE 12

U.S. EXPORTS OF CONSTRUCTION SAND AND GRAVEL IN 1992, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	Sand		Gravel	
	Quantity	F.a.s. value[1]	Quantity	F.a.s. value[1]
North America:				
Bahamas	4	58	(2)	6
British Virgin Islands	2	5	11	77
Canada	328	3,021	507	2,255
Dominican Republic	9	108	—	—
Guadeloupe	1	25	5	82
Mexico	521	2,676	15	961
Netherlands Antilles	(2)	11	8	151
Nicaragua	18	307	—	—
Saint Lucia	—	—	22	28
Other[3]	2	162	7	146
Total[4]	885	6,373	575	3,705
South America:				
Argentina	3	556	(2)	5
Chile	14	372	—	—
Ecuador	2	232	—	—
Peru	7	423	—	—
Venezuela	11	1,176	1	37
Other	(2)	47	(2)	4
Total[4]	36	2,806	1	45
Europe:				
Belgium	2	232	(2)	9
Denmark	1	147	—	—
Germany	1	49	(2)	48
Russia	1	15	—	—
United Kingdom	(2)	86	1	39
Other[5]	1	367	1	48
Total[4]	6	895	2	144
Asia:				
Japan	4	472	22	960
Korea, Republic of	1	49	2	110
Singapore	1	266	1	97
Taiwan	2	63	2	137
Other[6]	1	148	(2)	18
Total[4]	9	998	26	1,323
Oceania:				
Australia	1	162	(2)	87
New Zealand	1	33	—	—
Other	(2)	6	(2)	25
Total[4]	3	202	1	112

See footnotes at end of table.

TABLE 12—Continued

U.S. EXPORTS OF CONSTRUCTION SAND AND GRAVEL IN 1992, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	Sand		Gravel	
	Quantity	F.a.s. value[1]	Quantity	F.a.s. value[1]
Middle East:				
Oman	15	250	—	—
Saudi Arabia	3	680	(2)	7
Other	(2)	18	1	24
Total[4]	17	948	1	30
Africa:				
Congo	1	150	—	—
Nigeria	1	147	—	—
Other[7]	1	79	(2)	3
Total[4]	3	377	(2)	3
Grand total[4]	959	12,599	606	5,364
Grand total[8 9]	870	12,599	550	5,364

[1]Value of material at U.S. port of export; based on transaction price, including all charges incurred in placing material alongside ship.
[2]Less than 1/2 unit.
[3]Includes Antigua and Barbuda, Martinique, Montserrat, Panama, Trinidad and Tobago, Turks and Caicos Islands, and others.
[4]Data may not add to totals shown because of independent rounding.
[5]Includes Ireland, Italy, Sweden, the former U.S.S.R., and others.
[6]Includes China, Indonesia, Thailand, and others.
[7]Includes Angola, Guinea, and others.
[8]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.
[9]Total quantity and total value in thousand metric tons and thousand dollars.

Source: Bureau of the Census.

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF CONSTRUCTION SAND AND GRAVEL, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1991		1992	
	Quantity	C.i.f. value[1]	Quantity	C.i.f. value[1]
Antigua and Barbuda	92	r1,178	47	912
Australia	29	1,773	14	909
Bahamas	269	1,075	216	411
Barbados	40	332	29	223
British Virgin Islands	4	85	4	93
Canada	955	6,543	1,036	7,018
Dominica	12	59	7	59
Germany	8	2,790	3	2,174
Japan	33	538	18	818
Mexico	5	611	45	1,038
Netherlands Antilles	1	9	5	35
Norway	13	591	5	299
Taiwan	(2)	15	(2)	4
United Kingdom	1	552	2	485
Other[3]	r3	r487	13	986
Total[4]	1,465	16,638	1,445	15,463
Total[5 6]	1,329	16,638	1,311	15,463

rRevised.

[1]Value 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.

[2]Less than 1/2 unit.

[3]Includes Austria, Bangladesh, Belgium, Brazil, China, Denmark, France, Hong Kong, India, Indonesia, Israel, Italy, Luxembourg, Malaysia, Mali, Papua New Guinea, Philippines, Singapore, Sweden, Tanzania, the former U.S.S.R., and the United Arab Emirates.

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

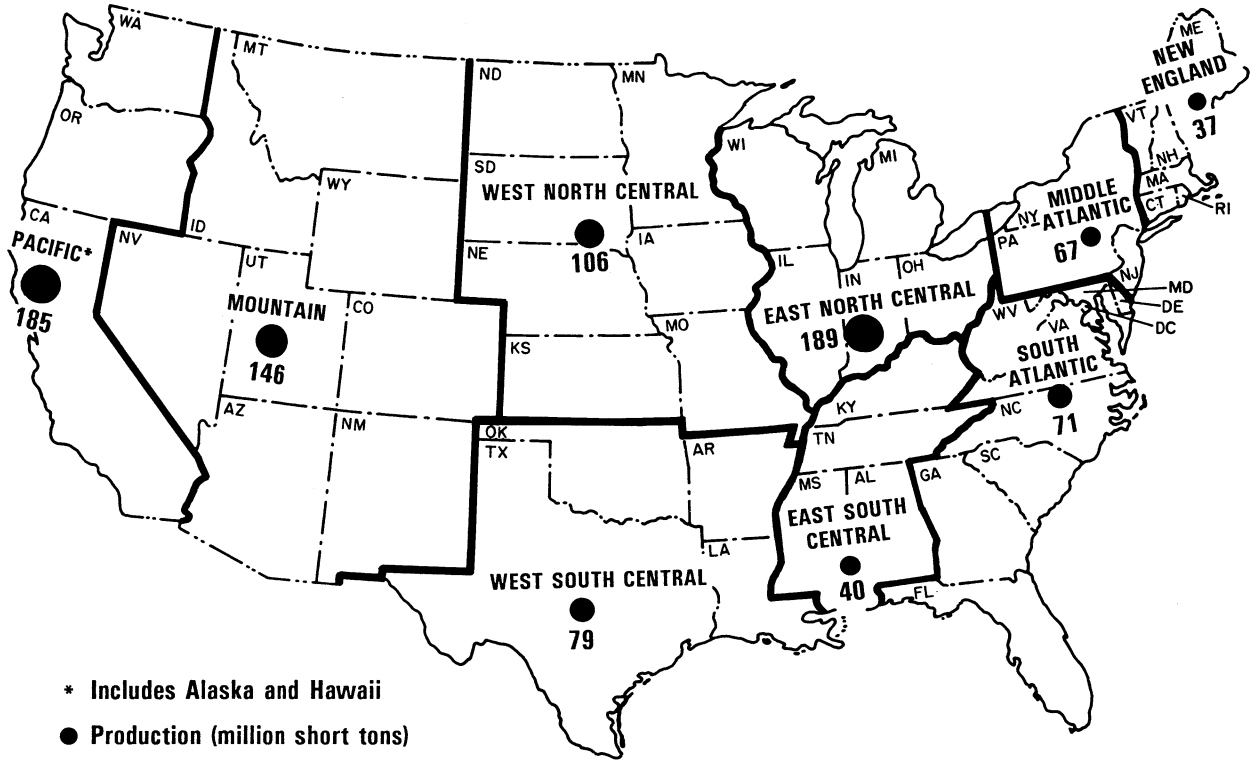
[5]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[6]Total quantity and total value in thousand metric tons and thousand dollars.

Source: Bureau of the Census.

FIGURE 1

PRODUCTION OF CONSTRUCTION SAND AND GRAVEL IN THE UNITED STATES IN 1992, BY GEOGRAPHIC REGION



INDUSTRIAL SAND AND GRAVEL

By Wallace P. Bolen

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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.

Complying with the provisions of the Metric Conversion Act of 1975 and the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418), beginning with this issue of the Annual Report for Industrial Sand and Gravel, the U.S. Bureau of Mines will publish its statistical information on industrial sand and gravel in U.S. customary units as well as in metric units. Initially, the reporting in dual units will be applied to the totals only, with increased emphasis on metric units in successive years.

DOMESTIC DATA COVERAGE

Production of industrial sand and gravel in 1992 increased to 27 million tons, about 5% more than production in 1991. Production increased in response to improved demand for silica for blasting, chemicals, fiberglass, filtration, flat glass, hydraulic fracturing (frac) sand, nonmetallurgical flux, silicon and ferrosilicon, and specialty glass.

Exports of silica sand and gravel decreased about 10% in quantity and 15% in value compared with those of 1991. Imports of industrial sand and gravel nearly doubled in quantity and the associated value increased 163%. Domestic apparent consumption of industrial sand and gravel in 1992 was 25.7 million short tons, an increase of about 7% compared to that of 1991.

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 159 industrial sand and gravel operations surveyed, 147 (92%) reported to the U.S. Bureau of Mines. Their combined production represented about 97% of the U.S. total published in table 1. The production of nonrespondents was estimated mostly using employment data. Of the 159 operations, 155 (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 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 "Annual Reports," reported a total of 317,000 tons of silica sand produced in 1884 in the United States, under "Glass Materials." In 1992, a total of 27 million tons of silica sand was produced in the United States for a variety of uses, of which 11.4 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 (SiO_2) 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% SiO_2 and a maximum of 0.1% aluminum oxide (Al_2O_3) and 0.02% iron oxide (Fe_2O_3). Third-quality flint glass could contain only 95% SiO_2 and as high as 4% Al_2O_3. Only in the low-quality amber glass was the content of Fe_2O_3 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 in a growing variety of 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 1992, 88 U.S. companies with 155 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.

Beyond the move toward larger operations, the industry has also developed into two groups: one, the larger national companies that produce many grades of silica, and the other, which consists mainly of smaller and local companies that produce industrial sand and gravel for limited uses and often include construction sand and gravel. Because companies that traditionally produced only construction sand and gravel may sometimes produce sand for industrial uses, the number of companies could change by upward of 10% annually.

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 also were 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 that is 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, which are 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 42% of 1992 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 been the largest factor for the sustained growth of industrial sand operations in Texas. California production remained large due to demands from local industry, particularly the glass container industry, of which the wine industry consumes a large portion, 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 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. Some producers employed flotation cells, with a variety of flocculants, to remove unwanted minerals and fines if they were not easily removed through mechanical scrubbing and separation, which most producers installed. 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. 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, postconsumer glass and scrap glass (cullet) that substitutes for batch mix (including industrial sand). Most glass recycling was restricted to container glass, with green and amber being consumed at a higher rate than flint, which 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 foundry sands and innovative ideas on recycling other materials should influence greater

recycling of silica products.

A report was published on the use of cullet in the glass industry. Cullet use reduces the demand for silica in glass production; therefore, cullet use and trends were an important indicator for silica consumption. This report considered various aspects of cullet use and handling and also looked at the savings in energy with cullet use as it varied by percent cullet in the batch mix. The highest savings were reportedly obtained when cullet levels were 80% to 90% of batch.[4] Glass recycling was put at 31% in the United States for 1991. This included glass used in glasphalt and those that were refilled and represents an increase from the 1990 rate of 28%.[5]

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, 1992 constant dollar prices of industrial sand rose steadily between 1973 and 1983. From 1985 to 1992, 1992 constant dollar prices fluctuated in the $15.75 to $16.75 range owing to decreased demand and tight competition in some markets. Prices are 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 SiO_2 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 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 placed 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 1992, the largest tonnage, 56% of all industrial sand, was shipped by truck because most users require a versatile and rapid delivery system. Substantial quantities, 38% 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

Legislation and Government Programs

On May 29, 1992, the Occupational Safety and Health Administration (OSHA) issued a final ruling that determined that nonasbestiform varieties of asbestos are far less dangerous than regular asbestos and therefore tremolite, anthophyllite, and actinolite should be exempted from regulation under the asbestos standard. OSHA stated that this will result in $73.6 million in annual savings and affect 970 ceramic and paint manufacturers and 25,000 aggregate-user operations.

The U.S. Bureau of Mines publication "Crystalline Silica Primer" was released to the general public to help in understanding the crystalline silica issue. This publication explains the nature of crystalline silica, where it is found and used, and how it is qualitatively and quantitatively identified.

Issues

Preliminary findings of a multimillion dollar study, conducted in Switzerland, involving 1,000 laboratory rats, indicate that fiberglass does not cause lung cancer.[6] An editorial that reviewed four studies on fiberglass and lung cancer also was published on this topic.[7]

Production

The Midwest (East and West North Central regions) continued to lead the Nation in production with about 41% of the 27 million tons produced in the United States, followed by the South (South Atlantic, East and West South Central regions) with about 35%, and the West (Pacific and Mountain regions) with 15%. *(See table 2 and figure 1.)*

Based on the 1990 census estimations on population, 1992 U.S. per capita industrial sand and gravel production was 0.11 ton. Per capita production by major geographic region was 0.19 ton in the Midwest, 0.11 ton in the South, 0.08 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 42% of the national total. Significant changes within the five major producing States included Michigan and New Jersey, where production decreased nearly 9% and 7%, respectively, and in Illinois, where production rose 6%. Production increased in the majority of States, but several States experienced a decrease in silica production. *(See tables 3, 4, and 5.)*

The U.S. Bureau of Mines canvassed 88 producers of industrial sand and gravel with 155 active operations. About 75% of the industrial sand and gravel was produced by 46 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., Construction Aggregates Corp., Simplot Industries Inc., Owens-Illinois Inc., and Manley Brothers of Indiana Inc. Their combined production, from 57 operations, represented 69% of the U.S. total.

Merger and acquisitions activity slowed in 1992 but operations moved in and out of the industrial sand and gravel sector as some companies (re)introduced silica for industrial uses while others removed operations from the industrial sand and gravel sector.

U.S. Silica's San Diego County, CA, operation did not produce or sell any industrial sand and gravel in 1992 after final closure in late 1991.

Fairmount Minerals has acquired 100% of the stock of United Western Supply Co. (Uni-West), one of the leading suppliers of silica sand to the U.S. foundry market with facilities in Denver, Portland, and Seattle.[8]

Little Hill Mines Inc., Pinal County, AZ, changed its name to Silica Mines Inc., in August.

L-Bar Products Inc., King County, WA, changed its name to Reserve Silica Corp.

The following producers were (re)introduced into the industrial sand and gravel population in 1992: Parr Industries Inc., Mobile County, AL; Savannah Abrasives Inc., Effingham County, GA; Irving Brother's Gravel Co. Inc., Grant County, IN; Northern Gravel Co., Muscatine County, IA; Winter Brothers Materials Co., St. Louis County, MO; Abrasives Inc., Grant County, ND; Schrader Sand and Gravel, Pike County, OH; Humble Sand Co. Inc., Ottawa County, OK; Taggart Sand Products, Providence County, RI; Nicks Silica Co., Madison County, TN; and Faulks Brothers Construction Inc., Waupaca County, WI.

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 27 million tons of industrial sand and gravel sold or used, 42% was consumed as glassmaking sand and 20% as foundry sand. Other important uses were abrasive sand (7%) and frac sand (6%). 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 3% of the U.S. total.

Specialty silicas were usually produced by means of chemical processing of natural silica or as a byproduct of other mineral or chemical processing. Although the U.S. Bureau of Mines did not specifically collect information for specialty silicas, their consumption does affect natural silica sales. Specialty silicas included, but are not limited to, fumed silica, fused silica, precipitated silica, sol-gel silica, and ultrahigh-purity silica. These silicas were used in abrasives, catalyst, electronics, food, health care, optics, paper, plastics, refractories, rubber, specialty coatings, and others. By 1992, specialty silicas sales had increased to more than $400 million and were expected to grow to $500 million by 1995.[9]

On the regional level, more than one-third of the glassmaking sand was produced in the South, followed by the Midwest and the West. Almost three-fourths of the foundry sand was produced in the Midwest. More than three-fourths of the hydraulic fracturing sand was produced in the Midwest, and the majority of the abrasive sand was produced in the South (62%). *(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 and Ricci Brothers Sand Co. Inc., both in Cumberland County, NJ, produced a major percentage of the abrasive blast sand in the region.

Midwest.—Unimin's plants in La Salle and Ogle Counties, IL; LeSueur and Scott Counties, MN; Jefferson County, MO; 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 plants in La Salle County, IL, were large producers for the glass, foundry, and frac markets and its St. Louis County, MO, operation was a large producer for the glass market. Construction Aggregates Corp., Ottawa County, MI; Nugent Sand Co. Inc., Muskegon County, MI; and Sargent Sand Co., Wexford County, MI, were all large producers for the foundry industry. Badger Mining, Jackson and Green Lake Counties, WI, was a major producer for the frac and foundry markets. Manley Brothers of Indiana, La Salle County, IL, was also a large producer for the glass and foundry markets. Major producers for the blast sand market included Oglebay Norton Co., Knox and Perry Counties, OH, and All Purpose Sand Co., St. Louis County, MO.

South.—Unimin and U.S. Silica were two of the largest producers of sand for the glass and foundry markets. Unimin's major plants were in Izard County, AR; Richmond County, NC; Pontotoc County, OK; Kershaw County, SC; Johnson County, TX; and Frederick County, VA. U.S. Silica's Bullock County, AL; Johnston County, OK; Lexington County, SC; Limestone County, TX; and Morgan County, WV, operations were the major contributors for these markets. Morie's Tuscaloosa County, AL; Marion County, GA; and Carrol County, TN, plants were large producers of foundry and glass sand. Cobb Industrial Corp., Red River Parish, LA; Foster-Dixiana Corp., Lexington County, SC; Huey Stockstill Inc., Pearl River County, MS; Mid-State Sand and Gravel Co., Allen Parish, LA; Pioneer Concrete of Texas Inc., Liberty County, TX; and Specialty Sand Co., Newton County, TX, were large producers of blasting sand. W.R. Bonsal and Co. and B.V. Hedrick Gravel and Sand Co., both in 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. WHIBCO in Kershaw County, SC, was an important producer of foundry sand. APAC Arkansas Inc., Crawford County, AR, and Short Mountain Silica Co., Hawkins County, TN, were important producers of glass sand. Oglebay Norton's Texas Mining Co., McCulloch County, TX, was also an important contributor of blast sand in the region.

West.—Corona Industrial Sand Co., Lane Mountain Silica Co., Owens-Illinois, Simplot Industries, and Unimin were the five largest producers of glass sand in the region, with major operations in Riverside County, CA; Stevens County, WA; Amador County, CA; Clark County, NV; and Contra Costa County, CA, respectively. Lane Mountain Silica, Stevens County, WA; Lone Star Industries Inc., Monterey County, CA; and P.W. Gillibrand Co., Ventura County, CA, were the major suppliers for the sandblasting industry in the region. Simplot Industries, Clark County, NV, also supplied a large portion of the foundry sand consumed. FMC Corp., Power County, ID; Rhone-Poulenc Basic Chemicals Co., Beaverhead County, ID; and Monsanto Industrial Chemicals Co., Caribou County, ID, each produced industrial gravel for phosphate rock processing.

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 1991; 38% was transported by rail, down from 40% in 1991; 3% by waterway; and 3% 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.

Prices

Compared with that of 1991, the average value, f.o.b. plant, of U.S. industrial sand and gravel increased 3% to $15.76 per ton. Average unit values for industrial sand and industrial gravel were $16.03 and $11.59 per ton, respectively. Nationally, ground industrial sand used as fillers for rubber, paint, and putty, etc., had the highest value per ton ($86.81), followed by ground silica for molding and core facings ($48.32), ground silica sand used in ceramics ($43.21), ground silica for scouring cleansers ($39.57), ground sand used for fiberglass ($29.64), and frac sand ($25.90).

Industrial sand and gravel prices generally increased as the industry rebounded from the very poor 1991 sales levels. Those end uses that sustained greater prices in 1992, compared to 1991, included blasting, ceramics, container glass, fiberglass, fillers, flat glass, foundry, refractory, scouring cleansers, and traction. Silica for chemicals, frac sand, roofing granules and fillers, silicon carbide, and specialty glass experienced a decrease in unit value.

The average value per ton of industrial sand and gravel was highest in the West ($17.51), followed by the Northeast ($16.67), the South ($16.01), and the Midwest ($14.72). Prices can vary greatly for similar grades of silica at different locations in the United States. For example, glass sand's average value per ton varied markedly, from $18.85 in the West to $10.05 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 1991, decreased 10% to 1,474,000 tons, and the value decreased 15% to $90.4 million. Of this, 66% went to Canada, 8% went to Mexico, 5% went to Brazil, 5% went to the Netherlands, 4% went to Japan, and the remainder went to numerous other countries throughout the world.

Imports.—Compared with those of 1991, imports for consumption of industrial sand nearly doubled to 181,000 tons valued at $2.5 million. Almost 75% of this was lower value silica from Belgium. Nearly 25% of the imports were from Australia. The remainder, sold for very high values per ton, was small amounts of specially prepared silica sand from Canada, France, Germany, Japan, Mexico, the Netherlands, Sweden, the United Kingdom, and Venezuela. *(See tables 7 and 8.)*

World Review

World production of industrial sand and gravel, based on information usually provided by foreign governments, was estimated to be 117.1 million short tons, a decrease of 5% from that of 1991. The United States was the leading producer followed by, in descending order, the Netherlands, Argentina, Germany, and Italy. 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, reliable information was difficult to obtain. In addition to those countries listed, many other countries were believed to have had some type of silica production and consumption. *(See table 9.)*

Current Research

Developments and research into new ways to produce specialty silicas and advanced ceramics and glasses, as well as improved technology and new uses of silica-based materials, illuminates areas that have potential to greatly impact consumption trends and amounts.

In previous years, this report has highlighted advanced composites and ceramics, and progress and research has continued in these areas. Glass fiber-reinforced polymer was increasingly being used in the auto industry in semistructural applications, high-gloss outer panels, and under bonnet parts.[10]

A new composite that has been developed offers twice the impact resistance of conventional fiber-reinforced plastics. The new material incorporates carbon and glass fibers in a crystallized matrix. If the glass fiber content reached 70%, the material was 20% lighter than nylon 6,6. The material was to be marketed as structural materials for engine rooms, industrial robot arms, and in sporting goods.[11]

Silicon carbide filler was introduced into a ceramic/metal composite to improve the wear of liners in slurry operation involved with mining. The new product has shown a tenfold increase over the wear life of current rubber or urethane liners. This development offers two benefits to the silica industry, decreased cost at the mine/mill, and possibly increased sales of silica.[12]

Silicon nitride was being evaluated as a potential material for engine valves. It was hoped that the use of advanced ceramics would lead to improved fuel efficiency and reduction of emissions for future auto engines. Weight savings had been reduced by at least 60% over the use of steel and spring force. Therefore, there were lower friction losses and lower consumption, exhaust, and noise emission.[13]

Owens-Corning Fiberglass was experimenting with glass-reinforced concrete as an alternative to traditional steel-reinforced concrete. It appeared that the glass-reinforced segment was holding up much better than the other test materials. This method of reinforcing could save millions of dollars in bridge repairs annually in the United States.[14]

Several advancements were reported on the processing of silica. These

advancements may offer opportunity for greater silica consumption. Geltech Inc. was creating a highly pure, porous silica by means of a sol-gel process. The sol-gel process produced pure silica by chemically reaching silicon alkoxide with water. This silica reportedly has good structural strength and can withstand high temperature.[15]

An exciting new route to silica compounds has been announced by researchers at the University of Michigan. Starting with ordinary silica sand, they have succeeded in creating a host of silica-based compounds that form the building blocks for a variety of new compounds.[16]

The technology and uses of glass and glass fibers continued to be researched and developed on many levels. Corning Inc. has introduced new vitrification technology for making durable, nonhazardous glass from municipal solid waste fly ash contaminated with toxic metals.[17]

Scientists at the Hebrew University in Jerusalem have succeeded in embedding virtually any chemical compound in glass. Applications that were considered possible included the use of glass as analyzing sensors for identifying chemicals, contaminants, and pollutants in air and water.[18] In a related report, researchers at the University of California-Los Angeles have developed a smart glass that changes colors in response to the presence of chemical compounds.[19]

Boeing Co. research has concluded that using hollow S-2 glass fibers can reduce the weight of composite parts by 15% to 20% over E-glass. Boeing tested the composites with the S-2 glass and those with E-glass and determined that although lighter, the S-2 glass composites retain most of the mechanical properties of E-glass. The fibers are manufactured by Owens-Corning Fiberglass Corp.[20]

Owens-Corning Corp. reported on a new product concept—fiberglass vacuum insulation. This was designed to meet new Federal requirements that appliances such as refrigerators and freezers be more energy efficient and be free of chlorofluorocarbons. The concept consisted of a vacuum panel of thermally crafted fiberglass inside a steel foil container. The design reportedly provided a very high performance insulation product with an R value per inch of 50, more than six times that of urethane foam insulations used today.[21]

Pilkington PLC of the United Kingdom has developed a technique for producing high-quality molten glass using an electrically powered furnace. Until now, glass produced using electric furnaces has contained microscopic bubbles. The savings provided by electric furnaces include easy installation, maintainability, and one-half the pollutant emission of a conventional furnace. The largest drawback was that the cost of electricity may be prohibitive.[22]

It has long been predicted that superthin glass coatings will eventually supplant traditional barrier materials in flexible packaging. Airco Coating Technologies said it will deliver its first commercial flexible film production system using SiO_x coatings.[23]

Semiconductor technology also impacts the silica industry via silicon chip technology and manufacture. Researchers from the Fraunhofer Institute for Solid State Physics, Munich, Germany, have caused chip material to emit light through a silicon-radiance effect. As a result of this work, the scientists are looking at possible subsequent applications for porous silicon in LED's, which would be much cheaper and easier to produce than other semiconducting materials such as gallium arsenide.[24]

The most promising hope for greater silica consumption remains fiber-optic replacement of copper wire and new installation. In 1992, fiber optics continued to garner much attention as a fast-paced growth market for glassmaking minerals. In 1991, shipments totaled $981 million and sales were predicted to be about $2.5 billion by 1996. Silica glass, which represents 95% of the market, will remain the most prevalent material used for optical fiber.[25] Another report concluded that fiber-optic undersea systems were showing growth at an average annual rate of 20%, to $12.5 billion by 1997.[26]

A pilot plant that would consume silica for the production of silicon metal was dedicated by Dow Corning in East Selkirk, Manitoba, Canada. This plant will apply a never before used technology for making silicon metal, used in the production of silicone products. The route uses silicon dioxide as a raw material rather than the silicon tetrachloride traditionally employed. Tests are expected to be finished by the end of 1993.[27]

OUTLOOK

Demand

The forecast range of total U.S. demand in the year 2000 was expected to be 27 to 37 million short tons for industrial sand and gravel. Probable demand was expected to be about 33 million tons. 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.

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, lighter safety glass was used in automobiles, and its use was growing. However, glass fibers and novel uses for glass may offer new avenues for silica sales for glass. For example, a paper was published discussing the use of glass as a host for hazardous waste. This topic has been the subject of ongoing discussion and research for several years and has been followed in this publication in recent years. This latest paper discusses glass as a host for heavy metal

oxides, particularly arsenic, barium, cadmium, chromium, lead, selenium, and silver.[28] Should this use become commonplace, consumption of glass sand may increase. 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.

Foundry Sand

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 sands as a greater percentage of cars sold in the United States will also be made in this country. Another important factor for the future consumption of virgin foundry sand was the recycling of used foundry sand. The level of recycling was not clear but it is thought to be increasing.

Other materials or minerals compete with silica as foundry sand but these other "sands" usually suffer a price disadvantage. The merits of carbon grain as a foundry sand were described recently by American Colloid Co. Although not a true mineral, this material does compete with silica sand. The carbon sand possesses a number of physical advantages that make it potentially highly suitable for foundry casting. However, this material is more than 10 times the price of silica sand and therefore its use would probably be limited.[29] Based on foundry activity, competing materials, and recycling, the probable forecast for foundry sands in the year 2000 was expected to be 7.5 million tons, and the range was expected to be 6 to 9 million tons.

Hydraulic Fracturing Sand

Frac sand was sold in greater volumes in 1992 compared to 1991, even though on June 12, 1992, the Baker-Hughes' rig count hit its lowest level since the tally was begun in the 1940's. Fortunately, the Baker-Hughes' count did finally sustain a year to year increase for the week ending October 16, 1992, and U.S. drilling permits surged 9.6% on a month to month basis in September 1992. Demand was expected to grow for this end use during the decade, partially due to strong exports of frac sand. Probable demand for hydraulic fracturing sand for the year 2000 was expected to be 2.1 million tons, with a range of 1.6 to 2.4 million tons.

Adequacy of Supply

Domestic production was expected to continue to meet more than 99% of demand through the year 2000. Imports, mostly from Australia, Canada, and Europe, were expected to remain minor.

The United States was the 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 for traditional uses.

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-tech 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 is 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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TABLE 1

SALIENT U.S. INDUSTRIAL SAND AND GRAVEL STATISTICS[1]

(Thousand short tons and thousand dollars)

	1988	1989	1990	1991	1992
Sold or used:					
Sand:					
Quantity	27,207	27,819	26,956	24,541	25,302
Value	$376,202	$395,807	$420,871	$377,578	$405,677
Gravel:					
Quantity	1,272	1,385	1,450	1,059	1,664
Value	$11,796	$14,388	$15,284	$12,899	$19,292
Total industrial:[2]					
Quantity	28,480	29,205	28,406	25,600	26,967
Quantity thousand metric tons[3]	25,837	26,494	25,769	23,224	24,464
Value	$388,000	$410,200	$436,200	$390,477	$424,968
Exports:					
Quantity	1,060	2,060	1,155	1,637	1,474
Quantity thousand metric tons[3]	962	1,869	1,048	1,485	1,337
Value	$30,843	$78,308	$83,826	$106,606	$90,403
Imports for consumption:					
Quantity	43	35	73	91	181
Quantity thousand metric tons[3]	39	32	66	83	164
Value	$1,918	$2,057	$3,148	$932	$2,454

[1]Puerto Rico excluded from all industrial sand and gravel statistics.
[2]Data may not add to totals shown because of independent rounding.
[3]One 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.

TABLE 2

INDUSTRIAL SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY GEOGRAPHIC REGION

Geographic region	1991				1992			
	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	148	1	$4,107	1	134	1	$3,912	1
Middle Atlantic	2,322	r9	34,294	9	2,182	8	34,669	9
Midwest:								
East North Central	8,869	35	120,355	31	9,205	34	128,610	30
West North Central	1,679	7	28,867	7	1,906	7	34,981	8
South:								
South Atlantic	3,986	16	64,837	17	4,075	15	69,263	16
East South Central	1,261	5	15,921	4	1,445	5	17,732	4
West South Central	3,768	15	59,021	15	3,968	15	64,878	15
West:								
Mountain	1,220	5	16,828	4	1,717	6	23,690	6
Pacific	2,348	9	46,247	12	2,334	9	47,234	11
Total[1]	25,600	100	390,477	100	26,967	100	424,968	100
Total thousand metric tons[2]	23,224	XX	XX	XX	24,464	XX	XX	XX

rRevised. XX Not applicable.
[1]Data may not add to totals shown because of independent rounding.
[2]One 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.

TABLE 3

INDUSTRIAL SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1991		1992	
	Quantity	Value	Quantity	Value
Alabama	531	6,133	667	6,768
Arizona	W	W	W	W
Arkansas	746	7,738	868	10,458
California	2,104	41,690	2,096	42,396
Colorado	W	W	W	W
Connecticut	W	W	W	W
Florida	551	5,989	477	5,167
Georgia	W	W	588	8,783
Idaho	W	W	802	9,214
Illinois	4,146	57,210	4,410	56,741
Indiana	W	W	118	1,278
Iowa	—	—	W	W
Kansas	W	W	W	W
Kentucky	W	W	—	—
Louisiana	W	W	519	9,267
Maryland	W	W	W	W
Massachusetts	30	401	9	151
Michigan	2,093	18,464	1,897	19,506
Minnesota	W	W	W	W
Mississippi	W	W	W	W
Missouri	W	W	710	10,931
Montana	W	W	W	W
Nebraska	W	W	W	W
Nevada	546	W	531	W
New Jersey	1,634	23,738	1,518	24,727
New York	W	W	W	W
North Carolina	1,174	15,565	1,199	17,533
North Dakota	—	—	W	W
Ohio	1,294	23,462	1,406	26,445
Oklahoma	1,241	20,918	1,071	19,011
Pennsylvania	W	W	W	W
Rhode Island	W	W	W	W
South Carolina	822	16,348	849	17,316
Tennessee	W	W	677	10,665
Texas	1,557	27,002	1,511	26,141
Virginia	W	W	W	W
Washington	W	W	W	W
West Virginia	W	W	W	W
Wisconsin	W	W	1,374	24,639
Other	7,132	125,820	3,671	77,831
Total[1]	25,600	390,477	26,967	424,968
Total thousand metric tons[2]	23,224	XX	24,464	XX

W Withheld to avoid disclosing company proprietary data; included with "Other." XX Not applicable.

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

[2]One 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.

TABLE 4

INDUSTRIAL SAND AND GRAVEL PRODUCTION IN THE UNITED STATES IN 1992, 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	34	22	397	1
25,000 to 49,999	16	10	655	2
50,000 to 99,999	34	22	2,395	9
100,000 to 199,999	25	16	3,440	13
200,000 to 299,999	12	8	2,976	11
300,000 to 399,999	12	8	4,181	16
400,000 to 499,999	10	6	4,484	17
500,000 to 599,999	6	4	3,280	12
600,000 to 699,999	2	1	1,301	5
700,000 and over	4	3	3,859	14
Total	155	100	[1]26,967	100

[1]Data do not add to total shown because of independent rounding.

TABLE 5

NUMBER OF INDUSTRIAL SAND AND GRAVEL OPERATIONS AND PROCESSING PLANTS IN THE UNITED STATES IN 1992, 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	3	—	1	—	—	4
Middle Atlantic	7	—	4	1	3	15
Midwest:						
East North Central	32	2	1	1	4	40
West North Central	6	1	1	—	5	13
South:						
South Atlantic	17	—	—	3	6	26
East South Central	12	—	—	—	3	15
West South Central	9	—	—	2	11	22
West:						
Mountain	7	2	1	—	—	10
Pacific	7	—	—	1	2	10
Total	100	5	8	8	34	155

TABLE 6

INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1992, 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	1,093	$15,885	$14.53	1,831	$15,914	$8.69	2,356	$31,980	$13.57	1,447	$28,038	$19.38	6,727	$91,817	$13.65
Flat (plate and window)	W	W	16.30	903	9,357	10.36	1,518	19,660	12.95	W	W	16.99	2,787	35,211	12.63
Specialty	W	W	17.11	394	5,472	13.89	278	4,600	16.10	W	W	25.09	899	14,221	15.82
Fiberglass (unground)	W	W	13.06	331	3,548	10.72	68	1,002	14.74	W	W	17.86	488	5,872	12.03
Fiberglass (ground)	—	—	—	W	W	15.09	324	12,043	37.17	W	W	15.17	492	14,584	29.64
Foundry:															
Molding and core	350	5,567	15.91	3,951	44,505	11.26	1,090	12,002	11.01	91	1,706	18.75	5,482	63,780	11.63
Molding and core facing (ground)	W	W	7.00	W	W	49.74	W	W	32.89	—	—	—	28	1,353	48.32
Refractory	W	W	10.50	47	761	16.19	36	706	19.61	W	W	23.00	86	1,511	17.57
Metallurgical:															
Silicon carbide	—	—	—	W	W	6.30	W	W	15.00	—	—	—	70	451	6.44
Flux for metal smelting	—	—	—	W	W	9.36	W	W	10.00	2	34	17.00	19	197	10.37
Abrasives:															
Blasting	189	4,482	23.71	301	8,075	26.83	1,098	19,781	18.02	179	4,399	24.58	1,767	36,737	20.79
Scouring cleansers (ground)	W	W	29.00	W	W	39.59	W	W	62.91	—	—	—	77	3,047	39.57
Sawing and sanding	W	W	19.00	—	—	—	W	W	14.94	—	—	—	W	W	19.00
Chemicals (ground and unground)	83	2,012	24.24	272	2,811	10.33	310	5,714	18.43	66	1,227	18.59	731	11,764	16.09
Fillers (ground):															
Rubber, paints, putty, etc.	W	W	19.59	53	3,800	71.70	48	6,847	142.65	W	W	20.00	129	11,078	86.81
Silica flour	—	—	—	W	W	38.38	W	W	26.55	W	W	33.00	92	3,356	36.48
Ceramic (ground):															
Pottery, brick, tile, etc.	W	W	75.00	74	3,150	42.57	85	3,718	43.74	—	—	—	159	6,870	43.21

See footnotes at end of table.

TABLE 6—Continued

INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1992, 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															
Filtration	114	2,108	18.49	168	4,166	24.80	185	2,577	13.93	18	665	36.94	485	9,516	19.62
Traction (engine)	41	352	8.59	117	1,297	11.09	55	646	11.75	23	386	16.78	235	2,681	11.41
Roofing granules and fillers	29	512	17.66	199	2,125	10.68	196	2,703	13.79	30	526	17.53	454	5,866	12.92
Hydraulic fracturing	—	—	—	1,203	32,469	26.99	367	8,146	22.20	13	354	27.23	1,582	40,969	25.90
Other uses, specified	403	7,599	18.86	1,033	22,973	22.24	594	8,536	14.36	844	14,908	17.66	XX	XX	XX
Other uses, unspecified[2]	—	—	—	W	W	13.06	304	3,429	11.28	500	10,404	20.81	913	15,255	16.71
Total[1] or average	2,302	38,517	16.73	10,877	160,423	14.75	8,913	144,090	16.17	3,210	62,648	19.52	25,302	405,677	16.03
Gravel:															
Metallurgical:															
Silicon, ferrosilicon	—	—	—	W	W	12.02	W	W	13.44	—	—	—	598	7,994	13.28
Filtration	—	—	—	W	W	25.00	W	W	40.42	—	—	—	22	735	33.41
Nonmetallurgical flux	—	—	—	—	—	—	—	—	—	773	7,597	9.83	773	7,597	9.83
Other uses, specified	13	63	4.85	234	3,169	13.54	576	7,783	4.53	68	679	9.99	271	3,016	11.13
Total[1] or average	13	63	4.85	234	3,169	13.54	576	7,783	13.51	841	8,276	9.84	1,664	19,292	11.59
Grand total[1] or average	2,315	38,581	16.67	11,111	163,591	14.72	9,489	151,873	16.01	4,051	70,924	17.51	26,967	424,968	15.76
Grand total thousand metric tons[3]	2,100	XX	XX	10,079	XX	XX	8,608	XX	XX	3,675	XX	XX	24,464	XX	XX

W Withheld to avoid disclosing company proprietary data; included with "Other uses, specified"; also included in "U.S. total" by use. XX Not applicable.

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

[2]Mostly estimated total production plus other uses (small quantities) as reported by producers.

[3]One 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.

TABLE 7

U.S. EXPORTS OF INDUSTRIAL SAND AND GRAVEL, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1991		1992	
	Quantity	F.a.s. value[1]	Quantity	F.a.s. value[1]
North America:				
Bermuda	(2)	6	22	208
Canada	1,199	13,515	975	12,368
Mexico	214	4,086	112	5,826
Panama	11	291	19	759
Other	18	r675	3	445
Total[3]	1,443	18,571	1,131	19,606
South America:				
Argentina	4	425	4	461
Brazil	21	394	68	300
Chile	4	236	(2)	7
Colombia	(2)	57	(2)	92
Ecuador	(2)	52	(2)	190
Peru	7	278	5	283
Venezuela	2	437	2	194
Other	r(2)	r25	1	330
Total[3]	39	1,904	80	1,568
Europe:				
Belgium	9	1,291	11	1,182
Denmark	(2)	153	9	1,086
Finland	5	104	4	94
France	1	103	2	514
Germany	10	3,145	15	2,804
Italy	5	600	6	599
Netherlands	10	5,556	78	2,367
United Kingdom	6	999	4	885
Other	23	r906	2	816
Total[3]	72	12,857	131	10,347
Asia:				
Indonesia	2	325	5	208
Japan	54	65,114	66	48,955
Korea, Republic of	10	2,520	16	3,109
Singapore	6	2,768	3	3,144
Taiwan	7	1,179	13	1,775
Other	1	366	25	709
Total[3]	80	72,273	128	57,900
Middle East and Africa:				
Ghana	(2)	12	(2)	10
Israel	(2)	121	(2)	87
Saudi Arabia	1	275	(2)	36
South Africa, Republic of	(2)	70	(2)	140
Other	(2)	38	1	41
Total[3]	1	517	1	314

See footnotes at end of table.

TABLE 7—Continued

U.S. EXPORTS OF INDUSTRIAL SAND AND GRAVEL, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1991		1992	
	Quantity	F.a.s. value[1]	Quantity	F.a.s. value[1]
Oceania:				
Australia	2	445	2	623
Other	(2)	39	(2)	45
Total[3]	2	484	2	668
Grand total[3]	1,637	106,606	1,474	90,403
Grand total thousand metric tons[4]	1,485	XX	1,337	XX

[r]Revised. XX Not applicable.
[1]Value of material at U.S. port of export; based on transaction price, including all charges incurred in placing material alongside ship.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.
[4]One 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.

Source: Bureau of the Census.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF INDUSTRIAL SAND, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1991		1992	
	Quantity	C.i.f. value[1]	Quantity	C.i.f. value[1]
Australia	(2)	161	45	1,758
Belgium	(2)	14	135	52
Canada	1	61	1	57
France	(2)	21	(2)	6
Germany	90	629	(2)	180
Japan	(2)	11	(2)	195
Mexico	(2)	7	(2)	19
Netherlands	—	—	(2)	3
Sweden	(2)	8	(2)	144
United Kingdom	(2)	21	(2)	31
Venezuela	—	—	(2)	10
Total[3]	91	932	181	2,454
Total thousand metric tons[4]	83	XX	164	XX

XX Not applicable.
[1]Value 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.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.
[4]One 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.

Source: Bureau of the Census.

TABLE 9

INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1988	1989	1990	1991	1992[e]
Argentina	10,645	r9,634	e9,900	r e9,900	9,370
Australia[e]	3,2170	2,210	2,210	r2,210	2,210
Austria	833	903	902	r2,304	2,205
Bosnia and Herzegovina[4]	—	—	—	—	165
Belgium	r2,693	r2,778	r2,818	r2,815	2,728
Brazil	r4,495	4,520	4,100	r3,431	3,858
Canada	3,094	r2,571	r2,294	r1,653	1,642
Chile[e]	330	330	330	330	330
Croatia[4]	—	—	—	—	330
Cuba[e]	610	610	550	550	500
Denmark	2	e2	3	e3	3
Ecuador[e]	55	3113	r55	r46	50
Egypt[5]	r39	r45	r559	e550	550
Finland	300	r302	e310	r222	220
France[e]	8,250	8,250	8,250	3,860	3,860
Germany:					
Western states	r6,753	r7,006	r7,144	—	—
Eastern states	1,312	1,318	e830	—	—
Total	8,065	8,324	7,974	8,443	8,800
Greece[e]	42	367	65	60	55
Guatemala	35	e34	e33	r19	22
Hungary	714	715	599	e570	550
Iceland	5	5	e5	5	5
India	3,239	2,782	r2,932	e2,980	2,980
Indonesia	464	333	182	r473	440
Iran[6]	914	907	r e959	r918	915
Ireland[e]	37	8	8	8	8
Israel	66	72	93	r65	65
Italy[e]	4,740	4,960	4,740	4,630	4,410
Jamaica	14	17	18	r17	17
Japan	4,630	4,826	4,884	r4,788	4,255
Kenya	r e8	12	r14	e14	14
Korea, Republic of	2	1	2	r1	2
Macedonia[4]	—	—	—	—	165
Malaysia	462	498	757	735	700
Mexico	r1,021	r1,137	1,431	r1,467	1,310
Namibia[e]	r—	r—	r—	r—	—
Netherlands	28,659	28,271	27,709	e27,560	22,046
New Zealand	61	113	r111	r109	110
Norway[e]	880	880	880	880	880
Pakistan	148	200	r144	r167	165
Paraguay	2,123	2,137	r e2,200	e2,200	2,200
Peru[e]	3174	83	110	r165	165
Philippines	281	r204	322	r619	550
Portugal[e]	6	6	6	6	6
Serbia and Montenegro[4]	—	—	—	—	550
Slovenia[4]	—	—	—	—	440

See footnotes at end of table.

TABLE 9—Continued

INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1988	1989	1990	1991	1992[e]
South Africa, Republic of	2,216	2,405	2,189	2,280	[3]1,929
Spain[e]	2,668	2,205	2,400	2,205	2,400
Sweden[e]	770	770	770	770	770
Tanzania	13	14	7	[r]5	5
Thailand	267	326	465	[r]174	187
Turkey	483	546	[e]600	[r e]560	550
United Kingdom	4,784	4,828	4,555	[e]4,410	3,970
United States (sold or used by producers)	28,480	29,205	28,406	25,600	[3]26,967
Venezuela	502	417	488	[r]378	440
Yugoslavia[7]	2,231	3,465	2,698	[e]2,315	—
Zimbabwe	61	68	69	[r]77	77
Total	[r]132,749	[r]133,108	[r]131,105	[r]123,545	117,141
Total thousand metric tons	120,444	120,766	118,996	112,102	81,844

[e]Estimated. [r]Revised.

[1]Table includes data available through June 15, 1993.

[2]In addition to the countries listed, Angola, Antigua and Barbuda, The Bahamas, China, Israel, New Caledonia, Panama, and the former U.S.S.R., among others, produce industrial sand, but current, available information is not adequate to formulate estimates of production levels.

[3]Reported figure.

[4]Formerly part of Yugoslavia; data were not reported separately until 1992.

[5]Fiscal years beginning July 1 of that stated.

[6]Fiscal years beginning Mar. 21 of that stated.

[7]Dissolved in Apr. 1992.

FIGURE 1

PRODUCTION OF INDUSTRIAL SAND AND GRAVEL IN THE UNITED STATES IN 1992, BY GEOGRAPHIC REGION

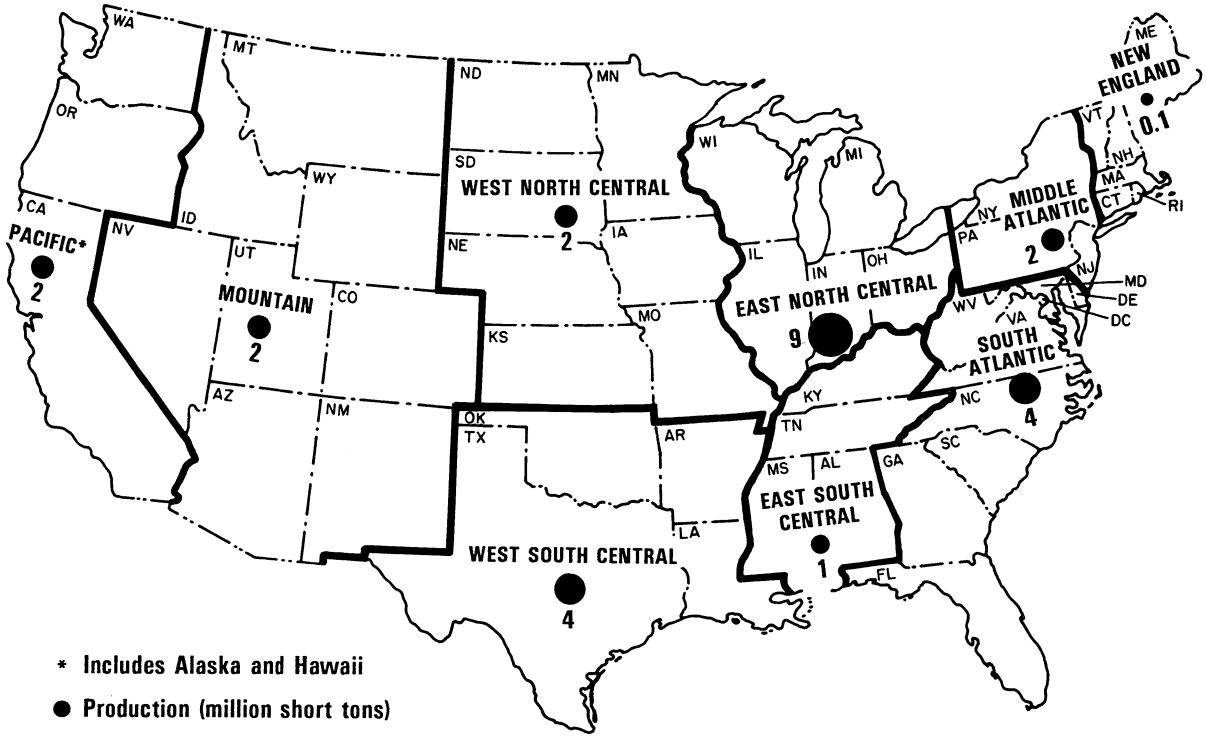
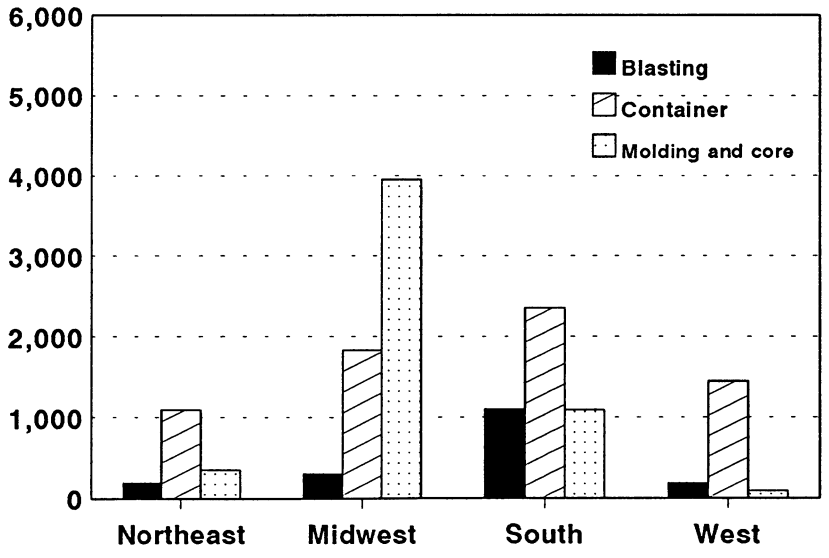


FIGURE 2

SAND USED IN SELECTED END USES, 1992

(Thousand short tons)



SILICON

By Larry D. Cunningham

Mr. Cunningham, a physical scientist with 13 years of 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. Lisa Harley, 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 (SiO_2) as quartz or quartzite is used to produce silicon-base products for the iron, steel, aluminum, and chemical industries.

The average annual dealer import price for silicon metal and ferrosilicon declined from that of the previous year. Based on contained silicon, overall domestic production increased to about 370,000 metric tons, and consumption of silicon increased to about 535,000 tons.

Overall U.S. trade volume of silicon exports was up by 10%, while overall trade volume of silicon imports increased by 26%. Domestic ferrosilicon producers filed a number of cases against importing nations alleging injury to the domestic industry.

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 cover 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 1992 was either 50%- or 75%-grade material, the majority being 50%-grade. The domestic silicon industry in 1992 supplied about 60% of all ferrosilicon products. Of the miscellaneous silicon alloys consumed in the United States, magnesium ferrosilicon is the most significant. Almost all ferrosilicon products are consumed by the iron and steel industry.

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 industry.

The first crystalline silicon was made in 1854. Comprehensive investigations of the effects of silicon in steel stimulated a

great demand for silicon in the steel industry in the 1880's, and with the development of the electric furnace in the late 1800's came expanded production of ferrosilicon. By 1949, the first silicon pure enough for use in transistors and other semiconductor devices was produced. Beginning in 1951, commercial production of high-purity silicon gave impetus to the rapidly expanding electronics industry.

Polycrystalline silicon (ultrapure, 99.9%) was a product largely confined to research until 1956, when its use in manufacturing components for commercial applications was estimated to have exceeded that used for research. By 1958, an estimated 20,412 kilograms of high-purity silicon valued at $16 million was consumed by the electronics industry for the manufacture of diodes, rectifiers, and transistors.

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.

Recovery of silicon from secondary sources is not normally practiced. The only secondary possibility is recovery from scrap metal. However, any value of contained silicon would be incidental to the value of the primary metal. In 1992, the average price for ferrosilicon was about $0.36 per pound and the average price for silicon metal was about $0.60 per pound. For the future, recycling of silicon in the form of ferrosilicon and silicon metal is expected to be insignificant.

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.

Economic Factors

Production of silicon metal and silicon alloys is extremely power intensive, requiring a power input of approximately 8,000 to 12,000 kilowatt-hours per ton of silicon content.

The location of ferrosilicon and silicon metal smelters is normally determined by balancing marketing costs against processing costs. Consequently, on a worldwide basis, smelting plants are near iron and steel industries or trade routes serving them, where cheap fossil fuel or electric energy is available or where a combination of these factors exists. The availability of hydroelectric power in large quantities at competitive prices, the lack of a sizable steel industry, and the presence of deep natural and ice-free harbors contributed to Norway becoming the largest exporter of ferrosilicon in the world. The high cost of electric power, proximity to world trade routes, and the demands of an established iron and steel industry have made Germany, Japan, and the United Kingdom three of the world's largest importers of silicon metal and ferrosilicon. During the 1980's, Brazil established itself as a major producer of silicon ferroalloys and silicon metal, joining countries such as Canada, Iceland, and Norway that have low power costs. In contrast, high power costs have forced Japanese ferroalloy producers to cease production of silicon metal and drastically curtail silicon ferroalloy production.

By 1960, consumption of high-purity silicon by the electronics industry was more than 31,751 kilograms. However, the market was becoming saturated with material resulting from increased output by new plants and the expanded production from older ones. Prices were in the range of $150 to $330 per pound compared with an average price of $330 per pound for metal consumed in 1958. By the mid-1960's, improvements in silicon devices and the increased use of integrated circuits in the computer and aerospace industries had contributed to an accelerated consumption of high-purity silicon.

Demand for metallurgical-grade silicon alloys and metal is determined by the level of activity in the steel, ferrous foundry, aluminum, and chemical industries and is little affected in the short term by prices for these materials. As a result, prices tend to vary widely with changes in demand and supply.

From the period 1955 to 1969, the

price of silicon alloys and metallurgical-grade metal remained stable. During this 15-year period, the domestic producer price fluctuated between $0.12 and $0.145 per pound for the 50%-grade ferrosilicon and between $0.181 and $0.219 per pound for metal.

Prices began to rise in the early 1970's owing to higher costs of scrap iron, metallurgical-grade coal, electric power, and the cost of newly installed pollution control devices to comply with local and Federal Government standards, which became effective in 1975. Responding to increased demand, rising inflation, and higher energy costs, prices rose steadily from 1977-81.

By the end of 1988, domestic producers reportedly were operating at close to capacity. However, the record-high prices of 1988 had declined significantly by yearend 1990. The sudden decline in prices was mainly caused by the oversupply of material resulting from the reactivation of idle capacity; the development of new capacity in South America; and the escalation of low-cost imports from China, South America, and the U.S.S.R. Consequently, production cutbacks were scheduled by several domestic producers as global production outpaced demand, resulting in a continued soft world market.

Principal elements in the cost of silicon and ferrosilicon production are (1) delivered costs of the ore; (2) energy cost; (3) cost of reductant coke or low ash coal; (4) cost of iron in the form of steel scrap, if required; and (5) labor. The cost of all these elements, and particularly the cost of energy, has increased rapidly since 1970. In addition, new capital costs for pollution control equipment were added.

ANNUAL REVIEW

Legislative and Government Programs

The U.S. International Trade Commission (ITC) in late June announced that it had made affirmative determinations in the preliminary countervailing duty investigation on imports of ferrosilicon from Venezuela and in the preliminary antidumping investigations on imports of ferrosilicon from Argentina, China, Kazakhstan, the Russia Federation, Ukraine, and Venezuela. The ITC found a reasonable indication that a U.S. industry is either materially injured or threatened with material injury because of imports of ferrosilicon from Venezuela that are allegedly subsidized. Similar findings were made on imports of ferrosilicon from Argentina, China, Kazakhstan, Russia, Ukraine, and Venezuela that are allegedly sold in the United States at less than fair value.

The investigations were instituted in response to petitions filed on May 22, 1992, by domestic producers AIMCOR, American Alloys Inc., and Globe Metallurgical Inc.; former producers Alabama Silicon Inc. and Silicon Metaltech Inc.; and union locals of the United Autoworkers of America, the United Steelworkers of America, and the Oil, Chemical and Atomic Workers.

The Department of Commerce (DOC), which conducts its own investigations, subsequently began its preliminary countervailing duty and antidumping investigations in these cases. The DOC in mid-August announced that it had made a preliminary affirmative countervailing duty determination on ferrosilicon from Venezuela. The Department made a preliminary finding that benefits, which constitute bounties or grants, are being provided to Venezuelan manufacturers, producers, or exporters of the subject merchandise. DOC directed the U.S. Customs Service to suspend liquidation (defer final import processing) of all entries of ferrosilicon from Venezuela, entered or withdrawn from warehouse, for consumption effective August 25, 1992. Customs required a cash deposit or bond at 4.97% ad valorem for entries of the merchandise.

The DOC in late October announced that it had preliminarily determined that ferrosilicon from China is being, or is likely to be, sold in the United States at less than fair value. The DOC directed Customs to suspend liquidation of all entries of ferrosilicon from China, that are entered or withdrawn from warehouse, for consumption effective November 5, 1992. Customs required a cash deposit or bond equal to the estimated margin amount, 137.73% (all manufacturers/producers/exporters), by which the foreign market value of the product exceeds the U.S. price.

Additionally, the DOC in late December announced that it had preliminarily determined that ferrosilicon from Kazakhstan, Russia, Ukraine, and Venezuela is being, or is likely to be, dumped in the United States. The DOC directed Customs to defer final import processing of all entries of ferrosilicon from Kazakhstan, Russia, and Ukraine for consumption effective September 30, 1992. Customs required a cash deposit or bond equal to the estimated margin amount of 104.18%. Suspension of liquidation of all entries of ferrosilicon from Venezuela was effective December 29, 1992. The estimated margin amount for Venezuela was 1.49%. At the same time, the DOC announced that it had preliminarily determined that ferrosilicon from Argentina is not being, nor is likely to be, sold in the United States at less than fair value.

The DOC and ITC will continue to conduct countervailing duty and antidumping investigations in these cases.

The DOC in October initiated a formal scope inquiry into the outstanding antidumping duty orders on silicon metal from Argentina, Brazil, and China, which have identical scopes, or specified ranges of silicon content of material covered under the rulings. In 1991, the DOC and ITC had determined that imports of silicon metal, containing between 96% and 99.99% silicon by weight, from these countries were sold at less than fair value in the United States and caused material harm to the domestic industry. The DOC assessed the dumping duty for China at 139.49% and that for Argentina at 8.65%. The duty for Brazil was assessed against individual producers over a range of 87.79% to 93.2%. The inquiry was in response to a request in March by petitioners in the original investigation that DOC determine that material containing a lower silicon content,

between 89% and 96% silicon by weight, having a relatively high aluminum content, is covered by the antidumping duty order in effect for silicon metal imports from China.

In Proclamation 6465 of August 25, 1992, the President proclaimed that it is appropriate to designate as preferred trading partners each of the former republics of Yugoslavia, other than Serbia and Montenegro, under the General System of Preferences.

During the year, the United States officially entered into agreements on trade relations with 5 of the 12 independent states that succeeded the former U.S.S.R. Most-favored-nation (MFN) status was extended to the Republic of Armenia, April 7; the Russian Federation, June 17; Ukraine, June 23; the Republic of Moldova, July 2; and the Republic of Kyrgyzstan, August 21. In addition, the United States officially extended nondiscriminatory treatment to products of the Republic of Albania effective November 2. MFN status means significantly lower U.S. import duties for silicon products from these states. MFN tariffs for silicon products range from duty free to 9% ad valorem, whereas non-MFN tariffs for silicon products range from $0.044 per kilogram of contained silicon to 45% ad valorem.

Silicon metal is a raw material for the production of many silicone-base products, including silicone breast implants. Congress granted the FDA regulatory authority for implant devices in 1976. However, on January 6, 1992, the Food and Drug Administration (FDA) placed a 45-day moratorium on the sale of silicone gel-filled breast implants. The FDA asked producers and medical practitioners to halt the sale and use of silicone gel-filled breast implants pending the review of the safety and effectiveness of such devices. The FDA moratorium was prompted by safety and health concerns surrounding leaky and/or ruptured implants allegedly causing autoimmune diseases. Subsequently, an FDA advisory panel of medical and other experts convened in February. The panel's job was to review safety issues and make recommendations on continued use of silicone gel-filled breast implants.

In mid-April, the FDA announced that, in keeping with the recommendations of the advisory panel, it would allow silicone gel-filled breast implants to be available only under special conditions. Women with an urgent need for reconstruction with implants would be allowed access to them. Manufacturers, with FDA approval, would set up studies that would enroll any woman who needs the implants for breast reconstruction. The FDA would require carefully controlled research studies for each model of implant that manufacturers wish to continue marketing. In addition, women would have to sign a special form certifying that they had been told about the risks of the implants and agree to enroll in a registry so that they could be notified about information on the implants in the future.

Production

Overall gross production of silicon products increased 2% compared with that of 1991. Production of silicon metal rose by 10%, while production of ferrosilicon and miscellaneous alloys declined slightly. There was a small increase in overall shipments of silicon-containing products. Producer stocks of silicon-containing materials decreased by 5% overall. Ferrous scrap used in the production of these products was estimated to be more than 170,000 tons.

Dow Corning Corp., Midland, MI, a joint venture between Dow Chemical Co. and Corning Inc., announced in March that the company would be permanently quitting the manufacturing of silicone gel-filled breast implants. Additionally, Dow would pay up to $1,200 per patient toward the cost of removing the company's implants from women who cannot afford the operation and whose doctors say the operation is medically necessary. Dow would also set up a $10 million fund for implant research. The company reportedly will cease providing silicone gel for other implantmakers, except where it is bound to do so under existing contracts. Dow pioneered the product in the early 1960's, and estimates put the company's total sale of implants since that time at about 600,000. The company, with a reported 30% share of the national implant market, decided to stop making and selling the implant devices after the FDA's January 6 moratorium on the sale of silicone gel-filled implants. Estimates indicate that up to 1 million women in the United States have silicone gel-filled breast implants. Also, Dow reportedly disclosed in December that it would no longer produce five implant grades of silicone for sale effective March 31, 1993. However, the company would continue to manufacture 45 other medical grades of silicone materials.

Additionally, Dow Corning Corp. in December commissioned a $25 million 6-megawatt silicon metal pilot plant in East Selkirk, Manitoba. The new process is said to be more energy efficient and environmentally cleaner than conventional methods. Construction of the plant began in late 1990. Funding for the project was provided by Dow Corning, the U.S. Department of Energy, the Canadian Government, and the Province of Manitoba. Dow planned to operate the plant through 1993 and then make a decision regarding the construction of a commercial-size facility.[1]

Hemlock Semiconductor Corp., Hemlock, MI, a joint venture between Dow Corning Corp., Shin-Etsu Handotai Co., and Mitsubishi Materials Corp., reportedly was embarking on a $65 million expansion of its polycrystalline silicon capacity. The expansion was intended to meet the growing demand for ultrapure semiconductor-grade silicon in terms of both quality and volume. The expansion is expected to be completed in 1994, with an increase in production capacity of about 75% anticipated. Hemlock supplies an estimated 20% of all polycrystalline silicon used worldwide.[2]

In October, Columbia Aluminum Corp., Goldendale, WA, reportedly reached a tentative agreement to purchase the silicon metal producer Silicon Metaltech Inc., Wenatchee, WA. Silicon Metaltech has operated since June 1990 under the protection of chapter 11 of the

U.S. Bankruptcy Code. The sale process is expected to take up to 6 months to finalize.[3]

In October, it was reported that Degussa Corp., the U.S. subsidiary of Germany's Degussa AG, had commissioned a new hydrophobic fumed silica plant in Waterford, NY. The $40 million facility reportedly is the first of its kind in the United States and will serve the growing domestic market for fumed silica used in silicone sealants, coatings, and printing inks. In addition to the general market, the new plant reportedly will supply the fumed silica requirements of an adjacent silicone manufacturing facility owned by the General Electric Co.[4]

Union Carbide Corp., Danbury, CT, disclosed that a number of companies were exploring the possibility of buying its OrganoSilicon Products, Systems, and Services group. The company intends to sell the group as part of a plan to sell $500 million in nonstrategic company assets during the next 2 years.[5] Group worldwide sales in 1992 reportedly were more than $300 million.

Globe Metallurgical Inc., Cleveland, OH, a major U.S. silicon metal producer, was reported to be considering the acquisition of Dow Corning's 12,000-metric-ton-per-year (mt/yr) silicon metal facility in Springfield, OR. Production from the plant is currently used for Dow's internal silicon metal applications.[6]

In late July, it was reported that Elkem Metals Co. would be shutting down a 45-megawatt furnace at its ferrosilicon plant in Ashtabula, OH. The furnace would be down for up to 8 weeks for scheduled maintenance and upgrading. The furnace upgrade was said to include modifications to improve operating and casting performance. A standby 45-megawatt furnace was to be restarted and operated during the maintenance period, and no loss of production was anticipated.[7]

Consumption and Uses

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. Overall reported consumption of silicon alloys and metal for most major end uses was up in 1992. *(See table 3.)*

Apparent consumption of silicon metal and silicon-containing ferroalloys was estimated to be about 535,000 tons of contained silicon. Consumption of silicon metal was estimated at 195,000 tons, while consumption of ferrosilicon and miscellaneous silicon alloys was estimated to be about 340,000 tons. Compared with that of 1991, consumption of silicon metal increased by more than 10%, and consumption of ferrosilicon and other alloys increased 5%. Ferrosilicon and miscellaneous silicon alloys accounted for more than 60% of all the silicon materials consumed, based on silicon content.

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. Overall ferrosilicon prices continued to decline, with the 50%- and 75%-grade material following similar price change patterns. The import price for 50%-grade ferrosilicon started the year at $0.35 to $0.355 per pound, reached a high in July of $0.388 to $0.393, then fell to $0.35 to $0.36 by yearend. The import price for 75%-grade ferrosilicon started the year at $0.315 to $0.32 per pound, peaked in July at $0.375 to $0.38, then fell to $0.355 to $0.363 by yearend.

The import price for silicon metal started the year at $0.585 to $0.595 per pound, fell to a low of $0.548 to $0.555 in April, then increased steadily to a high of $0.663 to $0.668 by yearend. During the year, domestic producers instituted a round of price increases that raised the price of silicon metal from a range of $0.56 to $0.60 per pound of contained silicon early in the year to $0.685 by yearend for some producers. The price increases reportedly were attributed to reduced producer inventories and increased demand by the aluminum and chemical industries.

Foreign Trade

U.S. exports of ferrosilicon increased 11% compared with those of 1991, based on gross weight. *(See table 6.)* Total value of ferrosilicon exports increased by more than 6%. Nearly 70% of the exported material was shipped to Canada and Mexico. Silicon metal exports were up by 3% based on gross weight, while the total value of the exports decreased by 16%. Canada, Japan, and the Republic of Korea were major recipients of the materials.

U.S. imports of silicon-containing alloys increased significantly compared with those in 1991. *(See table 7.)* Imports of ferrosilicon categorized as "55% to 80% silicon, other" increased by more than 30% based on gross weight, with the total value for this category increasing by nearly 30%. A substantial increase also occurred in ferrosilicon categorized as "Other," which included all ferrosilicon of less than 55% silicon content. Imports of "Other" ferrosilicon increased 70% based on gross weight and 60% by total value. Brazil and the former U.S.S.R. accounted for about 28% and 26%, respectively, of total imports. The schedule of tariffs that applied during 1992 to U.S. imports of selected silicon materials is given in table 5.

Overall imports of silicon metal products decreased 25% based on gross weight and 8% by total value. Imports of silicon metal categorized as "99.00 to 99.99% silicon" decreased by more than 36% based on gross weight and almost 30% by total value. Imports from Argentina, Brazil, and China for this category were down substantially, owing in part to dumping tariffs levied against the three countries in 1991.

The U.S. net import reliance for ferrosilicon and silicon metal products were estimated to be 38% and 17%, respectively, compared with 33% and 17% the previous year. The overall

import reliance for silicon products was estimated to be 31%.

World Review

Brazil.—Eletrovale SA Indústria e Comércio, a joint venture between State-owned Cia. Vale do Rio Doce (41%), Kawasaki Steel Corp. (20%), Mitsubishi Corp. (20%), and Metalur Mecanica (19%), reportedly completed the $30 million installation of a 30-megavolt-ampere (M•VA) furnace at its Nova Era Works, Minas Gerais State. The new furnace reportedly will double the company's annual ferrosilicon production capacity to about 44,000 tons.[8]

Ligas de Aluminio SA (Liasa), Brazil's largest silicon metal producer, in May sought protection from creditors under the Brazilian bankruptcy law, citing debts of about $56 million. In the late 1980's, Liasa boosted silicon metal production capacity at its Pirapora Works in Minas Gerais State from 20,000 mt/yr to about 48,000 mt/yr.

Rima Eletrometalurgia SA, a ferrosilicon and silicon metal producer, was reported to have made its final payment in November as part of the company's restructuring under credit protection. The company went into receivership in late 1990 owing to cash-flow problems resulting in part to high interest rates and electricity charges. Rima reportedly has the capacity to produce about 24,000 mt/yr of silicon metal, 12,000 mt/yr of ferrosilicon, and 9,000 mt/yr of calcium-silicon. In late December, the Rima facility was reported to be operating at full capacity. Most of the company's production is destined for export.[9]

Silex Trading SA, a Brazilian trading and finance company, purchased 80% of the shares of Eletroila SA, a silicon metal producer, in September from Norway's Ila og Lilleby Smelteverker for an undisclosed sum. The company's name was to have been changed to Eletrosilex with Ila og Lilleby retaining a 20% share in the operation. The company, located at Capitao Eneas in Minas Gerias State, has a reported silicon metal production capacity of about 22,000 mt/yr.[10]

Canada.—An explosion at Elkem Metal Co.'s Chicoutimi ferrosilicon plant in Quebec, Canada, on August 7, reportedly resulted in one fatality and caused considerable damage to the one-furnace facility.[11] Production at the 30,000-mt/yr ferrosilicon plant was suspended until December owing to an investigation into the cause of the explosion, and until required repair to the facility was completed. Customer needs reportedly were met from Elkem's worldwide ferrosilicon stocks.

China.—According to The TEX Report, Chinese exports of ferrosilicon totaled 280,000 tons valued at $130.72 million, compared with 319,900 tons valued at $164.03 million in 1991. The decline in ferrosilicon exports was influenced by a rise in the domestic sales price for the material owing to an increase in demand from the iron and steel industry.

European Community (EC).—The European Commission imposed a 32% antidumping duty on imports of ferrosilicon from Egypt and Poland. The decision followed an investigation of a dumping complaint petitioned by the EC ferroalloy producer association in late 1990. The low price level of the imported material was claimed to be forcing EC producers to sell comparative material at prices that often did not cover production costs.

The Commission announced in July that it had initiated a preliminary investigation into imports of ferrosilicon from China and the Republic of South Africa. EC producers reportedly had claimed that substantial dumping of material was eroding EC market prices. A decision on the investigation is not expected until sometime in 1993.

In mid-August, the Commission announced that it had imposed permanent antidumping duties on silicon metal originating from Brazil. Provisional duties on Brazilian silicon metal imports to EC-member countries were imposed in April 1992. The duties result from a complaint by the EC Liaison Committee of Ferroalloy Industries in July 1990, on behalf of EC silicon metal producers. The final duties, expressed as a percentage of the net free-at-community border price, were imposed as follows: Rima Electrometalurgia, 34.6%; Electroila, 29.8%; Cia. Ferroligas Minas Gerais, 26.4%; Camargo Correa Metais, 20.4%; and Cia. Brasileira Carbureto de Calcio, 18.3%.

Germany.—Ferrosilicon production in the former east Germany reportedly was halted in February owing to poor economics and environmental conditions. In the late 1980's, ferrosilicon production at the Ferrolegierungswerk Lippendorf plant at Neukieritzsch reportedly was about 26,000 mt/yr.

Iran.—The Iran Ferrosilice Co. reportedly made plans to construct a 25,000-mt/yr ferrosilicon plant to be sited at Semnan, Iran. The company was said to have contracted with the German firm Mannesmann Demag AG for the construction of the plant, which would produce 75%-grade ferrosilicon. Commissioning of the plant is expected in late 1993 to early 1994. The new plant is expected to be the first ferrosilicon production facility in Iran with most material destined for domestic consumption.[12]

Japan.—According to The TEX Report, imports of ferrosilicon into Japan totaled 416,000 tons compared with 470,600 tons in 1991. China accounted for about 209,000 tons of ferrosilicon imports. Japanese exports of ferrosilicon totaled about 80,000 tons, with the majority of the material destined for the Republic of Korea and Taiwan. Imports of silicon metal into Japan increased to about 148,000 tons. Silicon metal imports from China and Brazil totaled about 78,000 tons and 41,000 tons, respectively. Consumption of silicon metal by the Japanese aluminum alloy sector was relatively unchanged at about 54,000 tons.

Kazakhstan.—In October, it was reported that ferrosilicon production at

the Yermakovsky Ferroalloy Works had been cut by more than 40% owing to poor market conditions and a deteriorating economy. Ferrosilicon production at the plant in 1991 was reported to be about 525,000 tons. The plant has an estimated annual ferrosilicon production capacity of about 750,000 tons.

Norway.—Ila og Lilleby, part of the Fesil KS group, applied for court protection in July to renegotiate the company's debts regarding ferrosilicon and silicon metal plants at Lilleby Metall, Holla Metall, Hafslund Metall, and Rana Metall. A debt committee composed mainly of Ila Lilleby's creditors was subsequently formed. At a meeting in November, the committee accepted in principle a proposal for refinancing the company. The refinancing package proposed by Lilleby provided for a combination of new share capital, write down of loans, improved loan conditions, and a dividend of 25% to creditors that have no securities or mortgages in any of the company's plants. The proposal was to be presented to Lilleby's creditors in early 1993.

During the year, Elkem E/S undertook a series of measures to improve the company's liquidity and earnings. The company decided to focus resources on its core business areas such as ferroalloys, silicon metal, aluminum, carbon/microsilica and energy, and to curtail or dispose of several less core activities. These restructuring measures resulted in a work force reduction of 679 employees. Additional measures were to be implemented in 1993, which would further reduce the company's work force by approximately 500 employees. In 1992, Elkem's ferrosilicon production was reported to be approximately 300,000 tons and its silicon metal production capacity was reported to be approximately 140,000 tons.[13]

Russia.—Overall production of ferrosilicon in the Russian Federation in 1991 totaled 538,000 tons compared with 433,000 tons in 1990, according to The TEX Report. In 1991, production at Russia's two largest ferrosilicon producers, the Chelyabinsky Electrometallurgical Works (240,000-mt/yr reported capacity) and the Kuznetsk Ferroalloy Works (350,000-mt/yr reported capacity) was reported to be about 200,000 tons and 270,000 tons, respectively. Russian exports of ferrosilicon in 1991 were reported to be about 83,000 tons compared with 75,000 tons in 1990.

Saudi Arabia.—The Gulf Ferro-Alloys Co. reportedly will tender a contract in January 1993 for the construction of its planned 75,000-mt/yr ferroalloys and silicon metal plant. The four-furnace operation will produce various grades of silicon metal, ferrosilicon, manganese alloys, and silicomanganese. About 7,000 tons of the planned 10,000-ton silicon metal production will go to the Dubal aluminum smelter in the United Arab Emirates. Ferrosilicon production will be for export. Quartz feed material will be produced locally and imported from Iran and Oman.[14]

South Africa, Republic of.—Silicon Technology (Pty.) Ltd., Silitech, a subsidiary of Chromecorp Technology Pty Ltd., was reported to have purchased a carbide plant near Newcastle. Two electric furnaces at the facility used for carbide production, a 40-M•VA and a 56-M•VA, will be converted for ferrosilicon production. Annual combined ferrosilicon capacity is planned for about 55,000 tons. Ferrosilicon production at the facility is anticipated in early 1993.

Ukraine.—Ferrosilicon production capacity at the Stakhanovsk Ferroalloy Works in the Ukraine was reported to be about 650,000 mt/yr. In 1991, overall production of ferroalloys in the Ukraine reportedly decreased by 10% compared to those of 1990. For the same period, ferroalloy exports reportedly decreased by more than 30%.

Yugoslavia.—In June, it was reported that ferrosilicon production in Ruse, Slovenia, and Jegunove, Macedonia, appeared to be normal and largely unharmed by the ongoing civil war in the region. However, ferrosilicon and silicon metal production in Jajce, Bosnia Hercegovina, had shut down as a result of the war.[15] In the late 1980's, ferrosilicon and silicon metal production in the former Yugoslavia was more than 100,000 tons and 25,000 tons, respectively.

OUTLOOK

Demand for silicon metal is driven by consumption in the aluminum and chemical industries. For 1993, industry sources indicate that silicon metal demand in the aluminum industry will increase by less than 3%. The automotive sector will continue to 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. Industry sources indicate that the domestic silicon compounds industry will grow by more than 5% per year through 1997. Silicon growth in this sector is attributed to silicone elastomers (particularly injection-moldable silicone rubbers), silicon alloys used in superalloy production, and silicones used in household and personal care products, all of which are expected to increase about 7% per year during this period.

Ferrosilicon is consumed primarily by the iron and steel industry. The industry uses ferrosilicon for both deoxidation of molten metal and as an alloying agent. The outlook for steel is discussed in the annual report Iron and Steel. For 1993, no significant increase in Western World steel production is expected. Domestic steel production in 1993 is expected to improve somewhat over that of 1992 with a corresponding improvement in the demand for ferrosilicon. However,

domestic consumption of ferrosilicon is not expected to exceed the 390,000 tons consumed in 1990. Factors that could influence future consumption of ferrosilicon by the steel industry include technological changes and trade agreements. Additionally, the source of domestic ferrosilicon supply could be significantly affected by pending import cases. During the year, some domestic producers filed a number of antidumping and countervailing duty cases against various importing nations alleging injury to the domestic ferrosilicon industry. Preliminary findings by the ITC and the DOC in a number of the cases supported the charges.

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TABLE 1
PRODUCTION, SHIPMENTS, AND STOCKS OF SILVERY PIG IRON, FERROSILICON, AND SILICON METAL IN THE UNITED STATES IN 1992

(Metric tons, gross weight, unless otherwise specified)

Material	Silicon content (percentage)		Producers' stocks, December 31, 1991	Gross production[1]	Net shipments	Producers' stocks, December 31, 1992
	Range	Typical				
Silvery pig iron	5-24	18	W	W	W	W
Ferrosilicon	25-55	48	44,591	238,562	198,214	48,846
Do.	56-95	76	22,085	79,976	75,882	20,672
Silicon metal (excluding semiconductor grades)	96-99	98	19,062	164,326	167,310	10,391
Miscellaneous silicon alloys (excluding silicomanganese)	32-65	—	14,286	69,095	67,641	15,194

W Withheld to avoid disclosing company proprietary data.
[1]Ferrosilicon 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 1992

Producer	Plant location	Product
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 1992[1]

(Metric tons, gross weight, unless otherwise specified)

Silicon content (percent)	Silvery pig iron	Ferrosilicon[2]				Silicon metal	Miscellaneous silicon alloys[3]	Silicon carbide[4]
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	—	27,954	—	21,829	(5)	(5)	1,564	(5)
Stainless and heat-resisting	—	47,862	—	56,294	(5)	436	291	—
Other alloy	(5)	9,711	—	23,820	(5)	(5)	(5)	(5)
Tool	(5)	(5)	—	2,384	(5)	—	—	—
Unspecified	22	74	—	88	745	8,866	361	96
Total[6]	22	85,602	—	104,414	745	9,302	2,216	96
Cast irons	17,671	113,370	3,472	16,079	302	38	16,599	30,072
Superalloys	—	W	—	89	W	W	—	—
Alloys (excluding superalloy and alloy steel)	W	3,477	—	W	—	W	21	—
Miscellaneous and unspecified	11	1,755	—	474	18	[7]187,912	2	—
Grand total[6]	17,704	204,205	3,472	121,056	1,065	197,252	18,838	30,168
Consumers' stocks, December 31	1,154	5,526	294	4,627	48	1,696	1,046	1,081

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1]Includes U.S. Bureau of Mines estimates.
[2]Includes briquets.
[3]Primarily magnesium-ferrosilicon but also includes other silicon alloys.
[4]Does not include silicon carbide for abrasive or refractory uses.
[5]Included with "Steel: Unspecified."
[6]Data may not add to totals shown because of independent rounding.
[7]Includes silicones, silanes, fumed silica, and other chemicals.

TABLE 4
TIME-PRICE RELATIONSHIP FOR SILICON PRODUCTS[1]

(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
1992	59.95	36.94	35.41

[1]U.S. dealer import price.
[2]Prices 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, 1992	
		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.

[1]Free from certain beneficiary developing 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.
[2]Not duty free for Brazil.
[3]Free for products of Canada, from beneficiary countries under the CBERA, and for products of Israel.
[4]Free from beneficiary countries under the CBERA and for products of Israel.
[5]0.7% ad valorem for products of Canada.
[6]Free from certain beneficiary developing countries under the GSP, from beneficiary countries under the CBERA, and for products of Israel.
[7]3.1% ad valorem for products of Canada.
[8]5.4% 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	1991			1992		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
Ferrosilicon:						
More than 55% silicon:						
Australia	386	234	$372	249	149	$292
Canada	5,196	3,118	5,471	5,500	3,300	5,471
Germany	771	473	888	427	257	641
Mexico	5,893	3,622	5,241	7,920	5,083	6,718
Taiwan	462	277	478	417	250	410
Other	r2,122	r1,277	r1,758	867	575	832
Total[1]	14,831	9,001	14,209	15,380	9,614	14,364
Other ferrosilicon:						
Canada	15,893	7,946	11,270	21,027	10,513	13,104
Japan	2,361	1,184	2,332	4,911	2,414	5,468
Korea, Republic of	1,748	867	1,746	1,800	879	1,653
Mexico	3,547	1,773	2,638	3,081	1,540	2,367
United Kingdom	5,149	2,574	4,138	6,782	3,391	5,680
Other	r6,864	r3,408	r6,673	3,014	1,466	3,189
Total[1]	35,563	17,751	28,798	40,616	20,203	31,461
Total ferrosilicon[1]	50,393	26,752	43,008	55,996	29,817	45,825
Metal:						
More than 99.99% silicon:						
Germany	27	27	1,232	78	78	2,506
Italy	99	99	4,835	65	65	2,623
Japan	1,020	1,020	52,995	972	972	47,902
Korea, Republic of	95	95	3,684	157	157	5,746
Malaysia	125	125	30,475	147	147	19,478
Other	r145	r145	r9,622	96	96	5,707
Total[1]	1,511	1,511	102,843	1,514	1,514	83,963
99.00% to 99.99% silicon:						
Italy	38	38	80	62	62	97
Mexico	202	200	278	86	85	111
South Africa, Republic of	159	158	192	68	67	74
United Kingdom	47	47	64	332	329	486
Venezuela	582	577	828	458	454	656
Other	r426	r421	r572	231	229	302
Total[1]	1,454	1,441	2,014	1,238	1,226	1,727
Other silicon:						
Canada	1,092	1,061	1,438	1,535	1,490	1,933
Germany	60	58	79	412	400	470
Japan	864	839	1,173	1,022	973	1,469
Korea, Republic of	664	642	984	904	878	1,216
Mexico	1,067	1,036	1,426	754	732	1,045

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	1991			1992		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
Metal—Continued:						
Other silicon—Continued:						
Other	r1,533	r1,488	r $2,364	1,151	1,067	$1,990
Total[1]	5,281	5,125	7,465	5,779	5,540	8,123
Total silicon metal[1]	8,246	8,077	112,323	8,531	8,281	93,813

rRevised.

[1]Data 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	1991			1992		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
Ferrosilicon:						
55% to 80% silicon, more than 3% Ca:						
Argentina	288	175	$273	495	292	$493
Brazil	5,339	3,596	5,037	703	451	640
Canada	253	185	181	90	68	56
China	70	40	74	—	—	—
France	1,939	1,175	2,767	—	—	—
Italy	339	210	409	46	30	64
Kazakhstan[1]	—	—	—	93	61	426
Norway	5,400	4,076	3,023	210	118	134
U.S.S.R.[2]	—	—	—	640	429	479
United Kingdom	72	41	71	210	118	123
Total[3]	13,700	9,498	11,836	2,486	1,565	2,415
55% to 80% silicon, other:						
Argentina	6,406	4,811	3,105	—	—	—
Brazil	21,174	15,761	9,953	60,602	45,733	30,324
Canada	11,843	8,934	7,323	16,252	12,214	9,290
China	3,773	2,837	1,948	3,270	2,464	1,581
Egypt	—	—	—	4,415	2,956	1,557
France	371	242	686	603	392	1,163
Germany	302	227	991	277	205	1,198
Iceland	—	—	—	8,043	6,113	4,066
Japan	23	17	27	13	10	18
Mexico	11	9	52	37	25	105
Norway	26,622	20,023	15,776	27,845	21,121	16,199

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	1991			1992		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
Ferrosilicon—Continued:						
55% to 80% silicon, other—Continued:						
United Kingdom	11,137	8,378	$5,900	8,825	6,704	$4,815
Venezuela	40,556	29,910	20,074	31,950	23,399	14,437
Total[3]	122,218	91,148	65,835	162,133	121,338	84,754
80% to 90% ferrosilicon:						
Brazil	—	—	—	700	609	487
Canada	69	59	28	6	5	1
Norway	—	—	—	20	18	4
Total[3]	69	59	28	726	632	493
Magnesium ferrosilicon:						
Brazil	210	99	130	1,713	760	1,061
Canada	19	3	8	394	177	143
France	72	23	84	—	—	—
Germany	412	214	1,253	746	351	2,208
Japan	105	45	217	126	54	268
Norway	42	20	15	252	116	91
United Kingdom	—	—	—	35	7	25
Total[3]	860	404	1,707	3,265	1,466	3,796
Other ferrosilicon:						
Brazil	5,252	2,024	917	5,335	2,028	991
Canada	7,024	1,826	2,210	7,004	2,731	2,465
China	250	96	226	—	—	—
Egypt	—	—	—	1,993	937	219
France	16	8	24	—	—	—
Germany	142	21	179	17	8	47
Kazakhstan[1]	—	—	—	10,649	5,114	3,069
Netherlands	16	2	20	—	—	—
Portugal	—	—	—	3	1	7
Russia[1]	—	—	—	1,532	720	434
U.S.S.R.[2]	33,666	16,066	10,472	52,457	24,727	15,220
Total[3]	46,367	20,044	14,049	78,990	36,266	22,452
Total ferrosilicon[3]	183,214	121,153	93,455	247,601	161,267	113,911
Metal:						
More than 99.99% silicon:						
China	1	1	15	(4)	(4)	7
Czechoslovakia	1	1	173	1	1	197
Denmark	2	2	457	1	1	27
France	14	14	842	12	12	869
Germany	316	316	13,282	323	323	11,355
Ireland	(4)	(4)	77	—	—	—
Italy	203	203	32,012	248	248	38,438
Japan	261	261	6,520	329	329	5,357

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	1991			1992		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
Metal—Continued:						
More than 99.99% silicon—Continued:						
Korea, Republic of	11	11	$54	5	5	$67
Malaysia	(4)	(4)	13	(4)	(4)	6
Mexico	—	—	—	(4)	(4)	3
Netherlands	—	—	—	(4)	(4)	11
Norway	—	—	—	(4)	(4)	8
Poland	1	1	144	—	—	—
Singapore	—	—	—	(4)	(4)	9
Switzerland	(4)	(4)	2	(4)	(4)	6
Taiwan	(4)	(4)	4	—	—	—
U.S.S.R.[2]	(4)	(4)	15	—	—	—
United Kingdom	(4)	(4)	1	(4)	(4)	219
Total[3]	811	811	53,613	919	919	56,581
99.00% to 99.99% silicon:						
Argentina	4,676	4,634	5,169	874	865	973
Australia	7,045	6,972	8,255	3,834	3,670	4,360
Brazil	2,150	2,133	2,160	200	198	247
Canada	7,333	7,277	9,864	9,827	9,696	13,623
China	1,819	1,807	1,391	56	55	73
Czechoslovakia	(4)	(4)	17	—	—	—
Denmark	—	—	—	13	13	17
France	1,620	1,607	1,934	—	—	—
Germany	1,600	1,585	1,963	63	63	115
Hong Kong	20	20	17	—	—	—
India	—	—	—	21	21	24
Japan	—	—	—	(4)	(4)	6
Korea, Republic of	1	1	3	15	15	10
Norway	1,035	1,027	1,295	783	777	915
Portugal	67	67	51	—	—	—
South Africa, Republic of	600	594	736	1,438	1,425	1,662
Spain	96	95	108	40	40	43
Sweden	1	1	8	39	23	80
United Arab Emirates	—	—	—	21	21	24
Yugoslavia	—	—	—	768	757	748
Total[3]	28,062	27,821	32,970	17,993	17,640	22,920
Other silicon:						
Argentina	415	408	403	861	846	775
Australia	—	—	—	100	99	118
Brazil	6,147	6,052	5,645	199	196	210
Canada	200	197	241	768	817	875
China	1,376	1,326	1,196	3,628	3,433	3,436
France	171	169	315	—	—	—
Germany	—	—	—	96	75	137
Greece	180	176	175	—	—	—

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	1991			1992		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
Metal—Continued:						
Other silicon—Continued:						
Hong Kong	—	—	—	100	84	$104
Italy	155	155	$20	—	—	—
Japan	—	—	—	2	1	38
Korea, Republic of	—	—	—	2	2	8
Macedonia	—	—	—	3,034	2,976	2,788
Mexico	—	—	—	(4)	(4)	2
Netherlands	—	—	—	(4)	(4)	3
Norway	—	—	—	658	645	451
South Africa, Republic of	—	—	—	576	567	661
Sweden	1	1	6	—	—	—
Yugoslavia	5,868	5,774	5,789	3,781	3,704	3,625
Total[3]	14,513	14,257	13,790	13,804	13,446	13,233
Total silicon metal[1]	43,386	42,888	100,373	32,716	32,004	92,734

[1]Formerly part of the U.S.S.R.; data were not reported separately until 1992.
[2]Dissolved in Dec. 1991; 1992 imports of unknown origin, possibly Kazakhstan, Russia, or Ukraine.
[3]Data may not add to totals shown because of independent rounding.
[4]Less than 1/2 unit.

Source: Bureau of the Census.

SILVER

By Robert G. Reese

Mr. Reese, a physical scientist with the Branch of Metals, has been the commodity specialist for silver for 11 years. Domestic survey data were prepared by Lisa Conley and Kevin Bacon, statistical assistants; and international data tables were prepared by Virginia Woodson, international data coordinator.

Although less volatile than in 1991, the average annual silver price declined for the fifth consecutive year. Analysts attributed the continued decline to weak investor demand combined with stable industrial consumption and abundant supplies. During the year, a number of companies responded to the continued weakness in the silver price by suspending mining operations at several silver-producing mines. As a result, domestic silver production declined for the second consecutive year. However, the drop in production was less than expected. Although mining ceased, many mines processed stockpiled broken ore and continued to produce silver.

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 111 silver-producing lode mines to which a survey form was sent, 109 responded, accounting for an estimated 93% of the total U.S. mine production shown in tables 1, 2, 4, 5, and 6.

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 1992.

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 National Defense Stockpile (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 proteinates. 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 coarser-sized 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 (Ag_2S), cerargyrite (AgCl), polybasite ($Ag_{16}Sb_2S_{11}$), proustite (Ag_3AsS_3), pyrargyrite (Ag_3SbS_4), and tetrahedrite $\{Cu_3(Sb, As)S_3\}$. 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 per troy ounce) to more than $260 per kilogram ($8 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

Public Law 102-281, enacted May 13, 1992, authorized a number of programs for using silver from the NDS. Title I of the law authorized the production of silver coins to commemorate the 200th anniversary of the White House. Title II authorized the minting of gold, silver, and copper-nickel clad coins to commemorate soccer's "World Cup," to be held in the United States in 1994. Title III authorized the production of silver medals to commemorate the sacrifices made and services rendered by the United States Armed Forces during the Persian Gulf conflict. Title IV authorized the production of gold, silver, and copper-nickel clad coins to commemorate the quincentenary of Christopher Columbus' discovery of America. Title V authorized the minting of gold, silver, and copper-nickel clad coins to honor James Madison and the Bill of Rights.

During 1992, the Mint began production of the White House and Christopher Columbus Quincentenary Commemorative Coins. Both silver coins had the same specifications. Each coin, manufactured from a 90% silver-10% copper alloy, weighed 26.73 grams. The diameter of each coin was 3.8 centimeters. Inscribed on each coin was its year of issue, "1992"; face value ($1); and the words "Liberty," "In God We Trust," "United States of America," and "E Pluribus Unum." Both coins were legal tender. The enabling legislation limited the number of coins to be issued to 500,000 for the White House commemorative coin, and 4,000,000 for the Christopher Columbus Quincentenary coin.

Included in the sales price of each coin was its face value and the cost of 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 surcharge. The $10 per coin surcharges collected from the sale of the White House coins were paid to the White House Endowment Fund. The fund was to use the proceeds to assist in its efforts to raise an endowment for support of the White House's collection of fine art and historic furnishings and for maintenance of the historic public rooms of the White House. The Christopher Columbus Fellowship Foundation received the $7 per coin surcharges collected from the Christopher Columbus Quincentenary coins. The foundation was authorized to use the collected surcharges along with any other authorized appropriations to provide stipends for fellowships to encourage new discoveries in all fields of endeavor.

Title V authorized the issuance of the James Madison-Bill of Rights commemorative coins beginning on January 1, 1993. The enabling legislation contained provisions for two silver coins. One coin was to have a diameter of 3.8 centimeters; weigh 26.73 grams; be composed of a 90% silver-10% copper alloy; and have a $1 face value. The obverse of this coin was to be emblematic of James Madison, the fourth President of the United States, while the reverse was to emblematic of his home, Montpelier. The law limited the number of dollar coins that could be minted to 900,000. The second silver coin was to have a diameter of nearly 3.1 centimeters; weigh 12.5 grams; be composed of a 90% silver-10% copper alloy, and have a face value of a half dollar. The design of the half dollar coin was to be emblematic of the first 10 amendments to the Constitution, known as the Bill of Rights, and was limited to 1,000,000 coins. Included in the sales prices for the coins were a $6 per coin surcharge for the dollar coin and a $3 per coin surcharge for the half dollar coin. Proceeds from the surcharges were to be used by the James Madison Memorial Fellowship Trust Fund to encourage teaching and graduate study of the Constitution of the United States.

The World Cup commemorative coins authorized by Title II were to be available not later than January 3, 1994. The silver coins authorized by the act were to have a $1 face value, and the number minted was limited to 5,000,000 coins. As with the other dollar silver coins authorized by Public Law 102-281, specifications for the coins were a diameter of 3.8 centimeters, weight of 26.73 grams, and to be struck from a 90% silver-10% copper alloy. To be included in the per coin sales price were costs of design and production and a $7 per coin surcharge. World Cup USA 1994, Inc., the organizing committee for the event, was authorized to use 90% of the proceeds received from the surcharge for the purposes of organizing and staging the 1994 World Cup. The remaining

10% of the surcharge proceeds were to be distributed to institutions through the United States Soccer Federation Foundation, Inc., in the form of scholastic scholarships to qualified students.

Eligibility for the silver medals authorized by Title III was restricted to those members of the United States Armed Forces, as determined by the Secretary of Defense, who served in a combat zone during the Persian Gulf conflict. The act also authorized the Secretary of the Treasury to mint and sell bronze duplicates of the silver medals. The sales price for the bronze duplicates was to be sufficient to cover the cost of the duplicates and the costs of designing and striking the silver medals. The silver medals authorized by the act were not to be struck or distributed until sales of the bronze duplicates and/or private donations were sufficient so that the medals could be produced at no net cost to the U.S. Government.

Public Law 102-484, the National Defense Authorization Act for Fiscal Year 1993, signed by the President on October 23, 1993, authorized the disposal of 2,611 tons of silver from the NDS. Public Law 102-484 also authorized the disposal of a number of other metals and materials from the NDS. The act anticipated completion of the disposals within a 5-year period beginning on October 1, 1992, unless it was deter-determined that completion of the disposals would cause undue disruption of the market. Before carrying out the disposals, however, the law required the President to submit a revised annual materials plan under section 11(b) of the Strategic and Critical Materials Stock Piling Act (50 U.S.C. 98h-2(b)). Contained in Public Law 102-484 were special limitations regarding the silver disposals. The disposal of silver could only be made in the form of coins or as material furnished by the Federal Government to a contractor in the performance of a Federal Government contract.

Production

Silver was produced from precious-metal ores at 81 lode mines and from base metal ores at 36 lode mines. In 1992, 18 mines each produced more than 30 tons of silver: their aggregated production equaled 79% of total domestic production. Silver was also produced at nine placer operations.

In late July, Homestake Mining Corp. acquired Corona Corp., a Canadian gold company. At the time of its acquisition, Corona had interests in 10 producing mines in Canada, Mexico, and the United States. At the 10 mines acquired with Corona, the principal product is gold, although most of the operations also recover varying amounts of byproduct silver. Company officials viewed the acquisition as an opportunity to acquire low-cost operations and reserves at a time of continuing low precious-metal prices. The acquisition was expected to lower Homestake's overall production costs.

Alaska.—During the year, workers at the Greens Creek Mine mined and processed about 441,200 tons of ore and recovered nearly 218 tons of silver.[2] During the year, the recovered silver grade increased from 511 grams per ton in 1991 to 587 grams per ton in 1992. The increase in recoverable silver was attributable in part to modifications made to the mill to increase its processing rate, and its metals separation capabilities. At yearend 1992, Greens Creek's estimated proven and probable reserves were about 11,100,000 tons grading 395 grams of silver per ton.

According to company officials, performance at the Red Dog Mine remained unsatisfactory owing to problems in processing some difficult ore types. The operation processed more than 1,435,000 tons of ore in 1992 compared with nearly 1,451,000 tons during the previous year. Average silver content of the ore was 99 grams per ton.[3] Several projects were undertaken during 1992 to improve the operation's dust control. Dust control reportedly is a problem in the Artic because the low temperatures make conventional treatments ineffective. Enclosing outside conveyors and stockpiles and constructing a specialized truck loading station were among the projects completed to improve air quality.

California.—Although mining ceased at Lac Mineral Ltd.'s Colosseum Mine in San Bernardino County during the third quarter, mill operations continued through yearend. The open pit operation recovered gold and byproduct silver using a carbon-in-pulp processing plant. Milling operations at the site were expected to cease near mid-1993.

Following the completion of most construction during the second quarter, the first gold pour at the Hayden Hill Mine occurred near mid-June. The mine, in Lassen County, recovered 896 kilograms of gold and nearly 2.5 tons of silver.[4] Initial production was lower than anticipated owing to startup problems, a lower than anticipated ore grade, and adverse weather during the fourth quarter. Mining occurred at two pits, approximately 300 meters apart. A 3,200-ton-per-day cyanide leach/carbon-in-pulp mill processed the higher grade ore. Lower grade ore was heap leached.

Mining operations were completed at the Shumake Mine in February. The mine, a small open pit operation near Los Angeles, used heap-leach technology to recover gold and silver. During 1992, the mine produced 846 kilograms of gold and 4 tons of silver.[5] Leaching was expected to continue through mid-1994.

Idaho.—Production began at the Black Pine Mine in Cassia County. The open pit heap-leach operation commenced mining and processing in December 1991, with the first metal pour in January 1992. The mine consisted of three deposits and had an expected life of 4 years. In 1992, the mine produced 1.5 tons of gold and 463 kilograms of silver.[6]

At its DeLamar Mine, NERCO Minerals Co. completed a program to detoxify the mine's tailings pond in response to a bird mortality problem. Included in the program was construction of a cyanide recovery facility to remove

the cyanide from the tailings before its deposition in the pond. The DeLamar Mine produced 1.2 tons of gold and 57 tons of silver in 1992.[7]

In June, Coeur d'Alene Mines Corp. purchased Hecla Mining Corp.'s 12.5% nonoperating interest in the Galena Mine. The acquisition increased Coeur's holding in Galena to 62.5%. Asarco, the mine's operator, owned the remaining 37.5%. In late July, operations at the mine were temporarily suspended. Company officials attributed the decision to continued low silver prices. In 1992, Asarco milled approximately 65,000 tons of ore and recovered 40 tons of silver.[8]

Hecla Mining Co. obtained all the required environmental and construction permits needed for its Grouse Creek project. During the permitting process, the project's supplemental environmental impact statement was praised by both State and Federal officials. The project addressed all necessary environmental concerns. Reportedly, the project will not impact any salmon habitat and sets a new precedent for the preservation of wet-lands. At yearend 1992, reserves at the Grouse Creek project were about 13.1 million tons grading 1.6 grams per ton gold and 34 grams per ton silver.[9]

Continued efforts by its workers to reduce costs enabled the Lucky Friday Mine to operate on a break-even basis for most of the year, despite lower silver prices. For the year, the mine produced 63 tons of silver from 159,000 tons of ore.[10]

The Sunshine Mine operated at about one-half capacity throughout 1992. Company officials reduced operations at the mine in early June 1991 owing to low silver prices and the need for the company to preserve cash. During 1992, exploration at Sunshine concentrated on locating additional higher-grade ore. According to company officials, early drill results support their theories, and the exploration program was expected to continue in 1993. During 1992, the mine produced 79 tons of silver.[11]

Hecla Mining Co. completed leaching at the Yellow Pine Mine in August. The heap-leach operation produced 63 kilograms of gold and 48 kilograms of silver in 1992.[12] During the year, the mine's electrowinning plant was disassembled and shipped to Hecla's La Choya project in Mexico. Although investigating development of sulfide reserves at Yellow Pine, the company expects reclamation of the site to be completed in 1993. The Yellow Pine Mine, previous winner of several environmental awards, won the Pacific Northwest Pollution Control Association's Industrial Pollution Control Award for its innovative strides toward water quality improvement.

Montana.—Production at the Beal Mountain Mine increased slightly owing in part to the installation of a new crushing plant and to an expansion in process plant capacity. During 1992, Beal Mountain recovered 1,624 kilograms of gold and 249 kilograms of silver, compared with 1,472 kilograms of gold and 243 kilograms of silver in 1991.[13]

Canyon Resources Corp. mined approximately 1.4 million tons of ore at its Kendall Mine. The Kendall Mine, an open pit heap-leach operation, produced about 2 tons of gold and 567 kilograms of silver.[14]

In its first full year after taking over mining operations, Pegasus set production records at the Montana Tunnels Mine. From startup until mid-June 1991, mining at Montana Tunnels had been performed by a contractor, while Pegasus operated the processing plant. Among the records set were tons of ore mined and production of gold, silver, and zinc. During 1992, Montana Tunnels mined 4.2 million tons of ore and recovered 2 tons of gold, 41 tons of silver, and 17,632 tons of zinc.[15]

Production at the Zortman/Landusky Mine declined slightly in 1992. Company officials attributed the drop to the mining of lower grade ore. During the year, the mine produced its 31st ton of gold. For 1992, the Zortman/Landusky Mine recovered 4 tons of gold and 24 tons of silver.[16]

Nevada.—At its Battle Mountain Complex, Battle Mountain Gold Co. recovered approximately 6 tons of gold and 13 tons of silver.[17] In 1991, the company had produced approximately 8 tons of gold and 13 tons of silver at this location. The company processed more than 1.1 million tons of ore through its on-site carbon-in-pulp mill and leached an additional 1.1 million tons. Corporate officials expected the high-grade millable ore in the Fortitude deposit to be depleted during the first quarter of 1993, resulting in a significant decrease in output. Heap leaching of several small nearby deposits will likely account for most of the production in 1993. Exploration and drilling during 1992 resulted in the discovery of additional low-grade mineralization that may be economical.

Although ore at the mine had been depleted in 1991, leaching on a reduced level continued at the Buckhorn Mine through yearend. Reclamation of open pits at the site and access roads were essentially complete. Leaching was expected to continue through 1993, at which time the heap will be decommissioned and the remaining reclamation work completed.

Production at the Bullfrog Mine increased during the year owing in part to the mining of higher grade ore. Surface operations at the mine encountered high-grade ore shoots not previously indicated by drilling. Underground development to access the higher grade North Zone reserves continued, and production from underground mining reached 750 tons per day. During the year, Lac Minerals Ltd. changed mining methods for the underground operation to undercut drift and fill to lower operating costs. In 1992, the mine produced 10 tons each of gold and silver.[18]

At the Candelaria Mine, continued leaching of previously mined ore resulted in the production of nearly 33 tons of silver and 62 kilograms of gold.[19] NERCO suspended mining operations at the mine in November 1990, owing in part to low silver prices.

During 1992, operating costs and production improved at the Florida Canyon Mine, although the grade of ore mined declined. Company officials attributed the lower costs and higher

production to the completion of a number of projects in 1992. Among these projects were an upgraded materials handling system, an increase in the mine's Merrill Crow plant capacity, installation of a baghouse in the refinery, and installation of a new mercury retort. In addition to these projects, Pegasus renegotiated its contract with the company performing the mining operations at the site, resulting in lower operating costs. For the year, Pegasus recovered 3 tons of gold and 1 ton of silver from the heap-leach operation.[20]

Silver production at the McCoy/Cove Mine increased significantly for the second consecutive year. In 1992, the mine produced 246 tons of silver, compared with 175 tons in 1991 and 62 tons in 1990.[21] The McCoy/Cove Mine consisted of two deposits, about 2 kilometers apart. Production at the Cove deposit occurred from both surface and underground operations. At the McCoy deposit, the pit remained closed, and only the underground operation produced ore. Gold production also increased slightly. Company reports attributed the increased production to an increased mining rate resulting from the purchase of six new 172-ton-capacity trucks and a new 17.6-cubic-meter wheel loader. The trucks replaced nine 77-ton trucks and enabled Echo Bay to increase the mine's mining rate from a nominal 150,000 tons per day to 168,000 tons per day.

At the Paradise Peak Mine, silver production declined for the second consecutive year, despite increased mill throughput and expanded heap leaching. The continued drop in silver production was expected owing to depletion of the high silver content portion of the ore body. Gold production, however, increased. In 1992, gold production was approximately 8 tons, while silver production was about 60 tons.[22] In 1991, the mine had produced 6 tons of gold and 72 tons of silver. The company milled approximately 1,567,000 tons of ore and leached about 4,277,000 tons. The previous year, the company milled 1.4 million tons and leached about 2.9 million tons.

The Rawhide Mine, owned and operated by Kennecott Corp. a wholly owned subsidiary of The RTZ Corp. PLC, produced 3 tons of gold and 25 tons of silver in 1992.[23]

Both silver and gold production at the Rochester Mine decreased slightly in 1992. The mine produced about 6,674,000 tons of ore and recovered about 169 tons of silver and 2 tons of gold. In 1991, the mine produced 178 tons of silver and 2 tons of gold.[24] Near midyear, the company completed construction of a new 186,000-square-meter leach pad, increasing the available leaching surface at the mine to 836,000 square meters.

Despite record mining and milling rates at the Sleeper Mine, byproduct silver production declined for the second consecutive year. Gold production at the mine also declined. Company officials attributed the drop to the continuing decline in ore grades. To help reduce operating costs, Amax Gold Inc. completed construction of a conveyor system to move ore to the leach pads in early 1992. For the year, the Sleeper Mine milled 814,000 tons of ore, added 7,811,000 tons of ore to its leaching pads, and recovered 8 tons of silver and 4 tons of gold.[25]

Although mining ceased at the Wind Mountain Mine in January, owing to the depletion of ore reserves, leaching continued throughout the remainder of 1992. During the year, the heap-leach operation produced 9 tons of silver and 2 tons of gold.[26] Although site reclamation began immediately, leaching was expected to continue as long as it was economically viable.

Other States.—Cyprus Minerals Co. halted mining operations at the Copperstone Mine in December following the exhaustion of economically recoverable ore reserves. The open pit mine, in Arizona, produced gold and a small quantity of byproduct silver. Although mining at the site was completed, mill operations were expected to continue through early 1993, during which low-grade ore previously mined would be processed. The company began reclamation of the mine site.

In 1992, the San Luis Mine in Costilla County, CO, produced 2 tons of gold and 871 kilograms of silver.[27] Production was lower than expected owing to some startup problems. During the year, the mine was closed temporarily to address elevated levels of cyanide in the tailings ponds. Officials attributed the high cyanide levels to two factors. A higher than anticipated copper content in the ore resulted in a higher than expected consumption of cyanide during processing. Additionally, the original detoxification system was unable to sufficiently lower the cyanide content of the mill's discharge. Fortunately, the tailings ponds performed as designed, and no cyanide was released to the environment. During the spring and summer, company officials reduced the cyanide levels in the ponds and installed a new detoxification unit.

Production at the Magmont Mine in Missouri declined by more than 40% during the year, and employment fell to 126 from 151. Surface drilling yielded no additional reserves, and it was forecast that the mine would be exhausted and shut down in the next 2 years. In 1992, nearly 873,000 tons of ore was milled compared with more than 1 million tons of ore in 1991.

At its copper refinery in El Paso, TX, Phelps Dodge Corp. recovered 74 tons of byproduct silver.[28] Feed material for the El Paso refinery came primarily from Phelp Dodge's 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 42,240,000 tons of ore. At its Chino and Tyrone Mines in New Mexico, the company mined about 15,567,000 tons and 1,173,000 tons of ore, respectively.

During May, Amax Gold Inc. exercised its option to acquire a 62.5% interest in the Haile property in Lancaster County, SC, from Piedmont Mining Co. Piedmont had operated a small mine on the property over the past 6 years, but suspended mining in August 1991 following negotiation of the option and earn-in agreement with Amax Gold. Leaching operations at the existing Haile

Mine essentially ended during 1992. The two companies formed a joint venture in July to further explore and develop the property. During the remainder of the year, the joint venture conducted various technical studies to determine the feasibility of developing a large-scale mine on the property. The joint venture planned to conduct additional studies and exploration drilling during 1993.

Lac Minerals halted mining at the Richmond Hill Mine in South Dakota during the third quarter. The open pit heap-leach operation recovered 1 ton each of gold and silver in 1992.[29]

In Utah, byproduct gold and silver production at the Bingham Canyon Mine increased to 16 tons and 134 tons, respectively.[30] In 1991, the mine had produced 14 tons of gold and 112 tons of silver. In January 1992, Kennecott completed the expansion of the mine's grinding and flotation facilities. The projects, begun in 1990, increased the mill's capacity by 33% to 117,000 tons of ore per day. In March, Kennecott announced plans to construct a new smelter at the mine and to expand the existing refinery. Completion of these projects is expected during 1995, at which time Kennecott expects to be capable of smelting and refining all of the copper concentrates produced by Bingham Canyon on-site.

Sunshine Mining Co. terminated its lease agreements for the Burgin and Trixie Mines in Utah following its decision to suspend operations at the Trixie Mine. Upon termination, the properties reverted to their lessor companies, Chief Consolidated Mining Co. and South Standard Mining Co. During the year, Sunshine recovered approximately 5 tons of silver and 187 kilograms of gold from the properties.[31]

Gold and silver production at Hecla Mining Corp.'s Republic Unit declined in 1992 despite setting a production record for the quantity of ore mined. Corporate officials reported that the mine's known high-grade areas were mined out and attributed the mine's lower precious-metal production to the milling of lower graded ore. In 1992, the Republic Unit processed 93,000 tons of ore and recovered nearly 2 tons of gold and 9 tons of silver. In 1991, 87,600 tons of ore was processed to produce 2 tons and 10 tons of gold and silver, respectively.[32]

Consumption and Uses

Apparent U.S. demand for silver in 1992, calculated as refinery production from primary materials and from old scrap plus net imports of refined bullion, was 4,057 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. As the U.S. economy recovered from the most recent recession, domestic apparent demand increased for the first time since 1989. The increase, however, was less than 6%, reflecting the sluggishness of the recovery and the continued lack of investor demand.

Near mid-1993, the Silver Institute published estimates of silver consumption in 1992 by end use. CPM Group, a private consultant, developed the estimates for the Silver Institute. According to CPM, domestic industrial silver consumption in 1992 of 3,698 tons was essentially unchanged from the previous year.[33] Photography remained the largest end use for silver, accounting for an estimated 2,003 tons. For electrical contacts and conductors, CPM estimated that domestic industries consumed 569 tons. Among the possible explanations for the stagnant consumption levels were the weak domestic economic recovery and efforts by many manufacturers to reduce operating costs through better inventory management.

Markets and Prices

The daily domestic silver price, as quoted by Handy & Harman, ranged from a low of $3.63 per troy ounce on December 29 to a high of $4.32 on January 16. The price began 1992 at $3.94 per troy ounce rose to its peak near midmonth, and gradually drifted downward for the remainder of the year. The average price for 1992 of $3.94 marked the fifth consecutive year in which the average had declined. In 1991, the low price of $3.58 occurred on February 26, the high price of $4.53 occurred on June 10 and 11, and the average for the year was $4.04.

In Europe, 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 1992 at $3.87 per troy ounce and ended the year at $3.66. The low and high prices of $3.65 and $4.34 occurred on August 26 and January 21, respectively. The average for 1992 was $3.95. In 1991, the low, high, and average London spot prices were $3.55, $4.57, and $4.05, respectively.

Many factors contributed to the generally lower silver prices in 1992. Analysts cited sluggish U.S. and world economic growth, which tended to dampen the industrial demand for silver. Also cited were the relatively low inflation rates and the availability of large quantities of silver in both reported and unreported stocks. Low inflation rates discouraged additional purchases by those investors who view silver as a hedge against inflation. The availability of large stocks tended to hold down prices because investors tended to take profits whenever the silver price rose significantly.

The amount of silver represented by the future contracts traded on the Commodity Exchange Inc. (COMEX) decreased to 469,093 tons. In the previous year, futures contracts traded on COMEX represented 646,129 tons of silver. At the Chicago Board of Trade, the quantity of silver corresponding to the futures trading volume decreased from 3,654 tons in 1991 to 1,711 tons in 1992. On the Mid-America Commodity Exchange, the quantity of silver represented by the futures trading volume declined from 408 tons to 276 tons in 1992.

Stocks

Total accountable stocks at yearend 1992 decreased by 378 tons over those of yearend 1991. Declines in most

Government-held stocks more than compensated for the continued buildup of stocks held by futures exchanges and increased industry stocks. Analysts cited the lack of investor demand as the primary reason for the continued stock buildup on the commodity exchanges. Regarding the growth in industry-held stocks, analysts cited the low silver price along with increased optimism concerning the U.S. economy.

The total quantity of Government-held silver continued to decline. Department of the Treasury stocks declined by 253 tons to 775 tons by yearend 1992. Similarly, the NDS silver holdings declined from 2,611 tons to 2,255 tons. The U.S. Mint, as authorized by Congress, used NDS silver for various coinage programs. At yearend, the Department of Defense held 29 tons, an increase of 3 tons from the previous year. Since 1985, the total quantity of Government-held silver has declined by more than 2,200 tons. Various Government coinage programs have consumed nearly all the silver represented by this decrease.

Foreign Trade

U.S. silver exports improved in 1992, but remained lower than the totals reported for 1990. The countries receiving the largest increases in U.S. silver exports were Canada and the United Arab Emirates. Shipments to these countries increased about 119 tons and 108 tons, respectively. Increased shipments of refined bullion (45 tons) and waste and scrap material (72 tons) accounted for the increased trade with Canada. For the United Arab Emirates, the increased shipments consisted of refined bullion. The largest drop in U.S. silver exports was that to Japan, which decreased by 118 tons from the previous year. Cumulatively over the past 10 years, the United States has exported about 11,709 tons of silver. Canada (2,585 tons), Japan (2,503 tons), the United Kingdom (2,340 tons), and France (1,298 tons) have received most of the U.S. silver exports.

U.S. silver imports increased in 1992 for the fifth consecutive year, owing primarily to increased imports of impure silver-bearing materials, including waste and scrap, as well as doré and precipitates. The increased imports were due to increased exports by Germany (202 tons), Mexico (172 tons), Canada (140 tons), Peru (123 tons), and France (123 tons).

World Review

World mine production of silver decreased in 1992, despite increased production from countries such as Australia, Chile, and Mexico. For those countries where production increased, analysts attributed the higher production to factors such as capacity expansions and more efficient operations at existing mines, and to the opening of new byproduct mines. In those countries where production dropped, analysts cited factors such as the closure of uneconomic mines and the general economic and political conditions within the country.

CPM Group estimated that world fabrication demand for silver increased nearly 2% in 1992, to 18,360 tons, owing primarily to increased demand in India.[34] Demand for silver in industralized countries such as the United States, however, decreased slightly.

Australia.—In 1992, Aberfoyle Ltd. processed a record amount of ore through its mill at the Hellyer Mine. During the year, the mill processed nearly 1.4 million tons of ore with an average grade of 12.5% zinc, 7.1% lead, and 170 grams per ton silver. In 1991, the mill processed more than 1.2 million tons of ore.[35]

Company officials expected mining to end at the Pajingo Mine in mid-1993 owing to depletion of known reserves. Ore stockpiles, however, should allow the mill to operate through early 1994. In addition to surface mining, Battle Mountain Gold conducted limited underground mining at Pajingo during 1992. For the year, the mine milled 178,000 tons of ore and produced 1 ton of gold and 7 tons of silver.[36]

Production began at the Peak Mine in New South Wales. The gold-silver operation began commercial production in July and was officially commissioned in October. Through yearend, the mine had treated 215,911 tons of ore containing 480 kilograms of gold and 114 kilograms of silver.[37]

At the Red Dome Mine in Queensland, mining ceased near yearend. In 1992, the mine produced about 3 tons of gold and 14 tons of silver, compared with 2 tons and 7 tons of gold and silver, respectively, the year before.[38] In 1993, gold and silver will be recovered from stockpiled ore; however, several studies were being conducted that could result in additional reserves.

Bolivia.—Company officials began testing a new mill at the Kori Kollo Mine in December. The new carbon-in-pulp cyanide leach mill will be used to treat the sulfide portion of the deposit. In 1992, heap leaching at Kori Kollo recovered 2 tons of gold and 11 tons of silver.[39]

Canada.—Nerco completed construction of a pressure oxidation circuit (autoclave) at its Con Mine. The company planned to use the autoclave to process refractory ores and to treat and stabilize arsenic sludge produced by the mine's former owners as a byproduct of their gold operations. In 1992, the Con Mine recovered 4 tons of gold and 933 kilograms of silver.[40]

Placer Dome Inc. reported the production of 97 tons of silver at the Equity Silver Mine in British Columbia.[41] In 1991, the mine recovered 175 tons of silver. Company reports attributed the decline in production to the mining and processing of lower grade ores. The mine was expected to cease operation in late 1993, following the exhaustion of minable reserves.

At the Heath Steele joint venture, operations exhausted surface minable ore reserves at the Stratmat Boundary Mine early in the year, and production was shifted underground. Production also occurred at the joint venture's B-Mine. Heath Steele was a joint venture of Brunswick Mining and Smelting Corp.,

and Noranda Inc. For the year, the Heath Steele operations produced copper, lead, zinc, and 30 tons of byproduct silver.[42]

At its Kidd Creek Div., Falconbridge Ltd. reported the production of 111 tons of silver during 1992.[43] Production from the division's No. 1 and No. 2 Mines accounted for nearly all of the byproduct silver production. Development of the No. 3 Mine continued, and initial stoping began. A ramp being driven from the surface reached the 6100 level in December. Work continued on various reclamation projects, including rehabilitation of the complex's tailings pond. As part of its reclamation program, the company purchased three 85-ton trucks to haul waste rock from the surface for use as underground backfill.

Brunswick Mining and Smelting Corp. Ltd. mined and milled a record amount of ore at its No. 12 Mine during the year. In 1992, production averaged about 9,100 tons per day, approximately 7% greater than in 1982, its previous best year. For the year, the mine produced 232 tons of silver by milling 3,874,000 tons of ore.[44] Construction began on an effluent treatment system in 1992. Brunswick's smelter produced more than 90 tons of silver doré.

At the Sullivan Mine, byproduct silver production declined slightly, owing primarily to the processing of lower grade ore. In 1992, Cominco Ltd. milled 1,597,400 tons of ore grading 27 grams of silver per ton, compared with 1,688,300 tons grading 39 grams of silver per ton during the previous year.[45]

Highland Valley Copper Co. received the British Columbia Mine Reclamation award during the year. The award recognized the company's commitment to systematic research and development at its Valley Mine. Studies of subjects such as acid drainage potential and revegetation development were expected to aid in the development of viable land use plans for eventual mine closure. During the year, the mine produced about 32 tons of silver contained in concentrate, compared with about 33 tons the previous year.[46]

Chile.—Production at the El Indio Complex increased, owing in part to a corporate decision to concentrate on mining ores with a relatively higher precious-metal content. The El Indio Complex consisted of the El Indio and Tambo Mines. In the third quarter, the company completed a 4-kilometer tunnel. The tunnel provided access to the ore body at depth and was expected to be used for exploration and haulage. During the year, the operation milled about 1,078,000 tons of ore and leached 412,000 tons to recover 7 tons of gold and 47 tons of silver.[47]

In 1992, workers at the Escondida Mine milled 14,070,000 tons of ore to produce 762,800 tons of copper concentrate containing 2 tons of gold and 78 tons of silver.[48] During the year, the mine's partners agreed to expand Escondida's mining and milling capacities. Expected completion for the expansion projects was during the third quarter of 1993, at which time Escondida's nominal capacity would be 400,000 tons of copper in concentrate per year.

The La Coipa Mine produced 502 tons of silver in 1992 compared with 159 tons in 1991. The increased production represented the first full year production of a new 15,000-ton-per-day processing plant that began operating in October 1991. The new plant, a conventional cyanide leaching gold and silver recovery plant, replaced an existing 1,000-ton-per-day mill.

Production at the San Cristobal Mine decreased because of lower than anticipated ore grades. The mine, a typical open pit operation, used heap leaching to recover 2 tons of gold and 6 tons of silver.[49]

Indonesia.—In early 1992, workers at the Grasberg Mine completed various projects designed to increase the operation's mining and milling capacities. During the period 1989-92, mine and mill capacities increased from 20,000 tons per day to approximately 57,000 tons per day. To expand its mining operations, the company developed an access road between the mine and mill, purchased additional loading equipment, and purchased larger haul trucks. Construction of the access road reduced the company's dependence on an aerial tramway system to transport ore to the mill. At the millsite, the company increased its crushing capacity, expanded the number of primary mills from three to seven, and increased the site's flotation capacity. During the year, the operation milled more than 21 million tons of ore and produced 51 tons of silver, 20 tons of gold, and nearly 281,000 tons of copper.[50] To take advantage of the large reserves at the site, company officials, in August, approved plans to expand the operation's mining and milling capacity to 90,000 tons per day. The new projects were expected to be completed by mid-1996.

The Kelian Mine began operation in early 1992 and reached its operating capacity of 6 million tons of ore during April. For the year, the mine treated 6,197,000 tons of ore and produced doré containing nearly 15 tons each of gold and silver.[51]

Mexico.—The Mexican Government introduced a 10-Peso bimetallic circulating coin in late 1992. Each coin contained 5 grams of silver. The Government expected to begin production in 1993 of a 20-Peso bimetallic coin that would contain 8 grams of silver. Together, the 10-Peso and 20-Peso coins were expected to consume 715 tons of silver in 1993. Silver for the coins was to be purchased from new mine production within Mexico.

Copper and byproduct silver production remained essentially unchanged at the Maria Mine in the State of Sonora, despite declining ore grades. Officals attributed the stable output to increased productivity at both the mine and concentrator.

Silver production at the Real de Angeles Mine declined, owing in part to the mining of lower grade ore and lower mill recoveries. In 1992, the Real de Angeles Mine produced 254 tons of silver, compared with 264 tons during the previous year.[52]

New Zealand.—Operations at the Waihi Mine produced 2 tons of gold and 12 tons of silver during the year.[53] During the year, the company conducted studies aimed at reducing future operating costs. The present plan for the mine requires that both ore and waste be crushed at the mine site and then conveyed to either the mill or the waste dump. As the pit deepens, the ore becomes harder, thereby increasing operating costs. One possible solution being examined consists of driving twin tunnels between the mine and the mill. Construction of the tunnels would allow haulage of the waste material directly to the dump without crushing. This alternative was expected to be evaluated during 1993.

Papua New Guinea.—Silver production at the Misima Mine declined in 1992, despite an increase in the quantity of ore mined. During the year the mine produced 6,928,000 tons of ore and recovered 65 tons of silver, compared with 6,169,000 tons of ore and 80 tons of silver in 1991.[54] To improve its milling operations, the company constructed and incorporated a new secondary crushing plant at the site during 1992.

The Porgera Mine produced gold and byproduct silver-bearing ore from both surface and underground operations. In 1992, precious-metal production increased, owing in part to expansion of both the underground and mill facilities. Additional projects planned for the mill should allow the concentrator to process 8,500 tons of ore per day and allow increased production from the open pit operations.

OUTLOOK

The dominant component of domestic silver supply remains byproduct silver, recovered in 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 the principal product. Once concentrated, the additional cost to recover the silver is minimal. As a result, the quantity of silver supplied to the market is somewhat independent of the silver price. Another important consideration when forecasting domestic silver supply is the effort made over the past several years to reduce operating costs. Faced with prolonged declining prices, many precious-metal producers have successfully lowered their costs of production. Therefore, despite the recent temporary closure of some large primary silver mines, it is likely that during the period 1993-95, domestic silver mine production will remain between 1,600 and 2,000 tons. Worldwide, mine production of silver should remain near 15,000 tons.

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 upward or downward, but remain near 3,700 tons. Worldwide, silver demand will grow slightly with the gradual opening of new markets in less developed countries.

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[2]Hecla Mining Co. 1992 10K Report, 67 pp.
[3]Cominco Ltd. 1992 Annual Report, 68 pp.
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[7]NERCO Inc. 1992 10K Report. 103 pp.
[8]Coeur d'Alene Mine Corp. 10K Report. 58 pp.
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[10]Work cited in footnote 2.
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[12]Work cited in footnote 2.
[13]Work cited in footnote 6.
[14]Canyon Resources Corp. 1992 Annual Report. 44 pp.
[15]Work cited in footnote 6.
[16]Work cited in footnote 6.
[17]Battle Mountain Gold Co. 1992 Annual Report. 64 pp.
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[19]Work cited in footnote 7.
[20]Work cited in footnote 6.
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[22]FMC Gold Co. 1992 Annual Report. 30 pp.
[23]The RTZ Corp. PLC 1992 Annual Report. 146 pp.
[24]Work cited in footnote 8.
[25]Amax Inc. 1992 10K Report, 47 pp.
[26]Work cited in footnote 25.
[27]Work cited in footnote 17.
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[29]Work cited in footnote 18.
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[31]Work cited in footnote 11.
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[33]The Silver Institute. World Silver Survey 1993, 114 pp; available upon request from the Silver Institute, 1112 Sixteenth St., NW, Suite 2401, Washington, DC 20036.
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[35]Aberfoyle Ltd. 1992 Annual Report. 44 pp.
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[37]CRA Ltd. Press Release. Apr. 27, 1993, p. 5.
[38]Work cited in footnote 36.
[39]Work cited in footnote 17.
[40]Work cited in footnote 7.
[41]Placer Dome Inc. 1992 Annual Report. 60 pp.
[42]Brunswick Mining and Smelting Corp. Ltd. 1992 Annual Report. 28 pp.
[43]Falconbridge Ltd. 1992 Annual Report. 25 pp.
[44]Work cited in footnote 41.
[45]Work cited in footnote 3.
[46]Work cited in footnote 3.
[47]Work cited in footnote 18.
[48]Work cited in footnote 23.
[49]Work cited in footnote 36.
[50]Freeport-McMoRan Copper & Gold Inc. 1992 Annual Report. 28 pp.
[51]Work cited in footnote 37.
[52]Work cited in footnote 41.
[53]Amax Gold Inc. 1992 Annual Report. 42 pp.
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TABLE 1
SALIENT SILVER STATISTICS

		1988	1989	1990	1991	1992
United States:						
Mine production	metric tons	1,661	r2,008	r2,121	r1,855	1,804
Value	thousands	$349,339	r$328,684	r$240,908	r$354,971	$228,563
Refinery production:						
Domestic and foreign ores and concentrates	metric tons	1,474	1,718	r1,939	1,879	2,158
Secondary (old scrap)	do.	852	714	454	r215	148
Exports:						
Refined	do.	444	430	736	787	911
Other	do.	555	850	1,112	894	843
Imports for consumption:						
Refined	do.	2,260	3,062	2,698	2,525	2,662
Other	do.	497	r244	r657	1,626	2,328
Stocks, Dec. 31:						
Industry	do.	480	544	583	618	677
Future exchanges	do.	5,862	7,795	8,636	8,755	9,382
Apparent demand, refined[1]	do.	4,142	5,063	r4,355	r3,832	4,057
Coinage	do.	275	264	265	285	NA
Price, average per troy ounce[2]		$6.54	$5.50	$4.82	$4.04	$3.94
Employment[3]		2,300	2,800	2,600	1,900	1,600
World:						
Mine production	metric tons	r15,484	r16,041	r16,216	r15,692	e15,345
Consumption:[4]						
Industry and the arts	do.	16,671	16,899	17,409	17,465	NA
Coinage	do.	799	1,141	799	840	NA

eEstimated. rRevised. NA Not available.

[1]Defined 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.

[2]Metals Week Annual Handy & Harman quotation.

[3]Mine Safety and Health Administration.

[4]Silver Market 1992. Compiled by Handy & Harman.

TABLE 2
MINE PRODUCTION OF SILVER IN THE UNITED STATES, BY STATE

(Metric tons)

State	1988	1989	1990	1991	1992
Alaska	1	W	W	W	W
Arizona	152	171	173	r149	165
California	15	21	21	15	18
Colorado	27	W	23	20	W
Idaho	340	439	442	337	254
Missouri	45	53	42	35	32
Montana	192	r195	220	222	197
Nevada	608	625	646	r583	614
New Mexico	93	78	48	W	W
Oregon	W	W	W	—	(1)
South Dakota	3	4	10	7	6
Utah	W	185	r143	W	W
Other States[2]	185	239	354	484	517
Total[3]	1,661	r2,008	r2,121	r1,855	1,804

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Other States."
[1]Less than 1/2 unit.
[2]Includes Illinois, Kentucky, Michigan, New York, South Carolina, Tennessee, Washington, and States indicated by symbol "W."
[3]Data may not add to totals shown because of independent rounding.

TABLE 3
TWENTY-FIVE LEADING SILVER-PRODUCING MINES IN THE UNITED STATES IN 1992, IN ORDER OF OUTPUT

Rank	Mine	County and State	Operator	Source of silver
1	McCoy and Cove	Lander, NV	Echo Bay Mining Co.	Gold ore.
2	Greens Creek	Admiralty Island, AK	Greens Creek Mining Co.	Zinc ore.
3	Rochester	Pershing, NV	Coeur Rochester Inc.	Silver ore.
4	Bingham Canyon	Salt Lake, UT	Kennecott-Utah Copper Co.	Copper ore.
5	Tray	Lincoln, MT	ASARCO Incorporated	Do.
6	Red Dog	NW Arctic, AK	Cominco Alaska Inc.	Zinc ore.
7	Sunshine	Shoshone, ID	Sunshine Mining Co.	Silver ore
8	Lucky Friday	do.	Hecla Mining Co.	Lead-zinc ore.
9	DeLamar	Owyhee, ID	NERCO DeLamar Co.	Gold ore.
10	Paradise Peak	Nye, NV	FMC Gold Co.	Do.
11	Galena	Shoshone, ID	ASARCO Incorporated	Silver ore.
12	Montana Tunnels	Jefferson, MT	Montana Tunnels Mining Inc.	Zinc ore.
13	Mission Complex[1]	Pima, AZ	ASARCO Incorporated	Copper ore.
14	White Pine	Ontonagon, MI	Copper Range Co.	Do.
15	Candelaria	Mineral, NV	NERCO Metals Inc.	Silver ore.
16	Continental	Silver Bow, MT	Montana Resources Inc.	Copper ore.
17	Ray Unit	Pinal, AZ	ASARCO Incorporated	Do.
18	Denton-Rawhide	Mineral, NV	Kennecott Rawhide Mining Co.	Gold ore.
19	Zortman-Landusky	Phillips, MT	Pegasus Gold Inc.	Do.
20	Morenci	Greenlee, AZ	Phelps Dodge Corp.	Copper ore.
21	Bagdad	Yavapai, AZ	Cyprus Bagdad Copper Co.	Do.
22	San Manuel	Pinal, AZ	Magma Copper Co.	Do.
23	Battle Mountain Complex	Lander, NV	Battle Mountain Gold Co.	Gold ore.
24	Chino	Grant, NM	Phelps Dodge Corp.	Copper ore.
25	Pinto Valley	Gila, AZ	Magma Copper Co.	Do.

[1]Includes Eisenhower, Mission, Pima, and San Xavier Mines.

TABLE 4

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
1988	(1)	108,310,781	372	9,573,505	674
1989	W	155,188,564	528	4,450,703	524
1990	W	r185,647,818	r623	W	W
1991	W	r174,429,682	r505	W	W
1992:					
Alaska	W	—	—	—	—
Arizona	—	W	W	—	—
California	W	21,048,056	W	—	—
Colorado	—	W	W	—	—
Idaho	—	W	W	W	W
Illinois	—	—	—	—	—
Michigan	—	—	—	—	—
Missouri	—	—	—	—	—
Montana	—	16,750,785	W	W	W
Nevada	—	W	W	W	W
New Mexico	—	W	W	—	—
New York	—	—	—	—	—
Oregon	—	—	—	—	—
South Carolina	—	W	W	—	—
South Dakota	—	6,420,485	6	—	—
Tennessee	—	—	—	—	—
Utah	—	W	12	—	—
Washington	—	W	W	—	—
Total	(1)	160,600,450	612	W	281
Percent of total silver	XX	XX	34	XX	W

See footnotes at end of table.

TABLE 4—Continued

SILVER PRODUCED IN THE UNITED STATES, BY STATE, TYPE OF MINE, AND CLASS OF ORE

Year and State	Lode				Total	
	Copper ore		Other[2 3]			
	Metric tons	Metric tons of silver	Metric tons	Metric tons of silver	Metric tons	Metric tons of silver
1988	222,306,768	485	10,439,162	130	r350,630,216	1,661
1989	230,558,434	529	16,890,785	W	407,088,486	r2,008
1990	r240,618,804	r490	W	514	r443,350,711	r2,121
1991	r261,207,859	480	W	414	r454,050,831	r1,855
1992:						
Alaska	—	—	W	W	W	W
Arizona	17,911,174	158	W	W	174,118,203	165
California	—	—	—	—	21,048,056	18
Colorado	—	—	W	W	3,309,380	W
Idaho	—	—	W	W	4,406,320	254
Illinois	—	—	W	W	W	W
Michigan	W	W	—	—	W	W
Missouri	—	—	6,106,993	32	6,106,993	32
Montana	W	W	4,315,172	21	39,412,419	197
Nevada	—	—	2	(1)	105,175,492	614
New Mexico	W	W	W	W	W	W
New York	—	—	W	W	W	W
Oregon	25,046	(1)	—	—	25,046	(1)
South Carolina	—	—	—	—	W	W
South Dakota	—	—	—	W	6,420,485	6
Tennessee	—	—	W	W	W	W
Utah	49,464,028	W	—	—	W	W
Washington	—	—	—	—	W	W
Total	263,011,518	473	W	439	444,957,822	1,804
Percent of total silver	XX	26	XX	24	XX	100

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Total," where applicable. XX Not applicable.

[1]Less than 1/2 unit.

[2]Includes gold-silver, lead, zinc, copper-lead, lead-zinc, copper-zinc, copper-lead-zinc ores, and old tailings, etc.

[3]Includes silver recovered from tungsten and fluorspar ores.

TABLE 5

LODE SILVER PRODUCED IN THE UNITED STATES, BY STATE

Year and State	Cyanidation		Smelting of concentrates			Smelting of ore		Other processes[1]		Total ore processed[2 3] (metric tons)	Total silver recovered[3] (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)	Ore treated (metric tons)	Silver recovered (metric tons)		
1988	113,464,375	758	236,925,134	4,943,949	884	239,195	19	1,512	(4)	r350,630,216	1,661
1989	158,054,354	790	248,846,575	5,164,847	1,195	W	W	W	W	407,088,486	r2,008
1990	r184,108,524	r784	259,153,747	6,214,949	W	87,210	W	1,230	(4)	r443,350,711	r2,121
1991	r177,765,160	r719	r276,137,341	r5,885,793	W	135,336	W	W	W	r454,050,831	r1,855
1992:											
Alaska	—	—	W	W	W	—	—	—	—	W	W
Arizona	W	W	173,121,500	2,919,084	161	W	W	—	—	174,118,203	165
California	21,048,056	W	—	—	—	—	—	—	—	21,048,056	18
Colorado	2,863,927	2	W	W	W	W	(4)	—	—	3,309,380	W
Idaho	W	W	W	W	W	—	—	—	—	4,406,320	254
Illinois	—	—	W	W	W	—	—	—	—	W	W
Michigan	—	—	W	W	W	—	—	—	—	W	W
Missouri	—	—	6,106,993	469,965	32	—	—	—	—	6,106,993	32
Montana	W	W	22,636,026	263,974	168	W	W	19,705	(4)	39,412,419	197
Nevada	105,175,490	614	—	—	—	1	(4)	—	—	105,175,492	614
New Mexico	—	—	W	W	W	W	W	—	—	W	W
New York	—	—	W	W	W	—	—	—	—	W	W
Oregon	—	—	25,046	3,852	(4)	—	—	—	—	25,046	(4)
South Carolina	W	W	—	—	—	—	—	—	—	W	W
South Dakota	6,420,485	6	—	—	—	—	—	—	—	6,420,485	6
Tennessee	—	—	W	W	W	—	—	—	—	W	W
Utah	W	7	W	W	W	45,361	5	—	—	W	W
Washington	W	W	W	W	W	—	—	W	W	W	W
Total	166,997,080	744	277,520,440	5,884,708	W	W	W	W	W	444,957,822	1,804

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Total," where applicable.

[1]Includes metal recovered at lode mines by gravity methods.

[2]Includes 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 fluorspar, molybdenum, and tungsten ores from which silver was recovered as a byproduct and excludes ores leached for recovery of copper.

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

[4]Less than 1/2 unit.

TABLE 6
SILVER PRODUCED IN THE UNITED STATES BY CYANIDATION[1]

(Metric tons)

Year	Extraction in vats, tanks, and closed containers		Leaching in open heaps or dumps[2]	
	Ore treated	Silver recovered[3]	Ore treated	Silver recovered[4]
1988	26,593,821	302	86,870,554	456
1989	38,855,007	300	119,199,347	490
1990	r45,120,367	290	r138,988,157	r494
1991	r50,812,589	r178	r126,952,571	r541
1992	61,085,725	332	105,911,355	412

rRevised.
[1]May include small quantities recovered by leaching with noncyanide solutions and by proprietary processes.
[2]May include tailings and waste ore dumps.
[3]May include small quantities recovered by gravity methods.
[4]May include metal recovered by leaching of previously mined ore at some inactive mines.

TABLE 7
U.S. REFINERY PRODUCTION OF SILVER

(Metric tons)

Raw material	1988	1989	1990	1991	1992
Concentrates and ores:					
Domestic and foreign	1,474	1,718	r1,939	1,879	2,158
Old scrap	852	714	454	r215	148
New scrap	1,505	1,495	1,221	r1,481	1,615
Total	r3,831	3,927	r3,614	r3,575	3,921

rRevised.

TABLE 8

U.S. EXPORTS OF SILVER, BY COUNTRY[1]

Year and country	Ores and concentrates		Waste 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)
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	229	49	r840,228	124,015	r53,127	8,486	r787,475	115,224	1,681,058	247,774
1992:										
Australia	—	—	117	18	—	—	18,453	2,785	18,570	2,802
Belgium	—	—	111,589	15,436	—	—	17,493	2,133	129,082	17,569
Canada	2,530	453	[3]410,197	[3]61,771	—	—	67,712	11,059	480,439	73,283
Chile	4,493	809	—	—	—	—	—	—	4,493	809
China	—	—	675	105	53	7	—	—	728	111
France	—	—	67,083	9,581	48,553	9,432	1,370	199	117,006	19,211
Germany	476	57	18,573	4,332	3,098	416	4,341	862	26,489	5,667
Hong Kong	—	—	8,135	1,013	—	—	15,469	1,970	23,604	2,983
Ireland	872	157	—	—	—	—	165	6	1,037	163
Italy	81	17	3,200	414	—	—	257	42	3,537	473
Japan	—	—	28,613	3,724	3,020	378	141,657	18,561	173,287	22,663
Mexico	—	—	1,061	159	—	—	—	—	1,061	159
Netherlands	—	—	10,669	1,303	—	—	66	12	10,735	1,315
Singapore	—	—	376	40	—	—	66,111	9,806	66,488	9,846
Sweden	—	—	20,499	2,878	—	—	—	—	20,499	2,878
Switzerland	—	—	67	9	31,668	5,512	2,189	302	33,924	5,823
United Arab Emirates	—	—	—	—	—	—	215,312	29,399	215,312	29,399
United Kingdom	54	10	62,581	9,304	2,501	359	337,670	44,855	402,807	54,528
Uruguay	—	—	—	—	—	—	20,870	3,276	20,870	3,276
Other	—	—	1,786	297	—	—	1,454	265	3,240	562
Total[2]	8,505	1,503	745,221	110,381	88,894	16,104	910,587	125,531	1,753,207	253,519

rRevised.

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, export data may not be comparable with 1988 data.

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

[3]All or part of these data have been referred to the Bureau of the Census for verification.

Source: Bureau of the Census.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF SILVER, BY COUNTRY[1]

Year and country	Ores and concentrates		Waste 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)
1988	191,324	$35,508	60,470	$12,995	245,122	$52,840	2,260,049	$476,181	2,756,964	$577,524
1989	r10,975	r3,246	90,753	96,254	142,739	27,943	3,061,548	578,781	r3,306,015	r706,223
1990	r101,189	r24,595	507,649	86,421	48,449	8,741	2,697,926	437,380	r3,355,213	r557,138
1991	21,422	3,659	1,452,501	153,299	151,836	25,740	r2,525,134	338,514	4,150,893	521,212
1992:										
Australia	—	—	7,426	43	—	—	—	—	7,426	43
Belgium	—	—	15,448	2,238	—	—	34	4	15,482	2,242
Brazil	—	—	6,012	6	—	—	1,006	125	7,019	132
Canada	20,093	3,161	100,830	8,516	140,502	18,196	775,639	99,734	1,037,064	129,607
Chile	—	—	273	36	208,375	52,864	62,265	8,417	270,913	61,318
Denmark	—	—	34,651	74	—	—	—	—	34,651	74
Dominican Republic	—	—	168	79	69,503	14,785	5,639	1,015	75,310	15,879
Estonia	—	—	46,300	789	—	—	—	—	46,300	789
France	—	—	123,056	699	—	—	—	—	123,056	699
Germany	—	—	456,367	2,012	1	6	—	—	456,368	2,018
Hong Kong	—	—	66,266	353	—	—	—	—	66,266	353
Ireland	—	—	1,477	49	—	—	—	—	1,477	49
Israel	—	—	2,772	50	—	—	—	—	2,772	50
Italy	—	—	1,371	53	—	—	373	67	1,744	119
Japan	—	—	5,948	554	—	—	—	—	5,948	554
Malaysia	—	—	152,032	3,024	—	—	(3)	3	152,032	3,027
Mexico	3,934	549	5,268	3,621	54,370	8,447	1,251,295	159,988	1,314,867	172,604
Netherlands	—	—	50,274	189	—	—	—	—	50,274	189
Peru	972	100	660	87	55,964	7,819	523,814	66,051	581,410	74,057
Philippines	—	—	52,027	417	—	—	—	—	52,027	417
Russia	—	—	65,209	1,211	—	—	—	—	65,209	1,211
Singapore	—	—	4,000	15	—	—	—	—	4,000	15
United Kingdom	—	—	575,343	28,448	—	—	29,059	3,878	604,402	32,326
Uruguay	—	—	—	—	—	—	12,441	1,604	12,441	1,604
Other	354	45	905	1,928	—	—	57	12	1,316	1,986
Total[2]	25,352	3,855	1,774,085	54,492	528,715	102,118	2,661,622	340,898	4,989,774	501,363

rRevised.

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import data may not be comparable with 1988 data.

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

[3]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 10

SILVER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Algeria[e]	r3	3	3	3	3
Argentina	79	83	83	56	60
Australia	1,118	1,075	1,138	1,180	3,1,245
Bolivia	232	267	311	r376	260
Brazil[4]	124	172	223	r194	194
Bulgaria[e]	71	59	54	40	40
Burma	9	r6	r6	5	4
Canada (shipments)	1,443	1,262	1,400	r1,339	1,207
Chile	507	545	655	r674	1,000
China[e]	110	125	125	150	170
Colombia[5]	7	7	7	r8	8
Costa Rica[e]	(6)	(6)	(6)	(6)	(6)
Croatia[7]	—	—	—	—	2
Czechoslovakia[e]	30	30	25	20	20
Dominican Republic	40	23	22	22	18
Ecuador[e]	(6)	(6)	(6)	(6)	(6)
Fiji	1	1	1	1	1
Finland	31	31	29	r30	27
France	24	21	22	r24	22
Germany:					
Eastern states	e60	60	20	—	—
Western states	e20	e9	8	—	—
Total	e80	e69	28	r7	2
Ghana[e]	1	1	1	1	2
Greece	61	r61	r63	r70	70
Greenland	14	15	10	—	—
Honduras	58	r50	r18	r39	35
India	41	35	33	32	32
Indonesia	r58	r74	67	80	90
Iran[e]	30	41	38	40	5
Ireland	6	7	r8	r11	3,13
Italy[5 8]	92	96	103	r176	160
Japan	252	156	150	171	170
Kazakhstan[e 5 9]	—	—	—	—	900
Korea, North[e]	50	50	50	50	50
Korea, Republic of[5]	227	239	238	r265	250
Macedonia[7]	—	—	—	—	15
Malaysia	11	13	13	13	15
Mali[e]	(6)	(6)	(6)	(6)	(6)
Mexico	2,359	2,306	2,346	r2,224	2,316
Morocco	226	237	241	r296	3,295
Namibia	r e108	108	r92	r91	88
New Zealand	2	5	5	r11	19
Nicaragua	1	1	1	2	2
Papua New Guinea	70	94	r106	125	130
Peru	1,552	e1,840	r1,762	1,770	1,570
Philippines	55	51	47	38	31
Poland	1,063	1,003	832	e870	850

See footnotes at end of table.

TABLE 10—Continued

SILVER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992e
Portugal	1	20	r42	r43	43
Romania e	23	26	12	10	10
Russia e 5 9	—	—	—	—	800
Saudi Arabia	4	r13	r16	r e16	17
Serbia and Montenegro[7]	—	—	—	—	100
Solomon Islands	(6)	(6)	(e 6)	(6)	(6)
Slovenia[7]	—	—	—	—	2
South Africa, Republic of	200	180	r161	r171	3172
Spain e	3353	530	500	r400	400
Sweden	208	228	243	r239	240
Taiwan	8	6	e6	—	—
Tunisia	r1	r1	r1	r e1	1
Turkey e	23	29	33	r46	63
U.S.S.R. e 5 10	r2,500	r2,500	r2,500	r2,200	200
United States	1,661	r2,008	r2,121	r1,855	31,804
Yugoslavia[5]	139	127	105	e94	—
Zaire e	374	70	84	80	70
Zambia[11]	24	20	17	r14	14
Zimbabwe	22	22	21	r19	20
Total	r15,484	r16,041	r16,216	r15,692	15,345

eEstimated. rRevised.

[1]Recoverable content of ores and concentrates produced unless otherwise specified. Table includes data available through June 23, 1993.

[2]In addition to the countries listed, Botswana produces silver (probably 1 kilogram or less per year), Austria, and Thailand may produce silver, but information is inadequate to make reliable estimates of output levels.

[3]Reported figure.

[4]Of total production, the following quantities, in kilograms, are identified as placer silver (the balance being silver content of other ores and concentrates): 1988—34,319; 1989—58,000; 1990—52,000; 1991—40,000 (revised); and 1992—40,000 (estimated).

[5]Smelter and/or refinery production.

[6]Less than 1/2 unit.

[7]Formerly part of Yugoslavia; data were not reported separately until 1992.

[8]Includes production from imported ores.

[9]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[10]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries other than those listed in this table.

[11]Year beginning Apr. 1 of that stated.

SLAG—IRON AND STEEL

By Cheryl Solomon

Ms. Solomon, a physical scientist with 7 years of U.S Bureau of Mines experience, has been the commodity specialist for iron and steel slag since 1990. Domestic survey data were prepared by Robin Kaiser, statistical assistant.

Iron and steel slags are byproducts of the iron and steel industry and are used in diverse 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, and soil conditioning.

Research during the year emphasized a wide range of uses worldwide for both iron and steel slags, such as blending in cement, agglomerating iron ore fines or steel tailings, or setting in drilling fluids. An international conference on fly ash, silica fume, slag, and natural pozzolans was held in Istanbul, Turkey. *(See Research section of this report.)*

Domestic consumption of reported iron slag showed a 6% increase when compared with that of 1991,[1] while the consumption of reported steel slag decreased by a little more than 3%.

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 99 operations canvassed, 99 responded, 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.[2] 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.[3]

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.[4] 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.[5]

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."[6]

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 transporting the slag away from the mill site, processing the slag, and recovering and distributing 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 it 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. Second, 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.

Technology

Slag processing systems include the following.[7]

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. Blue Circle Cement Inc. of Sparrows Point, MD, 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, because 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.[8] 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. Although 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 tons 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 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

Pennsylvania Residual Waste Regulations expanded the category of coproduct to include iron and steel slags after they were processed. Such slags, therefore, would no longer be considered waste products.[9]

Production

Many of the projects involving slag in 1992 were related to highway and road construction. The building market was still depressed; however, it had somewhat improved from that in 1991.

Heckett Co. closed its Mississippi Steel plant in Jackson, MS and Bethlehem Steel plant in Johnstown, PA. Heckett started up a plant in Hickman, AR; however, no outside sales were expected until the Nucor Steel mill built the roadways.

The Levy Co. of Portage, IN, supplied blast furnace slag chip to resurface the Indianapolis Speedway acceleration and deceleration lanes. The project followed the prior resurfacing of the entire track with slag. Levy also resurfaced Highway I-55 Burr Ridge, IL, with steel slag chips. In addition, the Levy Co. reconstructed the parking area, running track, and tennis courts of Merrillville Indiana High School with blast furnace slag ballast and slag dense-graded base.

Standard Lafarge's Eastern Region, headquartered in Coraopolis, PA, completed shipments of more than 450,000 tons of blast furnace slag coarse aggregate for portland cement concrete used in the construction of the new Greater Pittsburgh International Airport terminal facility in 1992. *(See cover photo.)*

Consumption and Uses

Sales of slag products generally reflected demand from the construction industry. The Department of Commerce reported that value of new construction in 1992, $426.7 billion, increased by 6% compared with that of 1991.[10] The value of highway and street construction, $32.8 billion, was estimated to have increased by approximately 9% from that of 1991.

Blast furnace slag was 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 was the predominant form of iron slag processed in the United States, accounting for 90% of blast furnace slag sales in 1992. The most significant end use in 1992 for air-cooled slag was as a road base. Air-cooled blast furnace slag also was used as an asphaltic concrete aggregate, other concrete aggregate, fill, mineral wool, glass manufacture, and railroad ballast. *(See table 5 for related data.)*

Consumption of combined expanded and granulated slag was 1,407,000 tons valued at $24,925,000. 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 asphaltic aggregates.

Reported steel slag consumption decreased slightly compared with that of 1991 *(see table 6)*. Steel slag used in asphaltic concrete and road bases decreased by 24% from that of 1991.

Transportation

Most slag is used within about a 50-kilometer (km) radius of its source. Trucking costs make slag uncompetitive with mined aggregates when transportation distances exceed about 50 km. 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 1992, 83% traveled by truck, with an average marketing range of 45 km; 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 10% 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 $7.06 per ton, almost 15% less than that of 1991, but well within the range of the past 5 years *(see table 7)*. The price of air-cooled blast furnace slag decreased from $6.10 per ton in 1991 to $5.88 per ton in 1992. However, with the exception of the 1991 data, the upward trend in prices for air-cooled slag begun in the early 1970's continued until the current year. Granulated and expanded slag price information was withheld to avoid disclosing company proprietary data. The unit value for steel slag decreased from $3.41 per ton in 1991 to $3.02 per ton.

Foreign Trade

Statistics developed by the U.S. Department of Commerce, Bureau of the Census, indicated that approximately 132,000 tons of granulated blast furnace slag was imported from Canada during

1992. These Canadian imports reportedly entered primarily through Savannah, GA, Cleveland, OH, Buffalo, NY, and Detroit, MI. The Canadian imports may be expanded or pelletized slag.

Exports of granulated slag were 2,060 tons. Most of the slag exports went to Canada; however, 600 tons of granulated slag was exported to Chile, Guatemala, Mexico, and Venezuela.

World Review

In 1992, slag cement plants were set up or expanded in a number of countries to supply cement to those areas in need. New European standards also were anticipated to possibly affect slag sales throughout Europe. In one example, in the United Kingdom, the industry sells the slag to contractors such as ready-mix companies that buy cement and slag. In other European countries such as Belgium, Germany, and the Netherlands, the slag is sold to the cement manufacturer, who would then blend it at the cement plant. The issue is concerned with standardization at the plant level and may become important in North America as well.

Australia.—In 1992, there was reduced demand for slag products and quarry products.[11] Production was about 3 million tons of iron and steel slag. About 375,000 tons of blast furnace slags was used in Australian cements, with another 500,000 tons used in road construction and as an aggregate in concrete. Slag production and consumption centered around the iron and steel slag produced by Broken Hill Proprietary Co. Ltd. (BHP) in two areas in Australia—Port Kembla and Newcastle.

The Port Kembla area of New South Wales had Australian Steel Mill Services, a consortium of Edward C. Levy Co. of Detroit, MI, and Queensland Cement Co., a wholly owned subsidiary of Holderbank Co. Approximately 1.3 million tons of blast furnace slag was processed into 700,000 tons of air-cooled slag and 600,000 tons of granulated slag. Approximately 50% to 60% of both types was used for road pavements, concrete aggregate, and cement manufacture. The rest was stockpiled. Approximately 500,000 tons of basic oxygen furnace (bof) slag was produced, with 100,000 tons used for road pavements and the rest stockpiled.

In Newcastle, there were three slag contractors, Boral Quarries, of Boral Ltd.; Steel Cement, Ltd. (owned mainly by a consortium of Australian and Japanese companies), and Steelstone Services (Australia). The first two contractors processed approximately 500,000 tons of blast furnace slag; 50% was air-cooled slag used in road pavements and construction and 50% was granulated slag used in cement manufacture and road construction. The latter contractor processed about 200,000 tons of steel slag, of which 50,000 tons was used for road construction and the balance was stockpiled.

In Whyalla, South Australia, 350,000 tons of blast furnace slag and 125,000 tons of steel slag were produced, but the plant was not near a significant market and was therefore not sold. Electric arc furnace slag also was produced in Melbourne, Victoria, and in Newcastle & Sydney, New South Wales.

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.[12]

Belgium.—All of the production of blast furnace slag, about 2.8 million tons in 1991, was granulated. The production of this slag was insufficient to meet the demand of the cement industry that purchases it. The price of the slag, therefore, has increased to the equivalent of $9 per ton. Steel slag production was approximately 1 million tons and went principally to fill, forest and farm roads, industrial roads, or parking lots. The steel slag also was used in hydraulic engineering, in the manufacture of Portland cement, in agriculture, and in steelmaking.[13]

Brazil.—Usinas Siderurgicas de Minas Gerais SA (Usiminas), Brazil's second largest steel mill, discovered a way to mix its own slag with clay and cement to make what it calls "ecological bricks."[14] Because the heat of the slag cooks the bricks in the open air, no oven-firing process is needed to harden them, as in the case of conventional bricks.

France.—In 1992, 13 million tons of pig iron and 4.7 million tons of blast furnace slag were produced, or 360 kg of slag was produced for every ton of pig iron.[15] Of this slag, approximately 50% was granulated, 40% was air cooled, 10% was pelletized, and a negligible amount was expanded or processed in other ways. Sales of slag, 6.9 million tons, included the slag produced, slag from stocks, and older slag banks. The amount of granulated and pelletized cement sold was 3.5 million tons. Of the granulated and pelletized slag, 2.6 million tons was used in cement, 0.4 million tons was used for coarse slag and slag sand on roadways, 0.3 million tons of lightly crushed slag was used on roadways, and 0.03 million tons was a mixture of granulated slag and crushed air-cooled slag used to make road bases. Sales of crushed air-cooled slag were 2.7 million tons and included slag from stocks and from older slag banks. Fifty-six percent of the air-cooled slag was used on roadways, 30% as coarse slag, 9% for concrete and slag bricks, 2% for ballast, and 3% in other uses.

There were approximately 10 blast furnaces in operation. There were two or three blast furnaces at Sollac at Dunquerque, and two-thirds of the production was granulated. Sollac at Fos-sur Mer had two blast furnaces, one of which was granulating two-thirds of its production and one that was pelletizing two-thirds of the production. Lorfonte at Hayange had two blast furnaces; where one was granulating 100% of the production and one was not granulating at all. Lorfonte at Rombas had two blast furnaces that granulated 100% of the production. Unimetal a Caen had one blast furnace that granulated 100% of production. The production at this blast furnace was expected to stop in July

1993.

Sixty-six percent of the granulated slag was utilized in France, and the remainder was used abroad. Ninety-eight percent of the air-cooled slag was used in France.

Germany.—There was 7.08 million tons of iron slag produced in Germany and 8.25 million tons was sold.[16] Some of the blast furnace slag sales were taken from stores of slag produced in prior years. Fifty-seven percent of the slag was air-cooled slag used for road construction, 38% was granulated slag for cement, 3% was granulated slag for road construction, 1% was foamed slag for road construction, and less than 1% was air-cooled slag for fertilizer. There was 4.7 million tons of steel slag produced in Germany, with 82.4% being sold. Fifty percent of the steel slag sold was used as aggregate for roads, 21% was recycled back to the blast furnace, 16% was for landfill, 7% was for fertilizer, and 6% was for other uses.

Slag used in Germany must conform to special requirements for leachability (in addition to conforming to certain technological requirements). The leaching was done according to German Standard DIN 38414. There were no common limits within Germany for the application of byproducts. Therefore the state of Northrhine-Westfalia (Nordrhein-Westfalen) created special limits for each of 11 byproducts. According to the leachability of the slags they could be used as aggregate in various fields of application, e.g. as aggregate in road construction in asphalt or unbound layers; in ground water protection areas as an aggregate under layers impermeable to water (such as asphalt or concrete layers) and in other ways.

India.—Both Champion Cement Industries Ltd. and Shubham Industries were in the process of setting up minicement plants in Orissa. The plants, with capacities of 45,000 tons and 39,600 tons per year, respectively, were to manufacture ordinary portland cement and portland slag cement.[17]

Sagar Cements also was setting up a new slag grinding unit at Visakhapatnam in Andhra Pradesh. The unit was to manufacture portland blast furnace slag cement with slag obtained from the Visakhapatnam steel plant. The plant could supply the deficient cement markets in West Bengal, Orissa, and the north coastal district of Andhra Pradesh.[18]

Japan.—The share of electric arc furnace steel in total Japanese raw steel production rose from 24.4% in 1980 to 31.6% in 1990. It slipped to 30.9% in 1991 with the recession, but rebounded to 31.3% in the first 10 months of 1992. There were approximately 100 electric arc furnaces with a capacity of 30 tons or more operating in Japan. The total number of blast furnaces installed at 9 major steelmakers in Japan totaled 47, with 14 of them suspended from operation for repair.[19]

These trends should impact the amount and type of slag that Japan has available. Japan already is operating under the Law for the Promotion of the Utilization of Recyclable Resources enacted in 1991. This plan provides for businesses to improve technologies for expanded use of iron and steel slag.[20]

Korea, Republic of.—Supplies of slag cement were expected to greatly increase following a massive expansion and construction of new plants.[21] The cementmakers have been attracted to the slag cement due to low production costs. Ssangyong Cement Industrial Co. Ltd. dedicated a 1.2-million-ton slag cement plant in Kwangyang that was expected to produce 100,000 tons of slag cement per month.[22]

Also in Kwangyang, combined production of slag cement by Ssangyong, Hankook Slag Cement, Koryo Cement, and Pohang Azu Cement was approximately 1.8 million tons in the second half of 1992.

Tongyong Cement and Halla Cement also were constructing slag cement plants in Kwangyang. The annual output was to range from 1 million to 1.2 million tons. Hankook Slag and Koryo were to have annual production capacities of 1.5 million tons and 1.2 million tons, respectively. The companies chose Kwangyang because there is a huge foundry there run by the Pohang Iron and Steel (POSCO) steel mill.

Slag cement, which is mixed with ordinary cement and slag in a 1:1 ratio, was used mainly for building dams and bridges because of its sustained strength and low creation of heat of hydration. Slag cement was first developed in Korea in 1978 for commercial production.

In addition, the Ministry of Environment added additional uses for steel slag to increase its practical applications.[23] The new regulations will help industrial circles increase recycling of the slag from revolving and electric arc furnaces, which had previously been considered industrial waste. Steelmakers such as Inchon Iron and Steel, Kangwon Industries, and Dong Kuk Steel Mill, which use electric arc furnaces, planned to install slag recycling facilities to make the former waste a value added material. POSCO was to develop other uses for slag in value added ceramic areas.

South Africa, Republic of.—R. Snowden of Ove Arup, Inc. in the Republic of South Africa presented a paper entitled, "The Specification and Use of Slag in South Africa" at the seminar, "Concrete Performance—The Role of Blended Cements," in October 1992. The following comments were obtained from this paper. Blast furnace slag manufacturing facilities were primarily in the Transvaal and in Natal due to transportation costs. There were three slag processing plants, Vanderbijlpark and Pretoria in Witwatersrand and Newcastle in Northern Natal. The slag was used in the manufacture of cement, where a 50-50 blend was used most often. Because dolomite is used instead of limestone as a flux in the blast furnace, the slags had a much higher magnesia content than most other slags.

The slag was used in such diverse structures as gravity concrete dam walls, multistory buildings, industrial applications such as chimney stacks, power stations, structures subject to

chemical attack, and marine structures such as breakwaters and harbors. The cement industry was privately owned in the Republic of South Africa, and there were no policies or pricing incentives that gave preference to the use of slag in concrete. The current ex-factory price of slag relative to the local cement price was approximately 55%. Therefore, the use of blast furnace slag could result in up to a 25% reduction in the cement cost. The availability of slag in the Transvaal and Natal led to a number of blending plants being installed. In 1991, consumption of slag as cement was 5.8% of the total cement market. Cement that was made of 45% slag comprised 3.5% of the market.[24]

Taiwan.—Almost 1 million tons of blast furnace slag was expected to be produced in 1993. This slag was to be used to produce slag powder and portland blast furnace slag cement. *(See Current Research section of this report.)*

United Kingdom.—The amount of blast furnace slag produced in 1992, approximately 3 million tons, did not vary much from that in 1991.[25] Building and construction markets remained depressed throughout 1992, and volumes and prices of cementitious materials stayed down. Ravenscraig Steelworks in Scotland closed in June 1992. Remaining in operation were the slag operations of Teesside and Scunthorpe in England and Lllanwern and Port Talbot in Wales. Similar to the slag marketing arrangements in the United States, the ironmaker or steelmaker did not market the slag; instead, there were companies that marketed the slag. There were two slag marketing companies, both owned approximately 50% by British Steel Co. and 50% by an aggregate producer. In England, East Coast Slag, owned by British Steel and Tarmac PLC, marketed the slag produced at Scunthorpe and Teesside. At the latter location, the iron slag was produced at Redcar and the steel slag was produced at Luckenby. In Wales, Cambria Stone, owned by British Steel and Wimpey Hobbs of George Wimpey PLC, marketed the slag produced at Llanwern and Port Talbot.

With respect to the type of processing of the slag, there was one granulator left in operation, at Scunthorpe, and another at Llanwern, which was expected to be commissioned in 1993. Two of the plants in the United Kingdom also used pelletized slag. Steel slag produced at Scunthorpe was the only steel slag sold in other than negligible quantities.

Evered Bardon PLC, the aggregates and quarry group, sold the slag cement division of Civil and Marine for 25 million pounds (approximately $38 million).[26] Civil and Marine Slag Cement Ltd. bought the slag cement business that has plants near London and in South Wales.

The British Standard (BS) 1047 was used for air-cooled blast furnace slag for aggregates. In addition, the majority of ground granulated blast furnace slag was produced according to BS 6699 for supply directly to the concrete manufacturer, ready-mixed, site-mixed, or precast, for production of portland blast furnace cement concrete.

Current Research

The fourth international conference on "Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete," was held in Istanbul, Turkey, May 3-8, 1992.[27] The conference was sponsored by the American Concrete Institute, Detroit, MI; the Canadian Centre for Mineral and Energy Technology of the Energy, Mines and Resources of Canada; and other organizations in Canada and Turkey. More than 25 papers on slag were presented. Topics included permeability, strength, temperature control, elasticity, shrinkage, and resistance to freezing and thawing.

Research studies on iron and steel slag focused on a variety of end uses. Agglomeration of fines, both iron ore fines as well as of steel tailings, were the subject of a couple of research studies. Uses for both iron and steel slag in cement were featured. Many of the studies focused on a number of different types of materials used together in cement, such as slag, fly ash, silica fume, etc. These studies were addressed in the 1992 Cement Annual Report chapter by this author.

Blast Furnace Slag.—The cold-bonded pelletization of iron ore fines using ordinary portland cement binder was emerging as a potential energy saving agglomeration process for proper utilization of Indian iron ore fines. The possibility of substituting ordinary portland cement/clinker by cheaper low-grade Indian granulated blast furnace slag was investigated by the Regional Research Laboratory in Assam, India.[28] One of the conclusions of the study was that 40% to 50% of the ordinary portland cement (opc) requirement in making cold-bonded iron ore pellets could be substituted by granulated blast furnace slag.

Ground granulated blast furnace slag (ggbfs) used in cement was the subject of a number of articles.

A study carried out in Canada was designed to formulate the proportioning of concrete mixes made with ggbfs activated with sodium silicate and to determine their properties and durability.[29] It was expected that the new information on resistance to freezing and thawing, chloride ion penetration, and sulfate attack would encourage the use of slag concrete in the construction industry.

In another study on ggbfs, concrete made from a 1:1 mixture of ciment fondu high-alumina cement (hac) and ggbfs showed an increasing trend in strength up to 5 years when kept under water.[30] In addition, the sulfate resistance of blended hac containing ggbfs was shown to be better than that of the hac by accelerated tests.

The microstructure and microanalysis of hardened cement pastes made from ggbfs and opc were studied at Oxford University.[31] Although much is known about the hydration chemistry of slag cements, there is relatively little knowledge about their microstructure at the level of resolution achieved with electron microscopy. The paper presented the results of application of this technique to the study of ggbfs/opc blends

combined with electron microprobe analysis.

A new method of obtaining improved zonal isolation using drilling fluid solidification technology was developed by the Shell Development Co.[32] Hydraulic blast furnace slag could be activated to set in drilling fluids, which are difficult to convert to cements with other solidification technologies. In addition, among other properties, the slag had low impact on rheological and fluid loss properties of drilling fluids and was available in large quantities from multiple sources. Although conversion of drilling fluids or muds into cements suitable for well cement operations has been a subject of interest in the petroleum industry for more than 50 years, improved zonal isolation in the annular space between a casing and borehole has been and continues to be the primary reason for pursuing this technology.

Slag cement showed good binding properties for agglomeration of fine tailings and backfill in a study conducted at Laurentian University in Sudbury, Ontario.[33] The Canadian mining industry produces more than 500 million tons of tailings and waste rock annually. The fine tailings cannot be used in backfill materials for surface impoundments. The fines usually end up in tailings ponds, but in many cases the tailings are reactive and degenerate with time, resulting in the seepage of acid and toxic heavy metals into natural drainage systems. This is a major environmental concern to the mining industry. Agglomeration of mill tailings, by using slag cement and lime, could produce a useful aggregate material for use as backfill.

In Taiwan, at the China Steel Co., the 1.1 million tons of blast furnace slag anticipated to be produced in 1993 would be used to produce slag powder and portland blast furnace slag cement. To extend the application range of the blast furnace slag cement, the reactivity of the slag and the methods to increase the activity of the slag were investigated. It was shown that a higher cooling rate could increase the reactivity and activity of this blast furnace slag. Slag powder with the finest granularity had very good reactivity.

Steel Slag.—The Pennsylvania Department of Transportation evaluated steel slag from open-hearth, basic oxygen, or electric arc steelmaking processes for use as an aggregate for bituminous asphalt mixes.[34] Bituminous asphalt mixes demonstrated several good mix characteristics when steel slag aggregates were used. They were high stability, high skid resistance, longer heat retention after mixing, and ease of compaction.

The removal of phosphorus is essential to recycle the iron, manganese, and lime in steelmaking slags. In a doctoral thesis from the University of Minnesota, the phosphorous mineralogy, its distribution in steelmaking slags, and methods for its removal were detailed.[35] Eighty percent of the phosphorus was associated with the locked dicalcium silicate, and a possibility of flotation upgrading was discussed.

Removal of chromate by reduction using slag from a steel plant was studied at the Ravishankar University in Raipur, India.[36] It was found that the slag could reduce hexavalent chromium, which is toxic, to trivalent chromium and then to chromium metal. Hexavalent chromium is found in industrial wastes mainly as chromates and dichromate chromium compounds that are added to cooling water to inhibit corrosion. The standard technique for the removal of chromates has been to lower the pH of the waste stream to 3.0 or lower with sulfuric acid. The disadvantages inherent in this reduction treatment are that SO_2 is released into the ambient air, the reduction is not 100% complete, the amount of residual hexavalent chromium depends upon the time allowed for the reaction, the pH of the reaction mixture, and the concentration and type of reducing agent employed, and the method is not cost effective. Slag produced from steel manufacture was seen as widely available and an effective material to convert hexavalent chromium.

A review of the reports concerning steel slag for blended cement (ssbc) manufacture as well as preliminary work utilizing Australian produced steel slag was conducted at the University of Wollongong.[37] The ssbc was investigated with respect to strength, volumetric stability, and grindability with and without incorporation of opc clinker. Steel slag contained a similar mineral composition to that of opc clinker; however, the slag could become unstable due to free calcium oxide. Experiments have proven that the combined use of ssbc and ggbfs and/or opc clinker could balance the composition fluctuations in the steel slag and some CaO in the steel slag could be absorbed by ggbfs, thereby preventing the occurrence of instability of ssbc specimens. Removal of the fine iron particles was absolutely necessary for steel slag to be manufactured into ssbc.

Studies from the University of Wollongong in 1991 showed that instant chilled steel slag had acceptable volume stability and compressive, tensile splitting, and flexure strength for use in concrete.[38] A subsequent study considered two additional aspects of instant chilled steel slag aggregate concretes—brittleness and fracture toughness. Considerable benefits could be derived from using instant chilled steel slag as coarse aggregate in concrete, such as increased strength and reduced brittleness compared to limestone.

The state of the art in the utilization of iron and steel plant byproducts was described in a German paper.[39] As a result of intensive research, a wide range of applications for all kinds of slags has been found. Depending on cooling rates, blast furnace slag showed different kinds of mineral structures and physical properties. Utilization of byproducts of the steel industry in Germany was detailed.

Two papers were reported on concerning the use of steel slag in China. One paper developed at the Tangshan Iron and Steel Co. covered the possibility of utilizing steel slag generated at every steelworks based on the formation of slag and its physical and chemical properties.[40]

Another paper described the methods of radiation treatment and results of radiation assessment for slag at Baotou Iron and Rare-earth Co.[41] The results showed that the slag could be utilized to

absorb radiation.

OUTLOOK

Production of steel slag was expected to rise owing to an increase in steel production. Because of increasing use of scrap in the steel mill, electric arc furnace slag production also was expected to rise.

Slag used in cement was likely to increase owing to the favorable cost with respect to cement, properties of slag that enhance the cement, and environmental factors.

Slag prices were expected to stay low, owing to increased competition among slag processors.

Consumption of the construction aggregate segment, including iron and steel slag, recycled materials, clays, etc., was forecast to rise by 12% each year to 50 million tons in 1995.[42] Growth would be greatly attributable to increased use of recycled concrete and asphalt materials, solid wastes, and incinerator ash in construction applications.

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TABLE 1

IRON AND STEEL SLAGS SOLD OR USED[1] 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
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
1992	12,697	74,620	[p]1,407	24,925	14,104	99,545	6,857	21,972	20,961	121,518

[p]Preliminary.
[1]Value based on selling price at plant. Includes estimated value data for several operations.
[2]Includes granulated to avoid disclosing company proprietary data.
[3]Data 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	1991				1992			
	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	6,163	37,142	6,593	40,241	8,631	50,230	9,269	54,593
Middle Atlantic:								
Maryland, New York, West Virginia	W	W	W	W	W	W	W	W
Pennsylvania	1,982	15,002	2,137	17,171	1,687	11,237	1,764	12,301
Total[2]	W	W	W	W	W	W	W	W
Undistributed[2]	2,744	14,249	4,565	52,465	2,378	13,152	3,071	32,652
Grand total[3]	10,889	66,393	13,293	109,877	12,697	74,620	14,104	99,545

W Withheld to avoid disclosing company proprietary data; included in "Undistributed."
[1]Value based on selling price at plant.
[2]Includes Alabama, Kentucky, Utah, and those indicated by symbol "W."
[3]Data may not add to totals shown because of independent rounding.

TABLE 3

PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1992

Company	Plant location	Slag source				Blast furnace slag type
		Iron blast furnace	Steel			
			Basic oxygen furnace	Open hearth	Electric arc furnace	
Alexander Mill Services	Blytheville, AR				X	—
Do.	Kankakee, IL				X	—
Do.	Charlotte, NC				X	—
Do.	Holsopple, PA				X	—
Do.	Washington, PA				X	—
Do.	Cayce, SC				X	—
Do.	Seguin, TX				X	—
Do.	Plymouth, UT				X	—
Blue Circle Atlantic Inc.	Sparrows Point, MD	X				Granulated.
Buffalo Crushed Stone	Buffalo, NY	X				Air-cooled.
CSR America	Middletown, OH	X				Do.
Dunbar Slag Co. Inc	Wheatland, PA	X		X		Do.
Fritz Enterprises Inc.	Lorain, OH	X				Do.
Heckett Co.	Fontana, CA		X			—
Do.	Wilton, IA				X	—
Do.	Chicago, IL	X				Air-cooled.
Do.	Riverdale, IL		X			—
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.	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.	Provo, UT	X		X		Air-cooled.
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	—
Do.	Alton, IL				X	—
Do. (South Works)	Chicago, IL		X			—
Do.	Chicago, IL	X			X	Air-cooled.
Do.	Granite City, IL		X			—

TABLE 3—Continued

PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1992

Company	Plant location	Slag source				Blast furnace slag type
		Iron blast furnace	Steel			
			Basic oxygen furnace	Open hearth	Electric arc furnace	
International Mill Service—Continued:						
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.	Saukville, WI				X	—
Do.	Weirton, WV		X			—
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			Do.
Do.	East Chicago, IL	X	X			Do.
Maryland Slag Co.	Sparrows Point, MD	X	X			Air-cooled.
Standard LaFarge Co.	Granite City, IL	X				Do.
Do.	Cleveland, OH	X				Air-cooled and expanded.
Do.	Cuyahoga, OH			X		—
Do.	Lordstown, OH	X		X		Granulated.
Do.	McDonald, OH	X		X		Air-cooled.
Do.	Mingo Junction, OH	X				Do.
Do.	Warren, OH	X				Do.
Do.	Youngstown, OH			X		—
Do.	Penn Hills, PA			X		—
Do.	West Alliquippa, PA	X				Air-cooled.

TABLE 3—Continued

PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1992

Company	Plant location	Slag source				Blast furnace slag type
		Iron blast furnace	Steel			
			Basic oxygen furnace	Open hearth	Electric arc furnace	
Standard LaFarge Co.—Continued:						
Do. (Brown Reserve)	West Mifflin, PA	X				Air-cooled.
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	X		Do.

TABLE 4
SHIPMENTS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1992, BY METHOD OF TRANSPORTATION

Method of transportation	Quantity (thousand metric tons)
Truck	17,369
Waterway	755
Rail	728
Not transported (used at plant site)	2,108
Total	[1]20,961

[1]Data 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 USE[1]

(Thousand metric tons and thousand dollars)

Use	1991		1992	
	Quantity	Value	Quantity	Value
Asphaltic concrete aggregate	1,634	9,577	2,121	13,270
Concrete aggregate	1,333	9,683	1,325	9,193
Concrete products	358	2,333	469	2,863
Fill	855	3,950	1,229	5,328
Glass manufacture	W	W	W	W
Mineral wool	449	3,056	745	4,872
Railroad ballast	221	1,288	177	829
Road base	5,339	30,282	5,894	31,183
Roofing, built-up and shingles	68	771	70	844
Sewage treatment	W	W	W	W
Soil conditioning	W	W	W	W
Other[2]	633	5,455	665	6,238
Total[3]	10,889	66,393	12,697	74,620

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Value based on selling price at plant.
[2]Includes ice control, miscellaneous, and uses indicated by symbol "W."
[3]Data may not add to totals shown because of independent rounding.

TABLE 6
STEEL SLAG SOLD OR USED IN THE UNITED STATES, BY USE[1]

(Thousand metric tons and thousand dollars)

Use	1991		1992	
	Quantity	Value	Quantity	Value
Asphaltic concrete aggregate	1,085	4,617	903	4,272
Fill	828	2,374	1,073	3,067
Railroad ballast	186	585	224	772
Road bases	3,238	10,625	2,400	7,256
Other[2]	1,623	5,531	2,256	6,604
Total[3]	6,959	23,732	6,857	21,972

[1]Excludes tonnage returned to furnace for charge material. Value based on selling price at plant.
[2]Includes ice control, soil conditioning, and miscellaneous uses.
[3]Data 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				Steel slag	Total slag
	Air-cooled	Granulated	Expanded	Total iron slag		
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
1992	5.88	W	W	7.06	3.02	5.80

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 1992, 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	6.26	4.00- 9.75	—	—	—	—	4.73	2.00-6.90
Cement manufacture	W	W	W	W	—	—	—	—
Concrete aggregate	6.95	1.67- 9.82	—	—	—	—	—	—
Concrete products	6.10	3.85- 7.84	—	—	W	W	—	—
Fill	4.43	3.00- 7.03	—	—	—	—	2.86	.15-6.76
Glass manufacture	W	W	—	—	—	—	—	—
Lightweight concrete aggregate	—	—	—	—	W	W	—	—
Mineral wool	6.63	4.00- 9.06	—	—	—	—	—	—
Railroad ballast	4.68	3.88- 7.40	—	—	—	—	3.45	.05-4.52
Road bases	5.29	2.62- 8.00	W	W	—	—	3.02	.59-6.13
Roofing, builtup and shingles	12.06	4.05-15.00	—	—	—	—	—	—
Sewage treatment	W	W	—	—	—	—	—	—
Soil conditioning	W	W	W	W	—	—	W	W
Other	3.36	1.61- 9.42	—	—	—	—	2.72	1.03-5.59

W Withheld to avoid disclosing company proprietary data.

SODA ASH

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 14 years of U.S. Bureau of Mines experience, has been the commodity specialist for soda ash since 1979. Domestic survey data were prepared by Maria Arguelles, mineral data assistant; and international data tables were prepared by Ted Spittal, international data coordinator.

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, and analyzed using trade data provided by the Journal of Commerce's Port Import Export Reporting Service (PIERS). 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 or the PIERS data. The discrepancy between the export data sets is because Census data report 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. The overland transit time between the plant and port and any carryover export inventory, both in domestic and foreign warehouses or teamtracks, are the major reasons for the difference between the export data.

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 2.6% of the total $32 billion nonfuel mineral industry that was surveyed by the U.S. Bureau of Mines in 1992, 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 3500 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 short 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 interferred 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 1 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.

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% Na_2O and not more than 0.005% Fe_2O_3; the ASTM, a minimum of 99.16% Na_2CO_3. 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 49% in 1992. Five of

the six U.S. companies have either Australian, Belgian, 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 numerous sodium carbonate-bearing mineral occurrences throughout the world; however, only 93 deposits in 23 countries have been geologically evaluated. Although several of these deposits have been quantified, most are economically insignificant or too remote to be commercially developed. The largest and the most economically significant deposit is the trona deposit in southwest Wyoming. 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.

There are 13 sodium carbonate-bearing minerals that contain varying percentages of sodium carbonate. They are, in descending order of sodium carbonate content (with bicarbonate converted to carbonate), thermonatrite, 85.5%; trona, 70.4%; nahcolite, 63.1%; bradleyite, 47.1%; pirssonite, 43.8%; northupite, 40.6%; tychite, 42.6%; natron, 37.1%; dawsonite, 35.8%; gaylussite, 35.8%; shortite, 34.6%; burkeite, 27.2%; and hanksite, 13.6%;

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 meters (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.

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 developed its Sua Pan salt and soda ash deposit in 1991. Elsewhere, deposits of natural soda ash occur in Bolivia, Brazil, Canada, India, Pakistan, the Commonwealth of Independent States (C.I.S.—formerly most of the U.S.S.R.), and Venezuela. Plans are under way 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 redried. 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. 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 1992, more than 238 million tons (262 million short tons) of trona (equal to about 132 million tons or 146 million short tons of soda ash) has been mined. Only about 0.7% of the 36 million tons (40 million 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 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, $Na_2CO_3 \cdot H_2O$. 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 that allow 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 Russia, 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 that 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.

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 1992 were as follows: Republic of Korea, 12.5%; Australia, 10%; Mexico, 10%; Taiwan, 10%; Thailand, 10%; Colombia, 5%; 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 is 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 U.S. 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. 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, Solvay Minerals has begun discharging its waste material into abandoned sections of its underground mine, thereby using less 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 a survey conducted by the U.S. Bureau of Mines, the Wyoming soda ash industry employed 1,212 people in the 5 trona mines and 1,678 people in the soda ash refineries in 1992. The total quantity of trona mined by the Wyoming soda ash industry was 14,885,012 tons in 1992.

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. 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 Solvay Minerals 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 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 unit trains.

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 24 ports that shipped soda ash in 1992, 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, 60%, in 1992.

ANNUAL REVIEW

Issues

The dissolving of the U.S.S.R. in December 1991 and of Yugoslavia in April 1992 had an adverse affect on soda ash production in those nations. It is doubtful that their domestic soda ash industry will thrive until economic and political stability are achieved. Elsewhere in the world, acquisitions and expansions of several operations were among the major highlights that occurred in 1992. In addition, U.S. soda ash exports to Europe increased substantially as a result of the removal of the antidumping tariff in 1990 into the European Community (EC).

Production

U.S. production of natural soda ash from California and Wyoming increased 4% to 9.379 million tons. A total of 137,433 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. In addition, 151,127 tons of soda ash equivalent was used to manufacture chemical caustic soda by FMC, Solvay Minerals, and Tg Soda Ash.

Solvay S.A. of Belgium, the world's largest synthetic soda ash producer, acquired in May through its U.S. subsidiary Solvay America, Inc., the 80% share of Tenneco Mineral Co.'s natural soda ash facility in Green River, WY, for $500 million; $200 million from internal funds and $300 million long-term debt arranged through Solvay America using U.S. financial sources.[1] Solvay also acquired the 68,000-ton-per-year chemical caustic soda unit, the 51,000-ton-per-year sodium sulfite unit, and the 54,000-ton-per-year ground trona unit. The transaction provided Solvay with access to several markets in the Western Hemisphere previously economically inaccessible from its plants in Europe. The transaction provided Tenneco Inc. the needed capital to pay down debt in its $3 billion restructuring action. Asahi Glass of Japan continued to hold its 20% ownership in the remainder of the operation. Tenneco Minerals in April had completed installing 635,000 tons (700,000 short tons) of new capacity, raising total production nameplate capacity to 1.81 million tons (2 million short tons) annually. The expansion exceeded the original design capacity, which was supposed to be 545,000 tons (600,000 short tons).

This was not the first time that Solvay of Belgium had been involved in the U.S. soda ash industry. The first synthetic soda ash plant constructed in the United States was in 1881 at Syracuse, NY, by the Solvay Process Co. whose employees were trained in operating the plant at Solvay's plant in Dombasle, France. When the Germans quit supplying the United States with potash in 1914, Solvay built and briefly operated a potash facility in 1916 at Searles Lake, CA, and constructed a town named Borosolvay. In addition, Solvay used solar evaporation to recover potash at Salduro in western Utah beginning in 1917. Solvay also constructed and operated synthetic soda ash plants at Detroit, MI, (1898 to 1969) and Hutchinson, KS (1908-18).

FMC Wyoming Corp. announced plans in December to add an additional 545,000 tons (600,000 short tons) of annual production capacity to its existing operation.[2] The $125 million expansion, if approved by corporate headquarters, would raise overall capacity 22%, or from 2.8 million short tons to 3.4 million

short tons. The project would add about 40 to 50 new jobs to FMC's present work force of 1,180 people.

On June 30, TOSOH Corp. of Japan formed TOSOH Wyoming Inc., a wholly owned subsidiary of TOSOH America Inc., through the purchase of a 24% partnership from BTR Nylex's U.S. subsidiary The Andover Group Inc. Andover owned Australian Consolidated Industries, which held 49% of the joint venture with General Chemical (Soda Ash) Partners in Wyoming. TOSOH paid $82 million for its 24% share of the operation that has a capacity of 2.2 million short tons per year. The Japanese company produces synthetic soda ash in Japan where it has a 240,000-ton-per-year facility.[3]

Vulcan Chemical Co. and Cominco American formed a joint venture in April to produce soda ash at Owens Lake, near Lone Pine, CA.[4] The planned facility will have an annual capacity of 545,000 tons (600,000 short tons), and is estimated to cost $100 million, not including transportation arrangements.

North American Chemical Co. in April announced that it planned to install an additional 545,000 tons (600,000 short tons) of capacity to its Argus facility at Searles Lake in California.[5] The project is scheduled to be on-stream in 1994 and is expected to cost $50 million. When completed, the total annual capacity of the facility will be 1.8 million short tons. The company will use new solution mining techniques and will enlarge the plant's soda ash drying facilities. North American also entered into a 50% joint venture in March with NaTec Resources Inc. that was producing sodium bicarbonate from nahcolite (natural sodium bicarbonate) in the Piceance Creek basin of northwest Colorado.[6] NaTec's facility has an annual capacity of 113,000 tons (125,000 short tons) of high-purity nahcolite. The partnership, named White River Nahcolite Minerals Ltd. Liability Co. (a newly created NaTec subsidiary), was finalized in June with NaTec receiving $10 million in cash payable over 4 years with no interest. In November, the company was renamed White River Nahcolite Minerals. North American ceased producing sodium bicarbonate at its Searles Lake operation, which had an annual capacity of about 20,000 tons.

Consumption and Uses

U.S. apparent consumption in 1992 decreased slightly compared with that of the previous year whereas reported consumption was virtually identical. The discrepancy between the two forms of consumption 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, which can take about 2 to 3 weeks before the cargo is actually exported, and carryover export inventories contribute to the discrepancy between reported and apparent consumption as well.

The recovery of the domestic economy in 1992 continued to have a negative effect on the domestic glass container industry; however, soda ash sales to the flat glass sector increased, indicating favorable economic conditions for the domestic construction and automobile manufacturing industries. The industrial building construction industry consumes about 57% of all flat glass made, whereas the automotive glass sector used 25%. Based on reported industry sales, the manufacture of glass products increased 3%. Glass manufacture represented about 49% of domestic soda ash consumption, with the container sector comprising 59% of this end use; flat, 27%; and fiber and specialty, 7% each. The other end uses include chemicals (primarily sodium bicarbonate, sodium chromates, sodium phosphates, and sodium silicates), 24%; soap and detergents, 12%; distributors, 6%; flue gas desulfurization, 2%; and pulp and paper, water-treatment, and miscellaneous, 2% each.

U.S. reported consumption of soda ash decreased in the chemical, soap and detergent, water-treatment, and flue gas desulfurization sectors in 1992. The change in demand was because of the general economic conditions of the major soda ash-consuming market. *(See table 4.)*

Detergents is the third largest use of soda ash. Soda ash 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 40% 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 domestic plant silos, warehouses, terminals, and on teamtracks amounted to 371,424 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. The majority of the U.S. soda ash producers that have been exporting to Europe have several foreign warehouses for product storage. These warehouses serve the needs of most foreign soda ash consumers that purchase U.S. soda ash.

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.

Beginning September 1, General Chemical Corp. announced it intended to increase its off-list prices by $5 per short ton, not to exceed the $98 list price. Increased export demand, the recovering U.S. economy, and emerging caustic soda replacement markets were cited as the justification for the price hike. Rhône Poulenc also announced a $5 off-list price increase to offset the high operating costs and continued investment in plant facilities. Most contracts are written with any new terms for the following year. By yearend, it did not appear that the price movement held.

The average annual value for dense natural soda ash, f.o.b. Green River, WY, and Searles Valley, CA, was $89.21 per ton ($80.93 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. The list price for Wyoming bulk, dense soda ash remained at $98 per short ton while the California price for the comparable product held at $123 per short ton. *(See table 5 and figure 1.)*

Foreign Trade

U.S. soda ash exports rose 8% in 1992 to reach a record high of 3.0 million tons. U.S. exports to 51 countries, on a regional basis, were as follows: Asia, 42%; Europe, 23%; South America, 17%; North America, 10%; Africa, 3%; Oceania, 2%; Central America and the Middle East, 1% each; and the Caribbean, less than 1%.

The U.S. soda ash industry has waited since the early 1980's for the trade barriers with the EC of Western Europe to end. With the removal of the antidumping tariffs on U.S. soda ash in late 1990, export sales to Europe began to rise. By yearend 1992, domestic soda ash exports to the EC were about 582,000 tons; a 1,323% increase from that of 1980. Total exports to Europe, including Sweden and Yugoslavia (exports actually went to Hungarian glass plants through a Yugoslavian port), were 695,000 tons in 1992. Figure 2 shows the level of exports to Europe relative to the U.S. total from 1980 through 1992. The graph shows the effect on U.S. soda ash exports from the implementation of the antidumping duty by the EC Commission after 1982 and the elimination of that duty in 1990. Figure 3 shows the level of exports to Europe among the six U.S. companies in 1991 and 1992 that are reflected in the increases for those years shown in figure 2.

Although export sales to Western Europe were strong during the past 2 years, three important issues began in about the third quarter of 1992. They were the rise in the strength of the U.S. dollar relative to European currency, the stagnation of European demand, and the reduction by Solvay S.A. of Belgium of its price of synthetic soda ash by 10% to 15% in certain countries. *(See tables 6, 7, and 8 and figures 2 and 3.)*

World Review

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 49% 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, the C.I.S., China, 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 9.)*

Capacity.—World soda ash production capacity is about 35 million tons divided among 36 countries. Approximately 70% of world capacity is synthetic soda ash and 30% is natural. The United States represents 30% of world capacity and 95% of the total natural capacity.

The largest soda ash company in the world, excluding state-owned facilities, is Solvay S.A. of Belgium. With its acquisition of Tenneco Minerals' natural facility in Wyoming in 1992, it operates 10 plants in 8 countries and has a combined annual capacity of about 6.07 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.

Australia.—Penrice Soda Products of Australia announced plans to expand and modernize its Osborne facility by 25% to 500,000 tons. The project will cost $20 million to $30 million over the next 4 years. The company plans to export 40% of its soda ash to various Asian countries by 1998.[7]

China.—A decrease in Chinese domestic consumption caused soda ash inventories to increase. As a result, production limits were implaced that caused utilization rates to fall to

approximately 70%.[8] Output was estimated at 4 million tons, of which about 200,000 tons was exported to several Asian nations. In 1985, it was forecasted that China would begin to become an active exporter.[9] The decline in consumption and production caused the price of Chinese soda ash to fall to 900 Renminbi Yuan ($164 per metric ton).

Ethiopia.—A natural soda ash project with an annual capacity of 200,000 tons on Lake Abijata was under consideration. Although the planned project is estimated to generate $4 million to $5 million in annual operating revenue, a large quantity of bird species represents an environmental problem. A feasibility study was delayed because of the prolonged civil war in northern Ethiopia.[10]

Germany.—The 300,000-ton expansion at the Bernburg synthetic soda ash plant that Solvay S.A. of Belgium regained control of in 1991 in the former German Democratic Republic was completed in July 1992. Although the expansion was for dense soda ash, the older facility also has a unit that has an annual capacity of 240,000 tons of light soda ash. The majority of the output of the complex is for consumers in Czechoslovakia and some C.I.S. Republics. Part of the modernization program will improve product quality such as reducing sodium chloride content in the soda ash to less than 0.15%. Solvay has already achieved this goal at its plants in Austria, Belgium, and western Germany.[11]

Jamaica.—The Government-owned Jamaican Bauxite Institute initiated a feasibility study to produce caustic soda using local limestone and imported U.S. soda ash from ANSAC. The country uses about 300,000 tons of caustic soda annually to treat bauxite ore. About 190,000 tons of limestone and 200,000 tons of soda ash would be required to produce 300,000 tons of 50%-strength caustic soda. A small 60,000-ton-per-year facility is under consideration with construction costs estimated at $20 million. The results of the feasibility study, which was funded by the European Investment Bank of Luxembourg, may allow for a larger-sized plant. The study began in November and is slated to take 6 or 7 months to finish.[12]

Pakistan.—ICI Pakistan, of which ICI PLC owns 61%, announced plans to expand its synthetic soda ash plant at Khewra, Punjab Province. Capacity will be raised from 146,000 tons per year to 196,000 tons per year. The expansion is needed to meet the growing domestic demand that has been 6% to 7% annually. The project is scheduled for completion in December 1994 at a cost of $32 million.[13]

Poland.—The two State-owned synthetic soda ash plants at Janikowo and Inowroclaw, with a combined capacity of 850,000 tons per year, were offered for sale at yearend as the country began to privatize certain industries. A foreign partner may acquire up to 80% of the operations that are anticipated to be sold together. Solvay of Belgium, Rhône-Poulenc of France, and Brunner Mond of England have indicated their interest in the joint venture but formal bids were not to be submitted until early 1993.[14] Improvements in soda ash handling were completed at the Port of Szczecin on the Baltic Sea in Poland by Fast Shipping Ltd. to accommodate shipments within and out of the country. New silos, warehouses, and handling equipment were installed to improve the quality control of soda ash distribution. Daltrade Ltd. of the United Kingdom serves as the import agent for Polish soda ash. Improvements have been made at the Ports of Howden Dyke, Humberside, and Perth in Scotland.[15]

United Kingdom.—Brunner Mond, which operates two synthetic soda ash plants at Lostock and Winnington, continued to restructure its business by eliminating 400 jobs over the next 2 years. The company formed five business units to streamline plant operations and administrative functions.[16]

OUTLOOK

The political changes that have occurred in the past 2 years in the former U.S.S.R. and in other Eastern European nations have begun to cause an economic impact in those countries. Some of the state-owned soda ash plants, such as those in Poland previously discussed, are being partially sold to private companies to generate needed revenue and to reduce operating and maintenance costs previously incurred by the Governments. Less economic, older soda ash plants, like that of Czechoslovakia that closed in 1991, will be targeted for possible closure in the next few years, thereby reducing world soda ash production capacity. This could represent a favorable opportunity for the U.S. soda ash industry to export product to these areas. It is very likely that some of the newer and more efficient plants will be modernized and equipped with pollution abatement technology to reduce atmospheric emissions and wastewater discharges in response to the growing international environmental movement. World soda ash demand continues to increase, which will provide the stimulus for foreign companies to continue considering investing in natural soda ash ventures in Wyoming and California to guarantee long-term and inexpensive supplies of soda ash. *(See figure 4.)*

Exports

The outlook for U.S. soda ash exports remains optimistic. 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 EC nations, the six individual U.S. soda ash producers will continue to strive to increase exports to that region. Stagnant market conditions in Europe, the strength of the U.S. dollar relative to European currency, and the decrease in the European soda ash sales price will probably lessen U.S. soda ash export sales for the short term. Because of the higher cost structure of manufacturing

synthetic soda ash, it is doubtful that the European sales price can remain low for very long before it has an adverse economic affect on the producers. Export opportunities to the Middle East and South America are very favorable. It also is likely that some South American production capacity could be reduced as certain countries examine the economic status of some facilities.

Glass

Domestic consumption of soda ash in the glass container sector declined for the fifth consecutive year 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.

The public's perception that glass is more 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.

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 international chloralkali supply and demand situation in 1992 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 the end of 1992, the domestic chlorine market rebounded and caustic soda became available at less expensive prices, which lessened the demand for chemical caustic soda from trona.

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 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 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.

In Europe, superconcentrated liquid detergents were introduced recently that use polyethylene glycol rather than water as the carrying agent. These newer detergents reportedly contained smaller-sized water softening particles, which increased the quantity of particles per wash and allowed them to disperse quicker, thereby enabling the cleaning agents to work faster.[17] In the United States, about 50% of all detergents contain enzymes that are effective at stain removal and are environmentally acceptable. Approximately 40% of powdered detergents and 60% of liquid detergents contain at least one enzyme.[18]

Consumer preferences also usually help 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 for detergents 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., Solvay Minerals Inc., and Tg Soda Ash, Inc., have begun 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 and ethylene dichloride 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 1992, about 144,000 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, Belgium, 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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TABLE 1
SALIENT SODA ASH STATISTICS

(Thousand metric tons and thousand dollars)

	1988	1989	1990	1991	1992
United States:					
Production[1]	8,738	8,995	9,156	9,005	9,379
Value[1]	$644,973	$764,146	$836,188	$835,577	$836,690
Production, Wyoming trona	13,713	14,774	14,665	14,674	14,885
Exports[2]	2,238	2,648	2,392	2,734	2,955
Value[2]	$286,945	$365,469	$346,693	$409,088	$433,606
Imports for consumption	121	129	146	134	72
Value	$15,999	$17,396	$20,495	$21,299	$12,772
Stocks, December 31: Producers'	261	221	287	234	371
Consumption:					
Apparent	6,595	6,516	6,844	6,458	6,359
Reported	6,494	6,469	6,527	6,278	6,278
World: Production	r31,306	r32,032	r31,938	r31,053	e31,067

eEstimated. rRevised.

[1]Includes natural and synthetic. Natural only, and soda liquors and mine water converted to soda ash equivalent in 1988 and thereafter; 73,365 tons in 1988, 95,027 tons in 1989, 111,894 tons in 1990, 117,289 tons in 1991, and 120,608 in 1992.

[2]Export data for 1988 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 1992

(Million short tons, unless otherwise specified)

Company	Plant nameplate capacity	Plant location	Source of sodium carbonate
FMC Wyoming Corp.	2.85	Green River, WY	Underground trona.
General Chemical (Soda Ash) Partners[1]	2.40	do.	Do.
North American Chemical Co.[2]	1.30	Trona, CA	Dry lake brine.
Rhône Poulenc of Wyoming, L.P.[3]	1.96	Green River, WY	Underground trona.
Solvay Minerals Inc.[4]	2.00	do.	Do.
Tg Soda Ash Inc.[5]	1.30	Granger, WY	Do.
Total	11.81		
Total metric tons	10.71		

[1]A joint venture between General Chemical Corp. (51%), Australian Consolidated Industries International (ACI—25%), and TOSOH Wyoming Inc. of Japan (24%), which purchased part of ACI's share June 1992.

[2]Acquired Dec. 1, 1990, from Kerr-McGee Chemical Corp., with Oriental Chemical Industries of Korea as partner (27%).

[3]Joint venture between Rhône-Poulenc Basic Chemicals Co. of France (51%) and Union Pacific Resources Co. (49%).

[4]Acquired mid-1992 from Tenneco Minerals Co. Operation is a joint venture with Solvay S.A. of Belgium (80%) and Asahi Glass Co. of Japan (20%), which became a partner in Feb. 1990. A 600,000-ton expansion was completed June 1992.

[5]Owned by Texasgulf Inc., subsidiary of Societe Nationale Elf Aquitaine of France (100%).

TABLE 3
SODA ASH SUPPLY-DEMAND RELATIONSHIPS[1]

(Thousand metric tons)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
						WORLD PRODUCTION					
United States	7,093	7,681	7,721	7,721	7,655	8,066	8,738	8,995	9,156	9,005	9,379
Rest of world	19,714	20,210	21,513	20,514	21,705	22,137	r22,568	r23,037	r22,782	r22,048	e21,700
Total	26,807	27,891	29,234	28,235	29,360	30,203	r31,306	r32,032	r31,938	r31,053	e31,067
						COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY					
U.S. production capacity	10,124	10,124	10,124	10,124	9,580	9,580	9,512	9,580	9,950	9,950	10,710
Wyoming trona ore production	9,826	10,442	10,618	10,726	12,008	12,582	13,713	14,774	14,665	14,674	14,885
Domestic sources	7,093	7,681	7,721	7,721	7,655	8,066	8,738	8,995	9,156	9,005	9,379
Imports	16	18	15	51	96	136	121	129	146	134	72
Industry stocks, January 1[2]	239	294	279	292	355	267	235	261	221	287	234
Total U.S. supply	7,348	7,993	8,015	8,064	8,106	8,469	9,094	9,385	9,523	9,426	9,685
Distribution of U.S. supply:											
Industry stocks, December 31[2]	294	279	292	355	267	235	261	221	287	234	371
Exports	1,006	1,484	1,495	1,584	1,859	2,017	2,238	2,648	2,392	2,734	2,955
Industrial demand[3]	6,048	6,230	6,228	6,125	5,980	6,217	6,595	6,516	6,844	6,458	6,359
						U.S. DEMAND PATTERN[4]					
Glass (total):	3,176	3,130	3,085	3,084	3,152	3,343	3,390	3,294	3,177	2,997	3,082
Container	2,268	2,177	2,087	1,996	1,951	2,107	2,128	1,961	1,909	1,823	1,812
Flat	454	522	544	635	680	821	852	907	851	767	837
Fiber	200	209	227	249	272	249	246	241	228	206	214
Other	254	222	227	204	249	166	164	185	189	201	219
Chemicals	1,179	1,270	1,406	1,361	1,179	1,238	1,445	1,412	1,573	1,510	1,492
Soaps and detergents	454	562	544	544	590	684	718	781	835	796	765
Pulp and paper	249	181	227	318	181	63	111	114	132	147	175
Water treatment	209	209	272	272	227	72	110	92	91	106	104
Flue gas desulfurization	NA	NA	272	159	181	183	200	208	207	171	144
Distributors	NA	NA	NA	NA	NA	349	373	380	376	403	387
Other[5]	781	878	422	387	470	168	148	188	136	148	129
Total U.S. consumption	6,048	6,230	6,228	6,125	5,980	6,100	6,495	6,469	6,527	6,278	6,278
Undistributed[6]	—	—	—	—	—	117	100	47	317	180	81
Total U.S. primary demand	6,048	6,230	6,228	6,125	5,980	6,217	6,595	6,516	6,844	6,458	6,359
						VALUES[7]					
Average annual value:											
Dollars per short ton	88.35	76.95	67.00	67.82	65.29	66.78	66.96	77.07	82.85	84.18	80.93
Constant 1992 dollars	127.46	106.69	89.01	86.86	81.46	80.74	77.92	85.96	88.72	86.99	80.93
Dollars per metric ton	97.39	84.82	73.85	74.76	71.97	73.61	73.81	84.96	91.33	92.79	89.21
Constant 1992 dollars	140.51	117.60	98.12	95.75	89.80	88.99	85.89	94.76	97.80	95.88	89.21

eEstimated. rRevised. NA Not available; included in "Other."

[1]Natural and synthetic except where noted.

[2]Natural soda ash only for 1987 and thereafter; natural and synthetic from yearend 1982-86.

[3]Also known as apparent consumption (production plus imports minus exports plus or minus stock changes) and is equal to "Total U.S. primary demand."

[4]Estimated consumption for 1982-86 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.

[5]Includes soda ash used in petroleum and metal refining, leather tanning, enamels, etc. Also includes data in categories indicated by "NA."

[6]Because 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, and unsold foreign inventories of U.S. producers.

[7]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 not be synonymous with the posted list prices of the commodity. Gross domestic product used to derive constant 1992 dollars; 1987=100.

Source: U.S. Bureau of Mines.

TABLE 4
REPORTED CONSUMPTION OF SODA ASH IN THE UNITED STATES, BY END USE

(Metric tons)

SIC code	End use	1988	1989	1990	1991	1992
32	Glass:					
3221	Container	2,128,250	1,961,039	1,908,983	1,822,631	1,811,613
3211	Flat	851,853	907,333	850,687	767,381	837,269
3296	Fiber	246,273	240,799	227,770	205,888	213,935
3229	Other	163,560	185,083	189,452	201,059	219,041
	Total	3,389,936	3,294,254	3,176,892	2,996,959	3,081,858
281	Chemicals	1,445,211	1,412,180	1,572,890	1,509,840	1,491,886
284	Soaps and detergents	717,894	780,634	834,690	796,305	764,973
26	Pulp and paper	110,996	113,962	131,973	146,674	174,859
2899	Water treatment[1]	109,865	92,268	91,056	106,196	104,293
	Flue gas desulfurization	199,630	208,296	207,067	170,952	144,226
	Distributors	373,439	380,021	375,803	403,286	386,591
	Other	147,456	187,073	136,323	147,289	129,357
	Imports[2]	120,609	128,790	145,533	134,312	71,663
	Total domestic reported consumption[3]	6,494,427	6,468,688	6,526,694	6,277,502	6,278,043
	Export[4]	2,662,472	r [5]2,644,618	2,588,477	2,797,145	2,909,096
	Total industry sales[6]	9,156,899	[7]9,113,306	9,115,171	9,074,650	9,187,137
	Total production	8,738,042	8,994,717	9,156,036	9,004,790	9,378,883

rRevised.

[1]Includes soda ash equivalent from soda liquors, purge liquors, and mine water sold to powerplants or water treatment: 73,365 tons in 1988, 95,027 tons in 1989, 111,894 tons in 1990, 117,289 tons in 1991, and 137,433 in 1992.

[2]Data 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."

[3]Reported 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.

[4]As reported by producers. Includes Canada. Data may not necessarily agree with that reported by the Bureau of the Census for the same periods.

[5]Revised from monthly Mineral Industry Surveys data because of 181 metric tons (200 short tons) of misreported export data in first quarter 1989.

[6]Represents soda ash from domestic origin (production and inventory changes) and imports, and for exports.

[7]An extra 23,548 metric tons (25,957 short tons) of coproducer sales is included in total, but specific end-use breakout is unknown.

TABLE 5
SODA ASH YEAREND PRICES

		1991	1992
Sodium carbonate (soda ash):			
Dense, 58%, Na_2O 100-pounds, paper bags, carlot, works, f.o.b	per 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	151.00
Bulk, carlot, same basis tons	do.	123.00	103.00

Sources: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials. V. 238, No. 27, Dec. 31, 1991, p. 31; and v. 242., No. 26, Dec. 25, 1992, p. 29.

TABLE 6

REGIONAL DISTRIBUTION OF U.S. SODA ASH EXPORTS, BY CUSTOMS DISTRICTS, IN 1992

(Metric tons)

Customs districts	North America	Central America	South America	Caribbean	Europe	Middle East	Africa	Asia	Oceania	Total	Percent of total
Atlantic:											
Miami, FL	—	157	232	159	—	—	—	—	—	548	—
New York, NY	13	—	8	—	23	9	—	—	—	53	—
Norfolk, VA	—	—	—	—	—	4	—	—	—	4	—
Philadelphia, PA	—	—	8,356	—	—	—	—	—	—	8,356	—
Savannah, GA	—	2	—	—	—	—	—	—	—	2	—
Gulf:											
Houston-Galveston, TX	—	77	11	37	122,371	—	37	—	—	122,533	4
New Orleans, LA	—	120	—	107	—	—	—	—	—	227	—
Port Arthur, TX	—	—	185,764	10,209	5,017	6,179	—	—	—	207,169	7
Pacific:											—
Anchorage, AK	—	—	—	—	—	—	—	(1)	—	(1)	—
Columbia-Snake River	—	16,543	149,124	—	371,416	—	74,626	1,076,087	72,267	1,760,063	60
Los Angeles, CA	—	10,214	158,357	—	190,466	14,966	22,014	161,922	200	558,139	19
San Diego, CA	2,749	—	—	—	—	—	—	—	—	2,749	—
San Francisco, CA	—	—	—	—	—	—	—	61	20	81	—
Seattle, WA	6,274	—	—	—	—	—	—	—	—	6,274	—
North Central:											
Chicago, IL	—	—	—	—	1	—	—	—	—	1	—
Detroit, MI	69,643	—	—	—	54	—	—	—	—	69,697	2
Duluth, MN	20	—	—	—	—	—	—	—	—	20	—
Great Falls, MT	36,440	—	—	—	—	—	—	—	—	36,440	1
Pembina, ND	12,938	—	—	—	—	—	—	—	—	12,938	—
Northeast:											
Buffalo, NY	917	—	—	—	—	—	—	—	—	917	—
Ogdensburg, NY	1,302	—	—	—	—	—	—	—	—	1,302	—
Portland, ME	717	—	—	—	—	—	—	—	—	717	—
Southwest:											
El Paso, TX	2,038	—	—	—	—	—	—	—	—	2,038	—
Laredo, TX	156,956	—	—	—	—	—	—	—	—	156,956	5
Unknown:	7,497	—	—	—	—	—	—	—	—	7,497	—
Total[2]	297,504	27,114	501,851	10,511	689,348	21,157	96,678	1,238,070	72,486	2,954,723	100
Percent of total[2]	10	1	17	—	23	1	3	42	2	100	—

[1]Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 7
U.S. EXPORTS OF SODA ASH, BY COUNTRY

(Metric tons)

Country	1988	1989	1990	1991	1992
Algeria	—	(1)	4,057	18	37
Angola	—	—	(1)	—	—
Argentina	32,671	86,735	74,259	123,894	116,301
Aruba	3	—	—	—	—
Australia	62,126	66,596	72,737	59,334	54,396
Bahamas	11	—	5	—	—
Belgium	[2]11,119	—	—	44,400	181,039
Belize	—	34	8	—	—
Bermuda	8	33	1,075	18	13
Bolivia	2,474	1,449	554	900	3,320
Brazil	136,345	220,381	101,873	204,390	82,484
Bulgaria	(3)	—	—	—	—
Canada	[4]180,195	[4]252,741	151,480	151,455	135,835
Chile	47,382	72,680	39,425	58,901	75,029
China	[5]331,597	317,086	56,159	58,092	64,258
Colombia	34,608	26,252	21,910	10,299	38,244
Costa Rica	2,009	5,577	8,479	7,935	8,047
Croatia[6]	—	—	—	—	35,699
Dominican Republic	2,074	5,219	2,722	2,724	3,152
Ecuador	7,649	11,281	10,634	4,475	5,954
El Salvador	1,730	3,146	—	2,986	3,252
France	11,125	4,874	11,474	28,131	38,814
Gabon	—	—	1	—	—
Germany	204	45	64	376	56
Guatemala	14,801	4,951	—	8,810	11,628
Guyana	—	—	8	5	(1)
Haiti	(1)	—	41	61	—
Honduras	[7]39	14	7	—	6
Hong Kong	[8]116,779	[8]189,571	40,734	2,898	1,996
Hungary	—	—	9,916	—	—
India	—	24	—	—	—
Indonesia	110,102	179,502	173,920	189,676	220,398
Iran	—	—	43,248	—	14,966
Ireland	—	—	(1)	—	—
Israel	5,860	—	9,757	10,450	6,179
Italy	3	—	—	—	32,689
Jamaica	5,983	3,998	6,059	3,561	4,128
Japan	247,175	289,781	337,207	273,729	262,411
Jordan	1	—	—	—	—
Kenya	7	—	—	—	—
Korea, Republic of	130,495	131,458	190,521	231,920	252,320
Kuwait	—	—	20	—	—
Malaysia	27,790	21,324	55,844	37,709	39,815
Mexico	77,996	141,731	191,820	236,957	161,723
Morocco	—	—	600	—	—
Netherlands	328	3	20,028	63,505	142,614

See footnotes at end of table.

TABLE 7—Continued

U.S. EXPORTS OF SODA ASH, BY COUNTRY

(Metric tons)

Country	1988	1989	1990	1991	1992
Netherlands Antilles	5	9	—	—	—
New Zealand	21,098	23,000	24,397	17,276	18,090
Nigeria	—	—	3	18	—
Panama	1,891	1,526	2,181	4,059	4,180
Peru	17,714	15,030	11,181	15,997	12,768
Philippines	34,975	90,324	86,095	71,245	114,106
Poland	—	—	—	32	3
Qatar	10	—	—	—	—
Russia[9]	([10])	—	—	—	—
St. Lucia	—	—	5	—	—
Saudi Arabia	5	([1])	—	12	13
Senegal	—	17	—	—	18
Singapore	[11]6,001	4,946	12,987	10,056	5,960
Slovenia[6]	—	—	—	—	14,804
South Africa, Republic of	165,361	186,952	170,370	135,331	110,236
Spain	2	—	9	71,568	146,028
Sudan	—	7	—	—	—
Suriname	23	152	—	—	—
Sweden	38,901	25,086	20,521	25,421	21,017
Switzerland	—	—	447	—	—
Taiwan	99,134	69,793	112,449	118,571	114,504
Thailand	71,051	69,167	103,635	111,476	148,624
Trinidad and Tobago	5,684	8,321	5,624	8,737	3,230
Turkey	—	—	58,530	—	—
United Kingdom	34,461	27,422	34,179	108,481	36,090
Uruguay	—	—	2,990	1,688	2,544
Venezuela	140,973	90,183	109,766	193,067	165,205
Yugoslavia[12]	—	—	—	23,444	40,497
Total[13]	2,237,981	2,648,439	2,391,996	2,734,090	2,954,723

[1]Less than 1/2 unit.
[2]Adjusted using PIERS data to include 12,257 tons exported in Mar. and Sept. through Los Angeles, CA, customs district.
[3]In July, 33,069 tons was shipped to China, but credited to Bulgaria, by the United States to fulfill Bulgarian export commitment. Data included with China.
[4]Data representing imports from the United States as reported by Statistics Canada, International Trade Div. The Bureau of Census export statistics indicated only 123,254 tons in 1988.
[5]Includes 33,069 tons shipped by the United States but credited to Bulgaria.
[6]Formerly part of Yugoslavia.
[7]Adjusted using PIERS data to include 43 tons in July through Tampa, FL, customs district.
[8]The majority was bagged and transshipped to China.
[9]Formerly part of the U.S.S.R.
[10]Erroneous notation of shipment of 1,193 tons ($190,800), to Russia through Houston customs district in May. The error is not included in total.
[11]Adjusted to include 4,410 tons shipped in September and December.
[12]Dissolved in Apr. 1992.
[13]Data 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 8

U.S. IMPORTS FOR CONSUMPTION OF SODA ASH

Year	Disodium carbonate[1]	
	Quantity (metric tons)	Value[2] (thousands)
1988[3]	120,609	$15,999
1989[3]	128,790	17,396
1990	145,534	20,495
1991	134,312	21,299
1992	71,663	12,772

[1]Beginning 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 (calcined) and No. 4208600 (hydrated and sesquicarbonate).
[2]C.i.f. value at U.S. ports.
[3]Also contains sodium carbonate, hydrated and sesquicarbonate.

Source: Bureau of the Census.

TABLE 9

SODA ASH: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992e
Albania	22	27	e27	e25	25
Australia e	300	300	300	300	300
Austria e	145	150	150	150	150
Belgium e	2379	380	r375	r380	375
Bosnia and Herzegovina[3 4]	—	—	—	—	50
Botswana	—	—	—	r62	150
Brazil	184	197	e200	r200	200
Bulgaria e	r1,078	r1,130	21,046	1,000	1,000
Canada e	325	325	315	r310	305
China	2,609	3,042	3,746	e3,800	4,000
Colombia	114	114	121	e120	115
Czechoslovakia	112	e110	104	r e104	100
Denmark	r—	r—	r—	r—	—
Egypt	48	e47	52	r52	51
France e	1,270	1,300	1,200	1,100	1,000
Germany:					
Eastern states e	2914	r800	r700	—	—
Western states	r1,404	r1,443	r1,436	—	—
Total e	r 22,318	r2,243	r2,136	r1,948	1,660
India	1,098	1,344	e1,400	e1,500	1,500
Italy e	612	615	610	600	600
Japan	1,083	1,105	1,135	r1,103	1,000
Kenya[5]	220	241	244	e245	245
Korea, Republic of e	280	280	280	300	300
Mexico[6]	421	456	448	e450	450
Netherlands e	400	400	400	390	390
Pakistan e	2134	135	135	r147	150
Poland	r965	r988	r981	r e900	970
Portugal e	155	150	150	150	150
Romania e	r918	r889	r640	r477	2457
Russia[7]	—	—	—	—	3,000
Spain e	560	560	550	500	500
Taiwan	127	116	e120	r109	110
Turkey e	379	381	385	385	385
Ukraine[7]	—	—	—	—	1,000
U.S.S.R.[8]	5,097	4,809	4,359	r e4,100	—
United Kingdom e	1,000	1,000	1,000	1,000	1,000
United States[5]	8,738	8,995	9,156	9,005	29,379
Yugoslavia[4 9]	214	204	173	e140	—
Total	r31,306	r32,032	r31,938	r31,053	31,067

eEstimated. rRevised.

[1]Table includes data available through Apr. 20, 1993. Synthetic unless otherwise specified.

[2]Reported figure.

[3]Formerly part of Yugoslavia.

[4]All production in Yugoslavia from 1988-91 came from Bosnia and Herzegovina.

[5]Natural only.

[6]Includes natural and synthetic. Estimated production of natural soda ash, in metric tons, was as follows:1988—176,000; 1989—190,000; 1990—190,000; 1991—190,000; and 1992—190,000.

[7]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

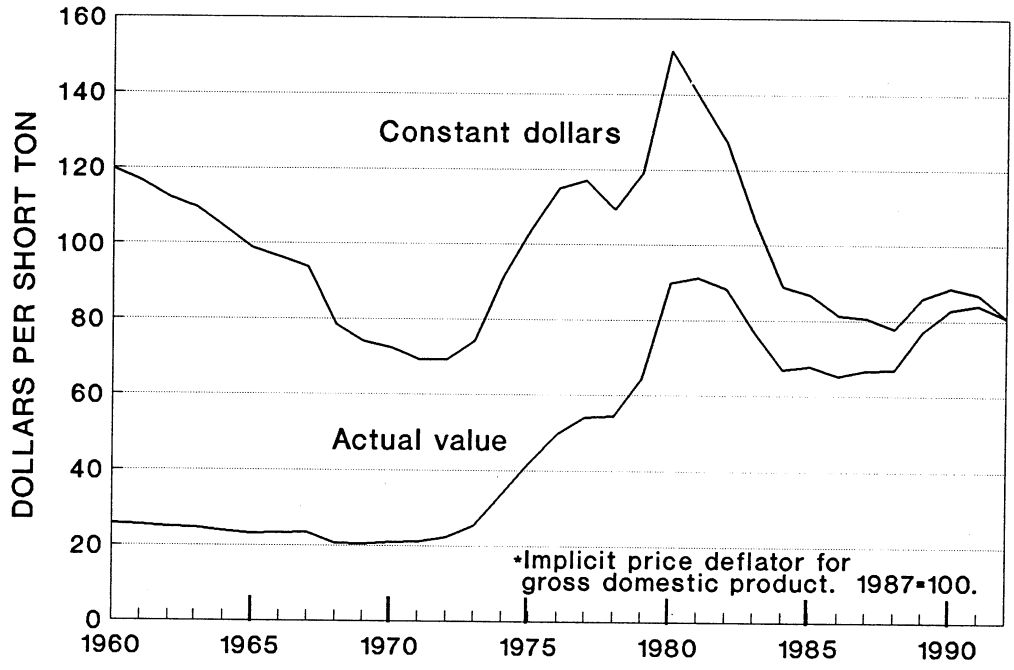
[8]Dissolved in Dec. 1991.

[9]Dissolved in Apr. 1992.

FIGURE 1

U.S. SODA ASH VALUES

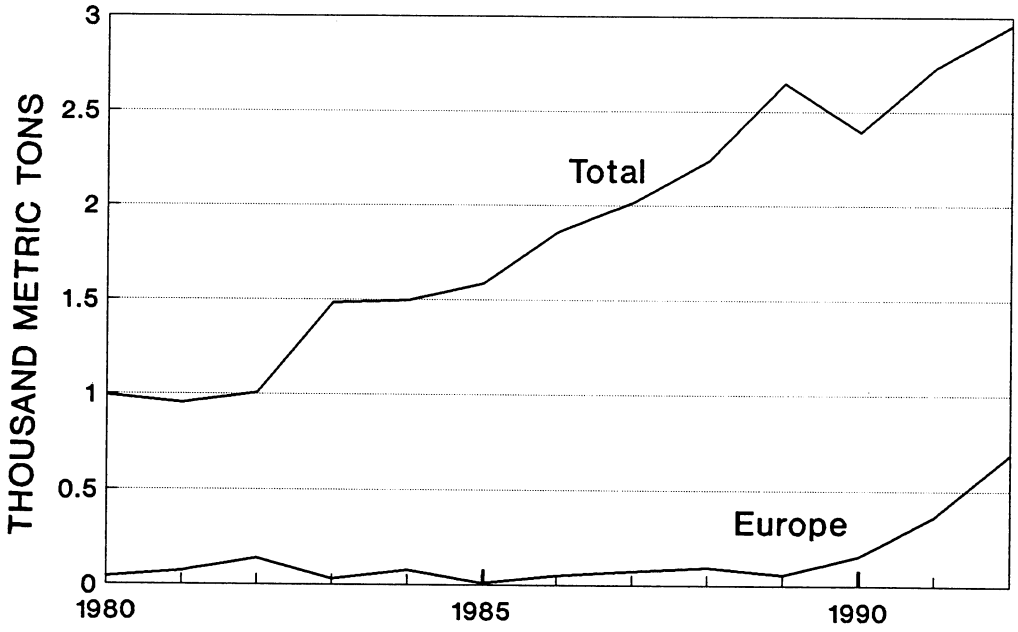
(Average value vs. 1992 constant dollars*)



Source: U.S. Bureau of Mines.

FIGURE 2

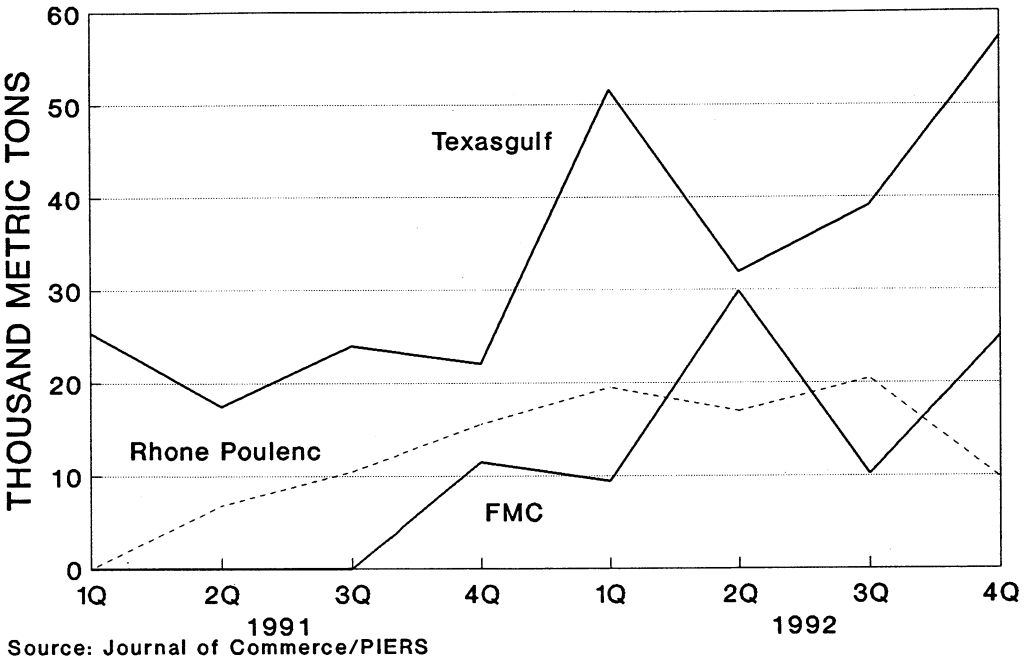
U.S. SODA ASH EXPORTS TO EUROPE RELATIVE TO TOTAL



Source: U.S. Bureau of the Census.

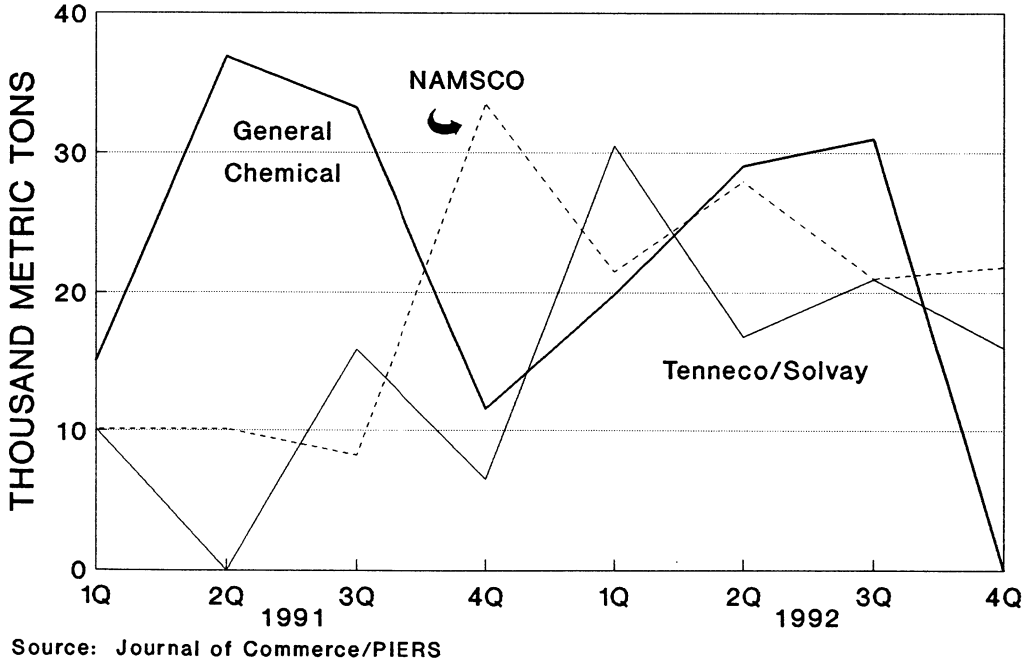
FIGURE 3

U.S. SODA ASH EXPORTS TO EUROPE, BY QUARTER AND COMPANY



Source: Journal of Commerce/PIERS

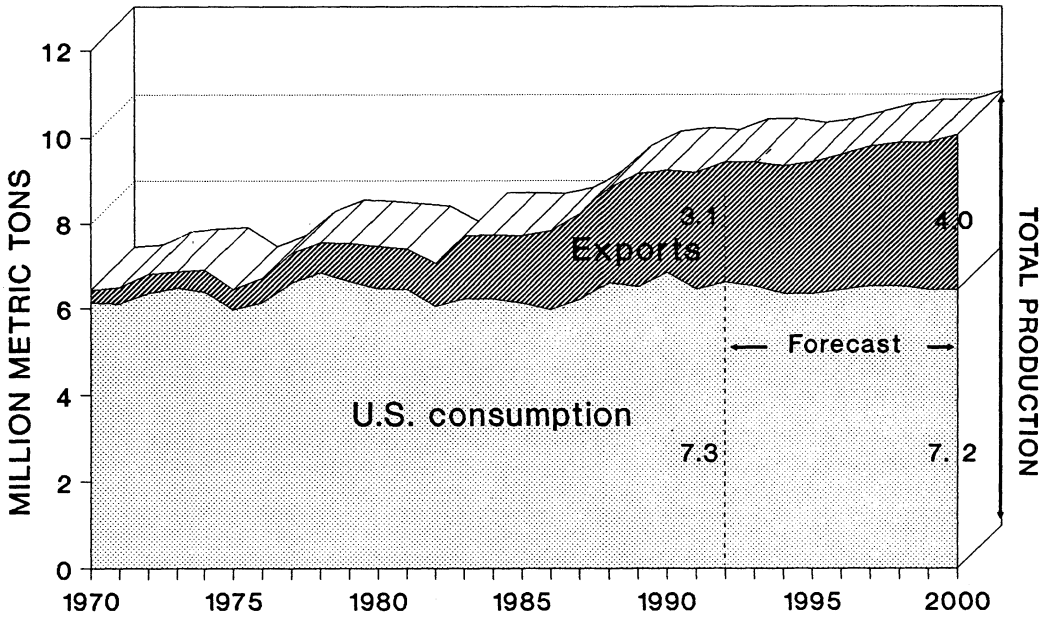
U.S. SODA ASH EXPORTS TO EUROPE, BY QUARTER AND COMPANY



Source: Journal of Commerce/PIERS

FIGURE 4

U.S. SODA ASH TRENDS: U.S. CONSUMPTION VS. EXPORTS



SODIUM SULFATE

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 14 years of U.S. Bureau of Mines experience, has been the commodity specialist for sodium sulfate since 1979. Domestic survey data were prepared by Maria Arguelles, mineral data assistant; and international data tables were prepared by Doug Rhoten, international data coordinator.

Sodium sulfate is produced from natural sources and as a byproduct from different chemical processes. Natural sodium sulfate is produced from naturally occurring brines and crystalline deposits found in California and Texas. It also is 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.

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 quarterly and annual surveys (aggregate data published in Current Industrial Reports, Inorganic Chemicals, MQ28A 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 Rudolf Glauber, a German chemist whose name is still associated with the hydrated crystal, Glauber's salt ($Na_2SO_4 \cdot 10H_2O$), and the anhydrous mixed sulfate, Glauberite ($Na_2SO_4 \cdot CaSO_4$).

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 ($Na_2SO_4 \cdot 10H_2O$). 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 13 companies operating 14 plants primarily in the Midwest and Mid-Atlantic regions. Total rated production capacity in 1992 was 776,000 tons, and the industry operated at 78% 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 postglacial 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 2.2 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 former 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% and

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. The brines in Texas do not yield any secondary products.

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 and 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 (EPA) 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. No data are 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 with 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

Total U.S. sodium sulfate production decreased more than 15% in 1992 according to preliminary statistics from the Bureau of the Census. U.S. apparent consumption declined 23%. Most of the decline in output was from byproduct sources that decreased 25% compared with that of the previous year. Production of natural sodium sulfate declined only about 5%. The downturn in production was attributed to the stagnant national economic conditions 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 1992. Figure 1 graphically shows the trend of U.S. production since 1970. Total production has declined 51% 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-based 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.

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.

Production

Domestic sodium sulfate production decreased 15% in 1992 primarily because of reduced demand for saltcake by the pulp and paper industry and declining use of high-purity material in powdered

detergents. Formosa Chemicals and Fibres Corp. USA decided not to construct a $700 million viscose rayon plant near Wallace, LA. Aside from generating 215 tons of sodium sulfate daily, the facility was to process 8,350 tons of hardwood pulp to make 300 tons of rayon fiber each day. The decision to not build the plant was because of long delays in the permitting process and the difficulty of operating the plant under the restrictions imposed by the EPA.[1]

The rayon staple fiber plant at Lowland, TN, was purchased in July by Lenzing A.G. of Austria from BASF Corp. The facility has a synthetic sodium sulfate production capacity of 34,000 tons annually. The transaction makes Lenzing the second largest domestic rayon manufacturer; Courtaulds Fibers is the largest.[2]

A battery recycling center is under construction in Waynesboro, GA, that is scheduled to recover about 27,000 tons of sodium sulfate annually. The facility, which is planned to be on-stream in early 1994, is owned by GNB Inc.[3]

The United States and Spain were the largest producers of total sodium sulfate, representing 14% each of the world total. Mexico produced 12%, followed by Canada, 7%; Japan and the former U.S.S.R., 6% each; and Germany, 5%. These seven countries accounted for approximately 63% of the world's output of total sodium sulfate, based on obtainable production data. *(See tables 5 and 6.)*

Consumption and Uses

Domestic sodium sulfate apparent consumption decreased 23% from that of the previous year. Most of the same conditions that affected demand in 1990 still remained in 1992. Concern for the environment was the paramount reason behind the stagnant supply and demand situation. Imports for consumption of sodium sulfate, primarily from Canada, were less than the historical average because of the depressed U.S. markets in which sodium sulfate is consumed.

An estimated 44% 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 the recycling of paper products. Kraft pulping represented about 83% of the domestic pulp market in 1992. 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 24% of the total demand for sodium sulfate.

The use of sodium sulfate in textiles apparently is increasing, according to industry sources. Salt traditionally has been used in the dyeing process to separate organic contaminants, promote "salting out" of dyestuff precipitates, and to blend with dyes to standardize concentrated dyes. The equipment used in this process used stainless steel, which was susceptible to corrosion because of the salt. The textile industry began substituting the salt with sodium sulfate, which is not corrosive to the manufacturing equipment. More than 100,000 tons of sodium sulfate was consumed by the textile industry in 1992, according to reliable industry estimates. *(See figure 2.)*

Stocks

Yearend inventories of natural sodium sulfate stored by the three producers were 47,006 tons, which was a 33% increase 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.

Markets and Prices

The average value declined from $87.34 per metric ton ($79.23 per short ton) in 1991 to $77.97 per metric ton ($70.73 per short ton) in 1992 for bulk sodium sulfate, f.o.b. mine or plant.

In May, Elf Atochem North America announced that it was raising its price of natural sodium sulfate by $5 immediately at its bagging facility in Charlotte, NC.[4] Prior Chemical Corp. announced an increase in its price of bagged anhydrous sodium sulfate from Mobile, AL, by $5 per ton effective August 1. The company also indicated that it would raise its off-list price of bagged and bulk material at different supply locations by $5 as of July 15.[5] North American Chemical Co. raised its off-list price of sodium sulfate by $5 effective August 1.[6] *(See table 7.)*

Foreign Trade

Canada represented virtually all of the total U.S. imports of sodium sulfate. Some imports were received from Germany, Japan, Mexico, and the United Kingdom. Total imports amounted to more than 158,000 tons in 1992, an increase of almost 1% compared with those of the previous year.

U.S. exports of 155,000 tons were 50% higher in 1992 when compared with those of the previous year. Approximately 46% of the total quantity was shipped to Australia, mainly for consumption by the detergent industry. Sodium sulfate also was exported to Chile, 13%; Colombia, 11%; New Zealand, 9%; and the Republic of Korea, 7%. The majority of exports were in the form of low-purity salt cake. *(See tables*

8 and 9 and figure 3.)

World Review

Industry Structure.—About 51% of the world sodium sulfate production in 1992 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 30 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 10.)*

Capacity.—The data in table 2 are rated capacities for domestic natural operations and byproduct recovering facilities in 1992. 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.—Salt of the Earth Co. was formed by members of the former Agassiz Resources Co., which closed in July 1991. The new company acquired Agassiz's plant at Saskatchewan and began producing natural sodium sulfate for sale to the Canadian detergent industry.[7]

Finland.—Kemira Fibres of Valkeakoski constructed a new sodium sulfate plant that increased the company's production capacity by 30,000 tons annually. The new plant, which cost FM30 million ($6.9 million), replaces the company's existing facility. The material will be sold primarily to various international textile manufacturers.[8]

OUTLOOK

Natural and synthetic sodium sulfate production and consumption decreased 36% and 46%, respectively, from those of 1980 to 1992. 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 least optimistically remain flat, in the next few years.

The United States has been a very important market for Canadian sodium sulfate. In 1992, 56% of Canadian output was exported to the United States. If domestic markets continue to decline, Canadian producers would continue to encounter financial hardships and would be forced to look for more distant export opportunities or consider possibly mothballing or closing some production capacity until market conditions improve. Sodium sulfate imports from Mexico were relatively minor in 1992 compared with those of the previous years.

Production

The changes in the domestic demand situation have 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.

Detergents

The use of sodium sulfate as a filler appears to have peaked in 1989. In 1992, sodium sulfate consumption in detergents reportedly was higher than that reported in 1991; however, the quantity of sodium sulfate available for consumption based on preliminary data reported by the Bureau of the Census indicates an opposite viewpoint. According to industry sources, the major detergent manufacturers switched back to making more traditional large boxes of powdered detergent. The changeover is unpredictable and varies depending on the economy, environmental considerations, etc. Sodium sulfate-based detergents compete with some of the popular sodium sulfate-free liquids and superconcentrates, which were first manufactured in Japan in 1987. Since their introduction into the United States in 1989, superconcentrates comprise 29% of the domestic detergent market.

Pulp and Paper

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 continue to increase as the demand for oxygen-based 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.

[1]Chemical Marketing Reporter. Formosa Throws in Towel on Viscose Rayon Plant. V. 242, No. 17, p. 5.
[2]Chemical Week. Lenzing Expansion Reflects Sunny Outlook in Rayon. V. 151, No. 6, p. 8.
[3]Chemical Marketing Reporter. Sulfate in Balance as Supply is Cut. V. 243, No. 4, p. 3.
[4]———. Bases and Salts. Sodium Sulfate. V. 241, No. 21, p. 28.
[5]———. Bases and Salts. Sodium Sulfate. V. 242, No. 2, p. 20.
[6]———. Bases and Salts. Sodium Sulfate. V. 242, No. 5, p. 12.
[7]Page 3 of work cited in footnote 3.
[8]European Chemical News. Kemira Starts Up New Na_2SO_4 Plant in Finland. V. 58, No. 1524, p. 6.

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Sodium Sulfate Deposits, Industrial Minerals and Rocks, Society of Mining Engineers, 5th ed., V. 2, 1983, pp. 1207-1223.

TABLE 1
SALIENT SODIUM SULFATE STATISTICS

(Thousand metric tons and thousand dollars)

	1988	1989	1990	1991	1992
United States:					
Production[1]	743	685	713	r720	609
Value[2]	$64,545	$62,703	$64,244	r$62,885	$55,900
Exports	77	62	62	103	155
Value	$8,737	$6,241	$6,704	$11,495	$11,865
Imports for consumption	136	173	162	157	158
Value	$11,962	$13,990	$13,155	$13,807	$13,444
Stocks, Dec. 31: Producers	54	24	39	35	47
Apparent consumption	798	r826	798	r778	600
World: Production	r4,862	r4,789	r4,751	r46,611	e4,297

eEstimated. rRevised.
[1]Includes natural and synthetic. Total production data for synthetic sodium sulfate, obtained from the Bureau of the Census, were revised in Dec. 1990 M28A Inorganic Chemicals, Current Industrial Report.
[2]The value for synthetic sodium sulfate is based upon the average value for natural sodium sulfate.

TABLE 2

U.S. PRODUCERS OF NATURAL AND SYNTHETIC SULFATE IN 1992

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., Westend plant	218	Trona, CA	Dry lake brine.
Ozark-Mahoning Co.[1]	141	Seagraves, TX	Do.
Total	404		
Sodium sulfate, synthetic:			
Lenzing A.G.[2]	34	Lowland, TN	Rayon manufacture.
Courtaulds North America Inc.	45	La Moyne, AL	Do.
Cyprus Minerals Co.[3]	16	Kings Mountain, NC	Lithium carbonate.
Flour Corp., Doe Run Co.	9	Boss, MO	Battery recycling.
W. R. Grace & Co.	8	Nashua, NH	Chelating agents.
J. M. Huber Corp.	32	Etowah, TN	Silica pigment.
Do.	14	Havre de Grace, MD	Do.
INDSPEC Chemical Corp.	35	Petrolia, PA	Resorcinol manufacture.
North American Rayon Corp.	14	Elizabethton, TN	Rayon manufacture.
Occidental Chemical Corp.	109	Castle Hayne, NC	Sodium dichromate manufacture.
Public Service Co. of New Mexico	6	Waterflow, NM	Flue gas desulfurization.
Teepak, Inc.	6	Danville, IL	Cellulose manufacture.
Star Enterprise[4]	3	Delaware City, DE	Flue gas desulfurization.
Total	372		
Grand total	776		

[1]Ozark's Brownfield plant, owned by Atochem North America (formerly Pennwalt), was placed on standby in Sept. 1987; 64,000 tons of capacity is not included in total industry capacity.
[2]Acquired from BASF July 1992.
[3]Facility idle since 1986.
[4]Owned by Saudi Refining Inc. (50%) and Texaco Inc. (50%).

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.[2]	1,814	2,268
Total	1,994	2,540
Africa:		
Botswana	188	227
World total[3]	3,300	4,600

[1]The 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."
[2]Dissolved in Dec. 1991.
[3]Rounded.

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 1992 dollars[2]	
	Short ton	Metric ton	Short ton	Metric ton
1970	18.28	20.15	62.96	69.41
1971	16.00	17.64	52.28	57.64
1972	16.26	17.92	50.67	55.84
1973	17.26	19.03	50.53	55.71
1974	23.99	26.44	64.60	71.19
1975	41.48	45.72	101.93	112.35
1976	49.25	54.29	113.85	125.50
1977	46.09	50.81	99.68	109.89
1978	46.06	50.77	92.35	101.79
1979	55.69	61.39	102.79	113.31
1980	62.42	68.81	105.25	116.03
1981	71.03	78.30	108.84	119.98
1982	83.00	91.49	119.75	131.99
1983	93.30	102.85	129.36	142.60
1984	92.16	101.59	122.44	134.97
1985	92.19	101.62	118.07	130.15
1986	86.11	94.92	107.44	118.43
1987	86.72	95.59	104.84	115.57
1988	78.81	86.87	91.70	101.08
1989	83.05	91.55	92.63	102.11
1990	87.66	96.63	93.87	103.48
1991	79.23	87.34	81.87	90.25
1992	70.73	77.97	70.73	77.93

[1]Based 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.
[2]Final implicit price deflators for 1992 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 RELATIONSHIPS[1]

(Thousand metric tons)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
WORLD PRODUCTION											
United States	r784	r776	r791	r736	r763	r725	r743	r685	r713	r720	609
Rest of world	3,337	3,306	3,611	3,773	3,846	4,170	r4,119	r4,104	r4,038	r3,891	e3,688
Total	4,121	4,082	4,402	4,509	4,609	r4,895	r4,862	r4,789	r4,751	r4,611	e4,297
CONSUMPTION AND DISTRIBUTION OF U.S. SUPPLY											
Domestic sources	784	776	791	736	763	725	743	685	713	r720	609
Imports	357	311	240	177	171	125	136	r173	162	157	158
Industry stocks, Jan. 1[2]	60	27	44	54	28	65	50	54	24	39	35
Total U.S. supply	1,201	1,114	1,075	967	962	915	929	r912	899	r916	802
Distribution of U.S. supply:											
Industry stocks, Dec. 31[2]	27	44	54	28	65	50	54	24	39	35	47
Exports	101	83	69	108	101	111	77	62	62	103	155
Industrial demand	1,073	987	952	831	796	754	798	r826	798	r778	600
U.S. DEMAND PATTERN[3]											
Glass	54	50	49	48	48	45	48	33	32	36	36
Pulp and paper	490	464	454	445	239	226	239	231	223	200	144
Soaps and detergents	426	425	363	318	414	392	415	495	479	400	264
Textiles	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	126
Other[5]	103	48	86	20	95	91	96	r67	64	r142	30
Total U.S. primary demand	1,073	987	952	831	796	754	798	r826	798	r778	600
VALUES[6]											
Average annual value per short ton[7]	83.30	93.30	92.16	92.19	86.11	86.72	78.81	83.05	87.66	79.23	70.73
Average annual value per metric ton	91.49	102.85	101.59	101.62	94.92	95.59	86.87	91.55	96.63	87.34	77.93

eEstimated. rRevised.

[1]Natural 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.

[2]Natural sodium sulfate only.

[3]Estimated using data from "Chemical Profile" issues on sodium sulfate by Chemical Marketing Reporter for 1983, 1986, and 1989.

[4]Included with "Other" prior to 1992.

[5]Includes 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.

[6]Dollars per ton for natural sodium sulfate, f.o.b. mine or plant.

[7]Although data from 1990 and thereafter will be published in metric units, historical values based on short tons will continue to be published for reference.

TABLE 6

SYNTHETIC AND NATURAL SODIUM SULFATE[1] 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	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	[4]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	r367	r353	r720	r366	354	30,904
1992	341	268	609	272	337	26,262

rRevised. W Withheld to avoid disclosing company proprietary data.

[1]All quantities converted to 100% Na_2SO_4 basis.

[2]Current Industrial Reports, Inorganic Chemicals, Bureau of the Census. Revisions from 1988 Annual (Preliminary), MA28A, Nov. 1989, p. 11, and MQZ28A, Feb. 1993.

[3]Includes Glauber's salt.

[4]Data do not add to total shown because of independent rounding.

TABLE 7

SODIUM SULFATE YEAREND PRICES

		1991	1992
Sodium sulfate (100% Na_2SO_4):			
East, bulk, carlot, works, freight equalized	per ton	$113.00- $114.00	$113.00- $114.00
Gulf, bulk, carlot, same basis	do.	110.00	110.00
West, bulk, carlot, same basis	do.	127.00	127.00
Salt cake (100% Na_2SO_4):			
East, bulk, f.o.b. works	do.	72.00	72.00

Sources: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials. V. 240, No. 27, Dec. 30, 1991, p. 31, and V. 242, No. 26, Dec. 28, 1992, p. 29.

TABLE 8

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)
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	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
1992:						
Canada	83,931	7,831,881	73,957	5,560,087	157,888	13,391,968
Germany	125	12,344	—	—	125	12,344
Japan	138	1,326	—	—	138	1,326
Mexico	12	7,796	191	29,441	203	37,237
United Kingdom	1	1,326	—	—	1	1,326
Total	84,207	7,854,673	74,148	5,589,528	158,355	13,444,201

[1]Beginning in 1989, import data were reclassified under the Harmonized Tariff System. Salt cake is HTS No. 2833111000. Includes "Other disodium sulfate, and other "(Glauber's salt); HTS No. 2833115050.
[2]C.i.f. value at U.S. ports.
[3]Classified as "Other disodium sulfate, anhydrous;" HTS No. 2833115010.

Source: Bureau of the Census.

TABLE 9
U.S. EXPORTS OF SODIUM SULFATE, BY COUNTRY

Country	Disodium sulfate, salt cake		Disodium sulfate, other		Total	
	Quantity (metric tons)	Value[1] (dollars)	Quantity (metric tons)	Value[1] (dollars)	Quantity (metric tons)	Value[1] (dollars)
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	—	—	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
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
Total	82,149	8,316,175	20,863	3,178,928	103,012	11,495,103
1992:						
Argentina	1,000	103,000	2	3,627	1,002	106,627
Australia	71,917	1,795,235	—	—	71,917	1,795,235
Bahamas, The	40	4,095	—	—	40	4,095
Bahrain	—	—	22	41,856	22	41,856
Belize	20	3,837	—	—	20	3,837
Brazil	—	—	2	2,762	2	2,762
Canada	286	37,715	—	—	286	37,715
Chile	15,827	1,844,556	4,008	388,752	19,835	2,233,308
China	—	—	19	20,975	19	20,975
Colombia	10,822	440,966	5,890	588,985	16,712	1,029,951
Dominican Republic	14	2,596	—	—	14	2,596
El Salvador	500	61,500	—	—	500	61,500
Germany	—	—	3	9,654	3	9,654

See footnotes at end of table.

TABLE 9—Continued

U.S. EXPORTS OF SODIUM SULFATE, BY COUNTRY

Country	Disodium sulfate, salt cake		Disodium sulfate, other		Total	
	Quantity (metric tons)	Value[1] (dollars)	Quantity (metric tons)	Value[1] (dollars)	Quantity (metric tons)	Value[1] (dollars)
1992—Continued:						
Guatemala	4,687	576,539	2,909	307,848	7,596	884,387
Hong Kong	—	—	64	63,284	64	63,284
Japan	—	—	46	22,372	46	22,372
Korea, Republic of	10,761	1,272,175	115	888,536	10,876	2,160,711
Mexico	339	27,342	1,079	294,721	1,418	322,063
New Zealand	13,480	1,379,723	—	—	13,480	1,379,723
Panama	—	—	(2)	5,250	(2)	5,250
Portugal	—	—	94	60,264	94	60,264
Singapore	—	—	15	16,380	15	16,380
Spain	—	—	2	4,941	2	4,941
Switzerland	—	—	(2)	4,295	(2)	4,295
Taiwan	—	—	28	53,808	28	53,808
United Kingdom	—	—	14	3,783	14	3,783
Venezuela	3,945	473,992	6,792	597,427	10,737	1,071,419
Total	133,638	8,023,271	21,104	3,379,520	154,742	11,402,791

[1]F.a.s. value at U.S. ports.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 10

SODIUM SULFATE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992e
Natural:					
Argentina	15,341	10,281	e11,000	e10,500	10,000
Canada	330,971	327,000	347,000	r332,000	280,000
Chile[3]	15,879	10,245	13,497	e13,000	13,200
China[e 4]	27,000	27,000	27,000	28,000	28,000
Egypt	r e42,000	45,677	41,418	r41,110	41,000
Iran	213,521	184,848	176,951	r144,204	150,000
Mexico[5]	r422,000	r478,000	r545,157	r517,600	518,000
Netherlands[e]	22,000	22,000	22,000	22,000	22,000
South Africa, Republic of	255	15	e20	e20	20
Spain[e]	450,000	450,000	430,000	450,000	450,000
Turkey	79,427	r68,183	r e70,000	r e75,000	75,000
Turkmenistan[6]	—	—	—	—	200,000
U.S.S.R.[e 7]	375,000	365,000	340,000	320,000	70,000
United States	361,345	339,761	349,256	353,836	p336,829
Total	r2,354,739	r2,328,010	r2,373,299	r2,307,270	2,194,049
Synthetic:					
Austria[e]	118,000	120,000	120,000	120,000	120,000
Belgium[e]	255,000	255,000	250,000	250,000	250,000
Bosnia and Herzegovina[9]	—	—	—	—	5,000
Brazil[e]	9,000	9,000	9,000	9,000	9,000
Chile[10]	47,000	56,245	59,509	e60,000	61,800
Finland[e]	35,000	33,000	33,000	33,000	33,000
France[e]	154,000	120,000	120,000	120,000	120,000
Germany:[e]					
Eastern states	180,000	175,000	170,000	—	—
Western states	175,000	r172,178	r167,120	—	—
Total	355,000	r347,178	r337,120	r e288,900	220,000
Greece[e]	7,000	6,000	6,000	6,000	6,000
Hungary[e]	9,000	9,000	8,000	8,000	7,000
Italy[e]	127,000	130,000	130,000	125,000	125,000
Japan	246,541	256,393	253,131	r249,817	240,000
Macedonia[9]	—	—	—	—	3,000
Netherlands[e]	15,000	15,000	15,000	15,000	15,000
Pakistan[e]	1,000	1,000	1,000	1,000	1,000
Portugal[e]	54,000	55,000	55,000	50,000	50,000
Serbia and Montenegro[9]	—	—	—	—	15,000
Spain[e]	165,000	165,000	160,000	150,000	150,000
Sweden[e]	100,000	100,000	100,000	100,000	100,000
Turkey[e]	27,000	27,000	27,000	30,000	30,000
U.S.S.R.[e 7]	270,000	270,000	250,000	220,000	180,000

See footnotes at end of table.

TABLE 10—Continued

SODIUM SULFATE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Synthetic—Continued:					
United Kingdom[e]	90,000	90,000	90,000	90,000	90,000
United States[11]	381,517	345,555	315,604	342,576	[8]272,484
Yugoslavia[12]	41,479	50,333	37,953	[e]35,000	—
Total	2,507,537	[r]2,460,704	[r]2,377,317	[r]2,303,293	2,103,284
Grand total	[r]4,862,276	[r]4,788,714	[r]4,750,616	[r]4,610,563	4,297,333

[e]Estimated. [r]Revised.

[1]Table includes data available through May 25, 1993.

[2]In 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.

[3]Natural mine output, excluding byproduct output from the nitrate industry, which is reported separately under "Synthetic" in this table.

[4]Byproduct sodium sulfate is known to be recovered but reliable data are not available; not included under "Synthetic."

[5]Total output as reported in the Anuario Estadístico de la Industria Química Mexicana.

[6]Formerly part of the U.S.S.R.; data were not reported seperately until 1992.

[7]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries, other than those listed in this table.

[8]Reported figure.

[9]Formerly part of Yugoslavia; data were not reported separately until 1992.

[10]Byproduct of nitrate industry.

[11]Derived 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).

[12]Dissolved in Apr. 1992.

FIGURE 1
PRODUCTION OF SODIUM SULFATE, NATURAL VERSUS SYNTHETIC

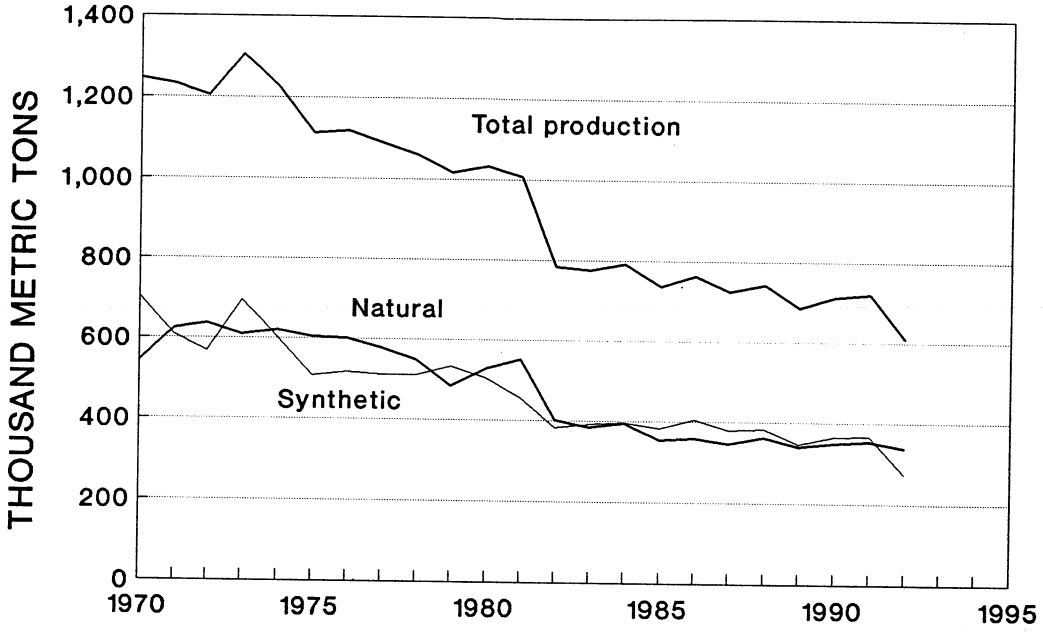


FIGURE 2
SODIUM SULFATE END USES

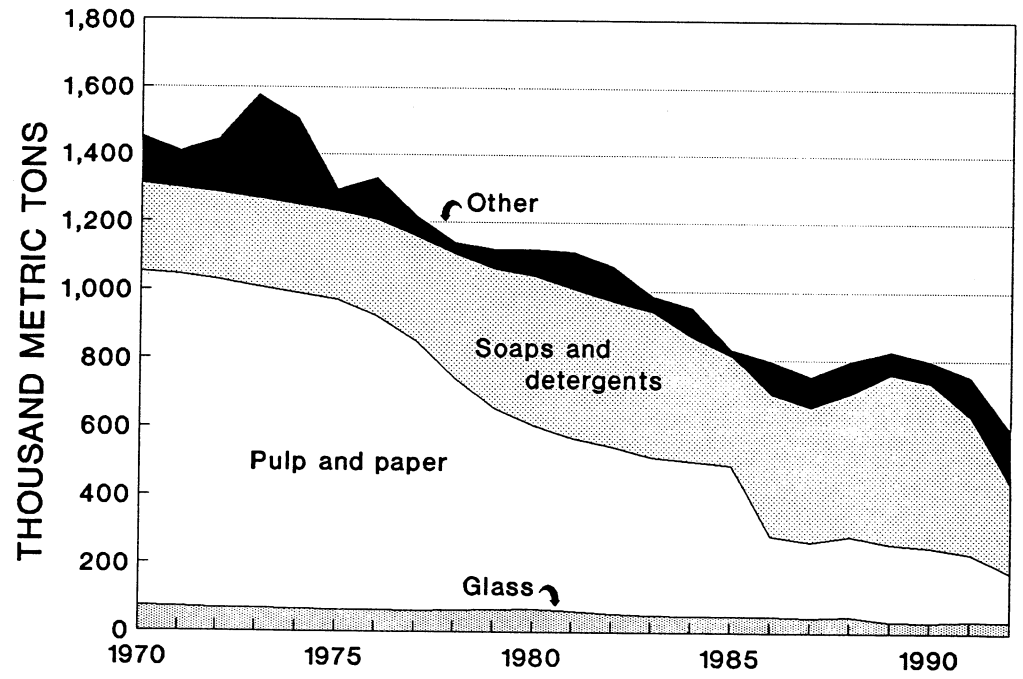
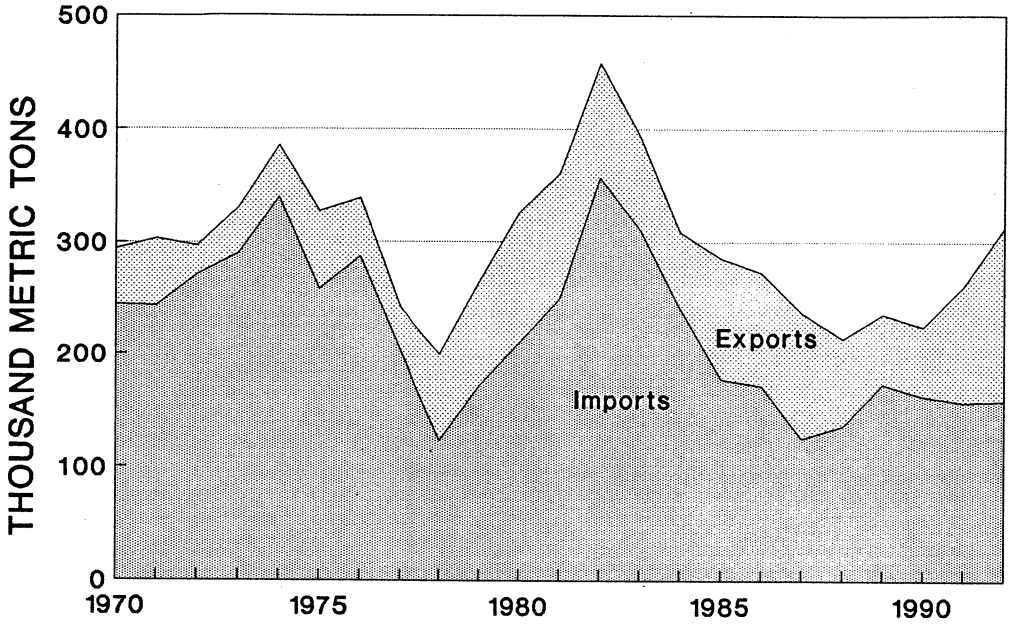


FIGURE 3
IMPORTS AND EXPORTS OF SODIUM SULFATE



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.

Complying with the provisions of the Metric Conversion Act of 1975 and the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418), beginning with this issue of the Annual Report for Crushed Stone, the U.S. Bureau of Mines will publish its statistical information on crushed stone in U.S. customary units as well as metric units. Initially, the reporting in dual units will be applied to the totals only, with increased emphasis on metric units in successive years.

A total of 1.16 billion short tons (1.05 billion metric tons) of crushed stone was produced for consumption in the United States in 1992, a 5.3% increase compared with that of 1991. This tonnage represents the second consecutive year of crushed stone production of more than 1.1 billion tons, approaching the 1987 through 1990 levels of production. *(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 2.)*

Foreign trade of crushed stone remained relatively minor again in 1992. Exports increased 66.9% to 4 million tons (3.7 million metric tons) while value increased 31.5% to $43 million compared with that of 1991. Imports of crushed stone, including calcium carbonate, also increased 35.1% to 7.7 million tons (7 million metric tons) while the value increased 57.3% to $60.7 million. Domestic apparent consumption of crushed stone was 1.16 billion tons. *(See tables 8 and 9.)*

The major issues of concern to the crushed stone industry are: the implementation of the Clean Air Act Amendments of 1990 and its complex legal and technical provisions; the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, section 404, dealing with "wetlands" and the associated "no net loss of wetlands" policy; the Storm Water Pollution Prevention Program; the Occupational Safety and Health Administration's (OSHA) Hazard Communication Standards regulating the use of products containing more than 0.1% crystalline silica; and the provisions of the Federal Endangered Species Act.

The removal of nonasbestiform Anthophyllite, Tremolite, and Actinolite (AT&A) from the scope of the present Occupational Safety Health Advisors standards for regulating occupational exposure to asbestos in 1992 eliminated one of the major area of concern of the construction aggregates industries.

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.

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, $CaMg(CO_3)_2$; 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 (AASTO). 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 1 quarry to large, diversified corporations with 50 or more crushed stone operations.

In 1991, the last year when a complete survey of the crushed stone producers

was conducted, 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. 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 1991 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, France, Germany, 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 [$CaMg(CO_3)_2$], 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 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 includes 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 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 most 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 commonly encountered beneath beds of limestone and is mined as a coproduct. Amphibolite rock commonly 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 types 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. 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 Issues.—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 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 the United Kingdom, using large oceangoing vessels. Some of these are self-unloading vessels.

ANNUAL REVIEW

A total of 1.16 billion short tons (1.05 billion metric tons) of crushed stone was produced for consumption in the United States in 1992, a 5.3% increase compared with that of 1991. This tonnage represents the second consecutive year of crushed stone production of more than 1.1 billion tons, approaching the 1987-90 levels of production. *(See table 1.)*

Legislation

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 nonasbestiform varieties will be regulated according to limits set for "particulates not otherwise regulated." The latest administrative stay of enforcement of the revised standards was also removed by OSHA effective May 29, 1992.

The U.S. Environmental Protection Agency (EPA) issued final general stormwater permits to regulate discharges resulting from industrial and construction activities that disturb 5 or more acres. Facilities that must be covered by a stormwater permit include many mining operations where water comes into contact with raw materials or wastes. All facilities covered by a general permit must prepare and implement a site-specific stormwater pollution-prevention plan. To assist industry in complying with the stormwater requirements, the EPA has developed guidance manuals on sampling and on pollution prevention management practices.

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.

Issues

The new complex legal and technical provisions of the comprehensive amendments of 1990 to the Clean Air Act and the implementing regulations for these provisions constitute a major area of concern to the crushed stone industry. One major emphasis of the amendments is expanded authority given to EPA and the States to enforce the new law and asses increased penalties. EPA is now authorized to issue administrative orders with penalties of up to $200,000 for noncompliance, and its field inspectors can issue citations for minor violations with penalties of up to $5,000 per day for each violation. The law also includes provisions for new Federal permits to be issued by the State agencies that include source specific emission limitations and related monitoring, recordkeeping, and reporting requirements. Complying with the new provisions of the Clean Air Act Amendments will constitute a major challenge to all crushed stone producers.

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 reintroduced in the 103d 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.

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 1.16 billion short tons (1.05 billion metric tons) of crushed stone was produced for consumption in the United States in 1992, a 5.3% increase compared with that of 1991. *(See table 1.)* Based on prior year data, it is estimated that about three-quarters of the crushed stone production continued to be limestone and dolomite, followed by granite, traprock, sandstone and quartzite, miscellaneous stone, marble, shell, calcareous marl, volcanic cinder and scoria, and slate, in order of volume. Production information by kind of stone is available only for odd-numbered years when full surveys of crushed stone producers are conducted by the U.S. Bureau of Mines.

The production estimates indicate that in 1992, compared with the reported 1991 data, the output of crushed stone increased in all geographic regions except the Pacific. The largest increases were recorded in New England, 19.3%; the East South Central, 14.7%; and the West North Central, 12.4%. The only region showing a decrease in the production of crushed stone was the Pacific with -10.6%.

The South Atlantic region continued to lead the Nation in the production of crushed stone with an estimated 252 million tons or 21.7% of the U.S. total, followed by the East North Central region with 228 million tons or 19.7%, and the East South Central region with 137 million tons or 11.8%. *(See table 3.)* Crushed stone was produced in every State except Delaware.

The 10 leading States in the production of crushed stone, in order of volume, were Illinois, Pennsylvania, Texas, Florida, Kentucky, Missouri, North Carolina, Ohio, Virginia, and Tennessee. Their combined production represented 49.7% of the national total.

Significantly less changes in ownership, acquisitions, and mergers occurred in the crushed stone industry in 1992 compared with prior years. Martin Marietta Aggregates of Raleigh, NC, acquired in the first half of 1992 a 50% interest in Kaser Corp. of Des Moines, IA. Kaser operates 10 quarries in Iowa and 3 quarries in Missouri.

Granite Construction Co. of Watsonville, CA, acquired from Tarmac America of Herndon, VA, 13 crushed stone and sand and gravel operations in southern California. The transaction also included 10 ready-mixed concrete plants and 5 asphalt operations.

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 reported only their total production and no breakdown by end uses, their production is included in "Unspecified, actual" totals. The estimated production of nonrespondents is reported under "Unspecified, estimated." *(See table 7.)* Production information by uses of stone is available only for odd-numbered years when full surveys of crushed stone producers are conducted by the U.S. Bureau of Mines.

Prices

Compared with the actual prices of 1991, the 1992 estimated average unit price for all crushed stone increased 2.6% to $4.82. Over a 21-year period, the average unit price of crushed stone increased from $1.72 per ton, f.o.b. plant, in 1972, to $4.82 in 1992. However, the unit price in constant 1987 dollars fluctuated between a low $3.37 per ton in 1991 and a high of $3.90 in 1971. Price information by kind of stone and uses is available only for odd-numbered years when full surveys of crushed stone producers are conducted by the U.S. Bureau of Mines.

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 increased 66.9% to 4 million tons (3.7 million metric tons) while value increased 31.5% to $43 million compared with that of 1991. About 95% of the exported crushed stone was limestone. Canada remains the major destination for the exported crushed stone with 88.3% of the total exports. *(See table 8.)*

Imports.—Imports of crushed stone, including calcium carbonate, also increased 35.1% to 7.7 million tons (7 million metric tons) while the value increased 57.3% to $60.7 million.

About 92% of the imported crushed stone was limestone, 47% of which came from Mexico, 31% from Canada, and 12% from the Bahamas. *(See table 9.)*

Imports of natural calcium carbonate fines decreased slightly to 2,300 short tons. About 65% of processed calcium carbonate was imported from France.

Shipments of crushed stone from the Bahamas, Canada, and Mexico into the United States continued in 1992. 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 1991 production of stone in Canada was 88 million metric tons, a decrease of 21% from the revised final 1990 total of 111 million tons, valued at $663 million. The Province of Ontario continued to be the largest producer of stone, with 38.7 million tons valued at $238 million, followed by Quebec with 34.8 million tons valued at $209 million. The two Provinces accounted for 83.7% of the total stone production. Preliminary estimates for 1992 stone production indicate a decrease of 7% to 81.6 million tons valued at $508 million. The Provinces of Ontario and Quebec continued to be the largest producers of stone with about 83% of the total output. The above totals do not include the crushed stone used in the Canadian cement and lime industries.

United Kingdom.—The 1991 production of crushed stone in Great Britain (Northern Ireland not included) was 184.9 million tons, a decline of 7% compared with the 1990 total, as reported by the British Geological Survey. Of this total, 148 million tons was used for construction purposes. About 62% of the total output of crushed stone was limestone and dolomite. Preliminary estimates indicate that the 1992 production of crushed stone remained at about the same level with the prior year at 185 million tons.

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 was to establish and provide the funding for a new Aggregates Research Center (CAR). On August 25, 1992, the formal ceremonies establishing CAR took place at the University of Texas at Austin. The center will be operated jointly by the University of Texas at Austin and Texas A&M University and financed by the AFTRE. The center's mission is to conduct scientific and technical research related to aggregates; coordinate technology transfer activities; establish a central information clearinghouse on aggregates technology; and develop undergraduate and graduate engineering courses and continuing education programs related to aggregates research.

A technical advisory committee overviewing the center's activity identified six priority areas of research that include: fine aggregates properties and their influence on end products; uses for fines resulting from the processing of aggregates; performance-related tests for aggregates; proper use of aggregates in asphaltic concrete to minimize rutting; prevention of alkali-silica and alkali-carbonate reactivity of aggregates in portland cement concrete; and nature and effects of coatings on aggregates.

Nineteen ninety-two was the last year of the 5-year Strategic Highway Research Program (SHRP) created by the U.S. Congress through the Surface Transportation and Uniform Relocation Assistance Act of 1987. SHRP's mission was 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 performance of asphalt concrete mixtures, a new set of specifications called Superpave is being finalized by SHRP. Superpave specifications use performance-based criteria and take into account environmental factors and traffic volumes and loads, a dramatic departure from earlier mixture specifications.[14] SHRP also continues to refine and improve its asphalt binder specifications that will produce a superior quality asphalt and address the rutting, low-temperature cracking, fatigue cracking, aging, and loss of adhesion problems.

SHRP's concrete program is in the final stage of developing new engineering guidelines, materials tests, and specifications that will produce consistently a more durable concrete for use in highway construction work. SHRP's program identified materials and the processes needed to produce a very early, high strength concrete that requires only 4 hours of curing time, therefore speeding up the construction process and reducing interruptions of the traffic flow.

Alkali-Silica Reactivity (ASR) of concrete is a major cause of deterioration in highway structures and pavements. SHRP's research found that lithium hydroxide introduced into concrete can prevent or inhibit ASR. Laboratory evaluations also showed that lithium hydroxide alone, or in combination with class-F fly ash, is very effective in inhibiting expansion even in concrete made with highly reactive aggregates.

SHRP's structure program is developing guidelines for evaluation, protection, and rehabilitation of structures. The presence of chloride in concrete is the number-one cause of distress in highway structures. Unprotected reinforcing steel used in concrete structures is highly susceptible to chloride-induced corrosion. Several of SHRP's research projects are exploring new ways of evaluating structures and preventing corrosion.

As the U.S. highway system ages and traffic volumes and weights continue to increase, roadway maintenance expenditures have become the fastest growing portion of highway budgets. The performance of materials, methods, and equipment used in highway maintenance and repair continued to be investigated by SHRP's highway operation program. Field tests to evaluate materials and procedures for pavement repair are being conducted by cooperative States under different climatic and installation conditions. Twenty-two such test sites have been built. The performance of the test sites will be monitored by the Federal Highway Administration (FHWA).

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. Eight hundred of the LTPP test sections contain common types of pavement in use throughout the United States, general pavement studies, and 340 other sites have been specially constructed to study certain engineering factors in pavement design. The collected data will provide vitally needed technical information regarding improved design techniques to highway agencies and pavement design organizations. Since its inception, the LTPP program has been international in scope. Fifteen countries are participating in the program, conducting research, and forwarding data to SHRP.

In July 1992, responsibility for the ongoing LTPP research and data collection effort was assumed by the FHWA, while the Transportation Research Board has assumed responsibility for maintaining the LTPP data base.

A low-cost dewatering technique for fine-grained slurries usually produced in

the processing of crushed stone has been developed by the U.S. Bureau of Mines. The technique consists of injecting a polymer into the line carrying the slurry and dewatering the resulting flocs on a static, hydrosieve screen. The key to successful dewatering is the formation of strong flocs that will not break apart as the floc moves down the screen. To produce strong flocs, the mixing time and the turbulent conditions in the flow line to the screens must be optimized. This is accomplished by varying the feed rate and the length of pipe carrying the slurry and the polymer mixture to the screens.[15] The initial field tests were conducted at a Birmingham, AL, limestone quarry. The waste slurry consisted of fine-grained calcium-magnesium carbonate. The testing program included an evaluation of the parameters for polymer concentration, mixing time, and effect of turbulence during the mixing. Field test results showed that 50% solids were produced using 1.4 pounds of polymer per ton of solids treated, at a cost of $0.50 per pound of polymer.

Just a few years ago, plant automation was considered to be something that can be implemented only in large crushed stone and sand and gravel operations. Today, plant automation has become a necessity essentially for operations of any size. The principal advantages of plant automation are improved product quality, lower unit cost for the final product, reduced plant wear, and improvements in health and safety of the operators. The current requirements to limit dust and noise exposure for example can, in many cases, be best handled by automating high-exposure tasks and removing workers from potentially high-exposure areas. These factors also apply to retrofitted plants.[16]

Variations in ore reserves can require careful mixing and blending of stone from different parts of the deposit to meet market requirements. The use of mine planning software presents a series of significant advantages: produces detailed production scheduling; provides significant cost savings, especially by reducing labor costs; provides rapid response in mine planning; and provides advanced quarry optimization.

Looking at plant automation and the future, two emerging technologies will have a significant impact on this industry: "smart sensors" and "expert systems." Smart sensors will play an important role in more efficient, more flexible automation processes while expert systems will be used for diagnosis of plant problems and early prediction of impending failures. Some basic research in the areas of adaptive learning networks (ALN's), fuzzy logic, and neural networks, the underlying technologies for smart sensors, as well as research in the development of expert system to diagnose equipment failures is being conducted by the Bureau.

Technology

The Metric Conversion Act of 1975 declared a national policy of coordinating the increasing use of the metric system in the United States and provided for the establishment of a U.S. Metric Board to coordinate the voluntary conversion to the metric system. It was followed by the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418), which declared the metric system of measurement "the preferred system of weights and measures for United States trade and commerce." The Act provides that each Agency of the Federal Government, by a date prior to the end of fiscal year 1992, will use the metric system of measurements in its procurements, grants, and other business-related activities. The only allowed exceptions are for circumstance that will demonstrate that the use of the metric system is impractical or is likely to cause significant inefficiencies or loss of markets to U.S. firms.[17]

Mine Safety and Health Administration (MSHA) and FHWA, two Federal Government agencies working closely with the crushed stone and sand and gravel industries, developed plans and schedules for their conversion to the metric system that were published for public comments during 1991. Although the MSHA metrication plan is scheduled to be completed in 18 months and in place by July 1993, the FHWA metrication schedule expands over a longer period of time and is scheduled to be completed by September 30, 1996.

The U.S. Bureau of Mines is also in the process of completing the conversion to the metric system in all its publications. Beginning with this issue of the Annual Report for Crushed Stone, the statistical information on crushed stone will be published in U.S. customary as well as metric units. Initially, the reporting in dual units will be applied to the totals only, with increased emphasis on metric units in successive years.

The participants of the 1992 European Concrete Study Tour sponsored by the American Association of State Highway and Transportation Officials, FHWA, and the American Concrete Pavement Associations observed highways and met with experts in Austria, Belgium, France, Germany, and the Netherlands. They also attended presentations made by experts from Italy, Portugal, Spain, and Switzerland concerning portland cement concrete pavements in their countries. The group of 21 American highway and pavement experts concluded that "the new and recently built portland cement concrete highways observed were built with a common philosophy—worry more about design, materials, and construction excellence, and less about cost. The European highways featured well-conceived, durable concrete slabs placed on thick, well-drained bases, resulting in superior pavement structures. The pavements were built with the best technology available, much of which has been developed in the United States. The European nations are building their portland cement concrete highways for the future with 30- to 40-year designed service life, compared to our 20 years. The European highways carry a large volume of trucks, with allowable axle weight substantially above those in the U.S."[18]

Jointed plain concrete pavements (JPCP) are constructed most often in Europe, and their design has been improved over time through effective research. Continuous reinforced concrete pavements (CRCP) have been built in

several countries, most commonly Belgium and France. The new and rehabilitation designers in most countries are developed by teams of experts and placed in "pavement design catalogs" for use by design engineers. Emphasis is on the design of total pavement system, not just the thickness of the concrete slab.

Warranties for pavement construction work are used in Europe. For concrete pavements, warranties range from 4 to 9 years. Two-layer slab construction is common in some countries for safety, noise, and economic reasons. A hard high-quality aggregate is used in the upper 4 to 7 cm (1.6 to 2.8 in) of the slab. Two-layer paving equipment is available to place this pavement in one pass.

Rehabilitation of pavements is performed at a higher level of condition than in the United States. Designer CRCP and JPCP overlays are common on old concrete pavements that are often cracked and seated or picked up and crushed and used as base. Jointed, steel-fiber-reinforced concrete and asphaltic concrete pavements have been used successfully in Belgium.

Recycling of pavements is on the rise in Europe, with total recycling of concrete and other construction materials required by law in Austria. Recycled concrete that includes up to 10% recycled asphalt concrete materials is used routinely in Austria. Concrete durability problems do not exist in Europe because high-strength concrete is used. Reduction of pavement-tire noise levels is an important environmental issue in Europe.

Recycling of construction materials, especially concrete and asphalt pavements as well as construction debris, is increasing throughout the United States as well as most industrialized countries. Construction and demolition debris (C&D) are bulky, difficult to handle, and expensive to move and dispose of materials. C&D represent 5% to 15% by weight of the waste stream and, for economic as well as environmental reasons, are becoming a subject of increased interest for expanded recycling programs. The reuse and recycling of C&D can make a significant contribution to aggregates conservation and reduced landfill requirements. The European Demolition Association, which represents more than 1,000 European demolition and recycling companies in Western Europe, recently conducted a survey of its members. The purpose of the survey was to determine the present status and practices in recycling and the future requirements of its members related to the expected growth of this industry. The review of the information provided by the survey indicated that: recycled material produced from concrete or mixed debris can be used as aggregates in new concrete; there is a need to create a larger market for recycled material by establishing national or preferably European specifications; and despite significant differences between the European Community countries, the volume of recycled C&D is expected to grow faster than in the past.[19] A similar report reviewing the status of recycling of construction materials in Canada was published by the Ontario Ministry of Natural Resources.[20]

More and more specialized software programs that increase efficiency and productivity of crushed stone and sand and gravel operations are now available. These software programs cover operations from mine planning to drilling and blasting, conveying, dispatching, and equipment management. Many of these software systems can be combined for overall computer management of aggregates operations. The programs can assist quarry and plant operators in increasing output by providing accurate, up-to-the-minute information, some of it not even available in the past.[21]

OUTLOOK

The demand for crushed stone in 1993 is expected to be about 1.2 billion tons, a 4% increase compared with that of 1992. Gradual increases in demand for construction aggregates are anticipated after 1993 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.

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TABLE 1
SALIENT U.S. CRUSHED STONE STATISTICS

		1988	1989	1990	1991	1992
Sold or used by producers:						
Quantity[1]	thousand short tons	e1,247,800	1,213,400	e1,222,000	1,102,900	e1,161,500
Quantity	thousand metric tons[2]	r1,132,000	r1,100,800	r1,108,600	r1,000,500	1,053,700
Value[1]	thousand dollars	e$5,558,000	$5,325,800	e$5,591,300	$5,186,800	e$5,593,700
Exports	value, thousand dollars	$30,413	$23,345	$41,400	$33,003	$43,400
Imports[3]	do.	$16,789	$36,870	$35,310	r$38,600	$60,700

eEstimated. rRevised.
[1]Does not include American Samoa, Guam, Puerto Rico, and the U.S. Virgin Islands.
[2]One 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.
[3]Excludes precipitated calcium carbonate.

TABLE 2
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
Total[3 4]	XX	1,100,800	5,325,800	4.83	XX	1,000,500	5,186,800	5.16

XX Not applicable.
[1]Includes "limestone/dolomite," reported with no distinction between the two.
[2]Data may not add to totals shown because of independent rounding.
[3]One 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.
[4]Total quantity and total value in thousand metric tons and thousand dollars.

TABLE 3

CRUSHED STONE SOLD OR USED IN THE UNITED STATES, BY REGION

(Thousand short tons and thousand dollars)

Region	1991[1]		1992e[1]	
	Quantity	Value	Quantity	Value
Northeast:				
New England	20,034	143,038	23,900	175,800
Middle Atlantic	121,885	677,232	125,500	718,900
Midwest:				
East North Central	218,485	841,993	228,300	910,100
West North Central	113,871	455,906	128,000	530,700
South:				
South Atlantic	249,862	1,311,453	252,200	1,356,800
East South Central	119,131	583,900	136,600	680,900
West South Central	113,631	423,772	124,000	477,300
West:				
Mountain	32,194	145,166	37,700	175,500
Pacific[2]	79,550	365,066	71,100	336,400
Total[3]	1,102,900	5,186,800	1,161,500	5,593,700
Total[4 5]	1,000,500	5,186,800	1,053,700	5,593,700

eEstimated.

[1]Data may not add to totals shown because of independent rounding, and differences between projected totals by States and by regions.

[2]Does not include Alaska and Hawaii.

[3]Includes Alaska, Hawaii, and "Other" totals; see table 5 for totals.

[4]One 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.

[5]Total quantity and total value in thousand metric tons and thousand dollars.

TABLE 4

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1992,[e] BY QUARTER AND REGION

Region	Quantity (thousand short tons)					Value total (thousands)	Percent coverage	Number of companies[2]
	1st quarter	2d quarter	3d quarter	4th quarter	Total[1]			
Northeast:								
New England	1,200	7,000	8,800	6,900	23,900	$175,800	53	17
Middle Atlantic	13,800	35,200	44,300	32,300	125,500	718,900	67	43
Midwest:								
East North Central	26,200	64,300	75,000	62,900	228,300	910,100	64	52
West North Central	22,900	35,400	40,200	29,400	128,000	530,700	57	45
South:								
South Atlantic	47,500	67,000	73,600	64,100	252,200	1,356,800	80	54
East South Central	25,600	36,300	39,400	35,300	136,600	680,900	71	21
West South Central	26,100	30,600	36,300	31,000	124,000	477,300	62	30
West:								
Mountain	6,000	10,800	12,300	8,600	37,700	175,500	51	23
Pacific[3]	15,100	19,600	19,300	17,100	71,100	336,400	33	26
Total[1]	184,400	306,100	349,200	287,600	[4]1,161,500	[4]5,593,700	XX	XX
Total[5 6]	167,285	277,689	316,789	260,906	1,053,700	5,593,700	XX	XX

[e]Estimated. XX Not applicable.

[1]Data may not add to totals shown because of independent rounding and differences between projected totals by States and by regions.

[2]Number of companies reporting for the quarterly survey.

[3]Does not include Alaska and Hawaii.

[4]Includes Alaska, Hawaii, and "Other" totals; see table 5 for totals.

[5]One 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.

[6]Total quantity and total value in thousand metric tons and thousand dollars.

TABLE 5

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

State	1991			1992[e]		
	Quantity (thousand short tons)	Value (thousands)	Unit value	Quantity (thousand short tons)	Value (thousands)	Unit value
Alabama	[2 3]27,145	[2 3]$161,843	$5.96	28,600	$175,600	$6.14
Alaska	[4]1,085	[4]4,688	4.32	3,000	13,400	4.47
Arizona	7,060	32,842	4.65	5,500	26,300	4.78
Arkansas	[2 5]22,140	[2 5]101,427	4.58	25,200	118,900	4.72
California	45,816	216,156	4.72	40,800	198,300	4.86
Colorado	8,401	41,022	4.88	12,000	60,400	5.03
Connecticut	[2 6]5,873	[2 6]52,701	8.97	5,900	54,500	9.24
Florida	[7]59,132	[7]260,901	4.41	59,300	266,900	4.50
Georgia	[6 7 8]41,339	[6 7 8]222,900	5.39	44,000	244,200	5.55
Hawaii	[6]10,486	[6]90,563	8.64	10,500	93,500	8.90
Idaho	3,230	15,057	4.66	4,000	19,200	4.80
Illinois	68,586	[4 10]295,362	4.31	72,700	322,800	4.44
Indiana	37,924	152,489	4.02	43,000	178,000	4.14
Iowa	[2 10]31,057	[2 10]147,815	4.76	38,000	186,200	4.90
Kansas	[11]16,802	[11]67,249	4.00	16,900	69,600	4.12
Kentucky	46,266	191,893	4.15	58,800	251,100	4.27
Louisiana	[6 12]W	[6 12]W	9.34	W	W	9.34
Maine	1,706	9,899	5.80	1,900	11,400	6.00
Maryland	25,545	188,001	7.36	23,800	180,400	7.58
Massachusetts	7,131	51,362	7.20	10,400	77,200	7.42
Michigan	40,989	129,490	3.16	38,600	125,500	3.25
Minnesota	8,378	30,624	3.66	10,500	39,500	3.76
Mississippi	1,632	6,603	4.05	2,500	10,400	4.16
Missouri	47,938	167,233	3.49	52,200	187,400	3.59
Montana	2,107	5,725	2.72	2,200	6,200	2.82
Nebraska	4,861	23,328	4.80	5,900	29,100	4.93
Nevada	1,199	6,527	5.45	1,200	6,700	5.58
New Hampshire	1,452	9,148	6.30	1,700	11,000	6.47
New Jersey	[4 6]16,680	[4 6]119,287	7.15	17,100	126,000	7.37
New Mexico	2,801	13,089	4.67	3,000	14,400	4.80
New York	34,871	195,639	5.61	36,800	212,700	5.78
North Carolina	[9 11 13]46,514	[9 11 13]243,920	5.26	48,600	262,400	5.40
North Dakota	11	[9]W	W	10	W	W
Ohio	[10]47,310	[10]184,177	3.89	48,500	194,500	4.01
Oklahoma	[3]25,678	[3]95,509	3.72	27,500	105,300	3.83
Oregon	[13]20,608	[13]89,322	4.33	16,800	74,900	4.46
Pennsylvania	[10 11]70,334	[10 11]362,306	5.15	71,600	380,200	5.31
Rhode Island	1,187	7,262	6.12	1,500	9,500	6.33
South Carolina	[2]18,216	[2]84,260	4.63	17,600	83,800	4.76
South Dakota	4,824	19,657	4.08	4,500	18,900	4.20
Tennessee	44,088	223,561	5.07	46,700	243,800	5.22
Texas	65,813	226,836	3.45	71,300	253,100	3.55
Utah	4,450	18,259	4.10	5,300	22,400	4.23
Vermont	2,685	12,666	4.72	2,500	12,200	4.88
Virginia	48,861	260,966	5.34	47,500	261,300	5.50
Washington	13,126	59,588	4.54	13,500	63,200	4.68
West Virginia	10,255	50,505	4.92	11,400	57,800	5.07

See footnotes at end of table.

TABLE 5—Continued

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

State	1991			1992[e]		
	Quantity (thousand short tons)	Value (thousands)	Unit value	Quantity (thousand short tons)	Value (thousands)	Unit value
Wisconsin	[5] [6]23,676	[5] [6]$80,475	$3.40	25,500	$89,300	$3.50
Wyoming	2,946	12,645	4.29	4,500	19,900	4.42
Other	22,664	144,044	6.36	20,700	124,400	6.01
Total[2]	1,102,900	5,186,800	4.70	1,161,500	5,593,700	4.82
Total[3] [4]	1,000,500	5,186,800	5.18	1,053,700	5,593,700	5.31

[e]Estimated. W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]To 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."
[2]Excludes dolomite.
[3]Excludes granite.
[4]Excludes sandstone.
[5]Excludes traprock.
[6]Excludes other.
[7]Excludes calcareous marl.
[8]Excludes marble.
[9]Excludes volcanic cinders.
[10]Excludes limestone-dolomite.
[11]Excludes quartzite.
[12]Excludes shell.
[13]Excludes slate.
[14]Data may not add to totals shown because of independent rounding.
[15]One 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.
[16]Total quantity and total value in thousand metric tons and thousand dollars.

TABLE 6

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1992,[e] BY QUARTER AND STATE

State	Quantity[1] (thousand short tons)					Value total (thousands)	Percent coverage	Number of companies[3]
	1st quarter	2d quarter	3d quarter	4th quarter	Total[2]			
Alabama[4]	6,200	7,700	7,600	7,100	28,600	$175,600	98	13
Alaska[5]	—	—	—	—	3,000	13,400	—	—
Arizona	1,400	1,300	1,400	1,400	5,500	26,300	21	3
Arkansas[4]	4,500	6,000	7,400	7,300	25,200	118,900	41	7
California	8,600	11,200	10,900	10,100	40,800	198,300	36	11
Colorado[4]	1,700	3,300	4,200	2,700	12,000	60,400	57	6
Connecticut[4]	300	1,900	2,000	1,700	5,900	54,500	54	5
Delaware	—	—	—	—	—	—	—	—
Florida	14,800	14,800	14,500	15,200	59,300	266,900	59	12
Georgia	7,400	12,100	13,300	11,200	44,000	244,200	97	8
Hawaii[5]	—	—	—	—	10,500	93,500	—	—
Idaho[5]	—	—	—	—	4,000	19,200	—	—
Illinois[4]	9,300	20,100	23,900	19,300	72,700	322,800	56	13
Indiana[4]	6,000	10,900	14,300	11,900	43,000	178,000	66	15
Iowa	7,000	11,100	11,600	8,300	38,000	186,200	50	8
Kansas[4]	3,400	4,600	4,900	4,100	16,900	69,600	76	12
Kentucky[4]	11,100	14,600	17,000	16,100	58,800	251,100	60	9
Louisiana[5]	—	—	—	—	W	W	—	—
Maine	100	500	700	600	1,900	11,400	80	4
Maryland	3,700	6,800	7,400	5,900	23,800	180,400	81	10
Massachusetts	500	3,000	3,800	3,100	10,400	77,200	54	5
Michigan	2,400	12,800	12,300	11,100	38,600	125,500	76	10
Minnesota	700	3,000	4,400	2,400	10,500	39,500	65	5
Mississippi[5]	—	—	—	—	2,500	10,400	—	—
Missouri	10,400	14,000	15,500	12,400	52,200	187,400	49	19
Montana[5]	300	800	700	500	2,200	6,200	34	3
Nebraska	1,100	1,500	2,100	1,200	5,900	29,100	96	6
Nevada	300	300	300	300	1,200	6,700	71	3
New Hampshire	100	500	600	500	1,700	11,000	67	3
New Jersey	1,900	4,700	5,300	5,300	17,100	126,000	81	7
New Mexico	500	900	900	700	3,000	14,400	38	4
New York	3,300	9,500	14,600	9,500	36,800	212,700	72	12
North Carolina	9,000	12,800	14,700	12,000	48,600	262,400	95	11
North Dakota[5]	—	—	—	—	10	W	—	—
Ohio	6,300	12,400	15,800	14,000	48,500	194,500	71	13
Oklahoma[4]	6,100	6,200	7,900	7,300	27,500	105,300	79	10
Oregon[4]	3,500	4,700	4,500	4,100	16,800	74,900	32	11
Pennsylvania[4]	8,700	21,200	24,400	17,200	71,600	380,200	61	24
Rhode Island[4 5]	—	—	—	—	1,500	9,500	—	—
South Carolina[4]	3,700	4,500	4,900	4,500	17,600	83,800	105	9
South Dakota	600	1,300	1,400	1,200	4,500	18,900	67	5
Tennessee	7,500	13,200	14,400	11,600	46,700	243,800	68	7
Texas	15,100	18,500	21,000	16,600	71,300	253,100	63	15
Utah	800	1,300	1,700	1,400	5,300	22,400	47	4

See footnotes at end of table.

TABLE 6—Continued

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1992,[e] BY QUARTER AND STATE

State	Quantity[1] (thousand short tons)					Value total (thousands)	Percent coverage	Number of companies[3]
	1st quarter	2d quarter	3d quarter	4th quarter	Total[2]			
Vermont[5]	—	—	—	—	2,500	$12,200	—	—
Virginia	7,900	12,700	14,200	12,700	47,500	261,300	72	17
Washington	3,100	3,600	4,000	2,800	13,500	63,200	26	3
West Virginia[4]	1,800	2,900	4,100	2,600	11,400	57,800	52	6
Wisconsin	2,400	8,100	8,800	6,200	25,500	89,300	52	10
Wyoming	700	1,600	1,400	900	4,500	19,900	93	5
Other[5]	—	—	—	—	20,700	124,400	—	—
Total	XX	XX	XX	XX	1,161,500	5,593,700	XX	XX
Total[6 7]	XX	XX	XX	XX	1,053,700	5,593,700	XX	XX

[e]Estimated. W Withheld to avoid disclosing company proprietary data; included with "Other." XX Not applicable.

[1]A majority of the 1992 quantity data have been revised owing to adjustments of quarterly data to agree with 1992 totals.

[2]Data may not add to totals shown because of independent rounding and differences between projected totals by State.

[3]Number of companies reporting for the quarterly survey.

[4]To 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."

[5]Due to a low number of reporting companies, no production estimates by quarters were generated.

[6]One 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.

[7]Total quantitiy and total value in thousand metric tons and thousands dollars.

TABLE 7

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY MAJOR USE

Use	1989			1991		
	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand) short tons)	Value (thousands)	Value per ton
Coarse aggregate (+1 1/2 inch)	42,689	$197,250	$4.62	35,528	$168,423	$4.74
Coarse aggregate, graded	231,092	1,088,284	4.71	226,770	1,144,769	5.05
Fine aggregate (-3/8 inch)	73,167	318,089	4.35	72,418	343,217	4.74
Coarse and fine aggregates	284,913	1,116,429	3.92	281,391	1,187,536	4.22
Agricultural	23,035	119,799	5.20	22,302	131,974	5.92
Chemical and metallurgical	122,489	404,668	3.30	114,181	423,658	3.71
Special uses	11,836	187,157	15.81	8,825	144,917	16.42
Other miscellaneous uses	4,047	22,968	5.68	981	7,616	7.76
Unspecified:[1]						
Actual	333,085	1,482,690	4.45	259,223	1,255,712	4.84
Estimated	87,081	388,431	4.46	81,253	378,997	4.66
Total[2]	1,213,400	5,325,800	4.39	1,102,900	5,186,800	4.70
Total[3 4]	1,100,800	5,325,800	4.83	1,000,500	5,186,800	5.18

[1]Includes production reported without a breakdown by end use and estimates for nonrespondents.

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

[3]One 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.

[4]Total quantity and value in thousand metric tons and thousand dollars.

TABLE 8

U.S. EXPORTS OF CRUSHED STONE IN 1992, BY DESTINATION

(Short tons)

Destination	Limestone for cement manufacturing	Other	Chalk, crude	Granules, chippings	Total[1]
North America:					
Antigua and Barbuda	—	—	—	3	3
Bahamas, The	66	—	—	—	66
Barbados	—	—	54	—	54
Bermuda	56	—	—	—	56
Canada	3,390,224	714	2,761	164,085	3,557,785
El Salvador	66	—	—	—	66
Guatemala	—	—	22	288	310
Mexico	1,745	29	280	14,027	16,080
Panama	—	—	80	—	80
Trinadad and Tobago	—	—	40	—	40
Total	3,392,157	743	3,237	178,403	3,574,541
South America:					
Brazil	—	26	104	—	130
Chile	40	—	1	—	41
Ecuador	—	—	37	388	425
Peru	—	—	11	—	11
Venezuela	1,074	36	69	274	1,454
Total[1]	1,113	63	222	662	2,060
Europe:					
Austria	8,135	—	—	—	8,135
Belgium	61,660	—	3	—	61,663
Denmark	2,148	53	—	—	2,201
France	38,427	873	6	—	39,305
Germany	92,135	3,084	10	1	95,231
Ireland	110	—	—	—	110
Italy	77,240	441	—	18	77,699
Latvia	—	—	2,249	—	2,249
Netherlands	2,028	1,696	—	—	3,725
Norway	—	18	—	—	18
Portugal	1,720	—	—	—	1,720
Spain	4,409	12	—	—	4,421
Sweden	6,625	—	—	—	6,625
Switzerland	26,994	—	—	278	27,272
United Kingdom	39,244	476	114	234	40,068
Total[1]	360,876	6,654	2,381	530	370,441
Asia:					
China	19,218	184	—	42	19,444
Hong Kong	—	—	—	159	159
India	—	11	—	4	15
Indonesia	794	3	—	—	797
Japan	23,645	14,410	1	229	38,285
Korea, Republic of	1,254	—	—	248	1,502
Malaysia	—	57	—	—	57
Phillipines	265	—	—	—	265
Singapore	—	—	8	49	56

See footnotes at end of table.

TABLE 8—Continued

U.S. EXPORTS OF CRUSHED STONE IN 1992, BY DESTINATION

(Short tons)

Destination		Limestone for cement manufacturing	Other	Chalk, crude	Granules, chippings	Total[1]
Asia—Continued:						
Taiwan		18,426	19	—	163	18,608
Thailand		—	37	—	—	37
Total[1]		63,601	14,722	9	894	79,226
Oceania: Australia		3,693	529	107	—	4,329
Middle East and Africa:						
Egypt		—	—	—	19	19
Israel		—	18	2	—	20
Kuwait		—	—	—	11	11
Qatar		—	—	1	—	1
Saudi Arabia		—	—	—	247	247
South Africa, Republic of		—	—	2	—	2
Total		—	18	5	277	300
Grand total[1]		3,821,441	22,729	5,961	180,767	4,030,897
Grand total	metric tons[2]	3,466,800	20,600	5,400	164,000	3,656,800
Total value	thousand	$20,500	$12,800	$2	$10,100	$43,400

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

[2]One 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.

Source: Bureau of the Census.

TABLE 9

U.S. IMPORTS OF CRUSHED STONE AND CALCIUM CARBONATE FINES, BY TYPE

(Thousands short tons and thousand dollars)

Type	1991		1992	
	Quantity	C.i.f. value	Quantity	C.i.f. value
Crushed stone and chips:				
Limestone[1]	3,667	21,239	3,216	23,248
Limestone for flux or cement manufacturing	1,781	13,498	3,900	31,906
Quartzite	3	485	1	442
Other	275	2,676	619	4,373
Total[2]	5,726	37,898	7,735	59,969
Calcium carbonate fines:[3]				
Natural chalk	(4)	47	(4)	55
Calcium carbonates—other chalk	2	704	2	658
Total	2	751	2	713
Grand total[2]	r5,700	38,600	7,700	60,700
Grand total[5 6]	5,200	38,600	7,000	60,700

rRevised.

[1]Excludes limestone for cement manufacturing.

[2]Data may not add to total shown because of independent rounding.

[3]Excludes precipitated calcium carbonate.

[4]Less than 1/2 unit.

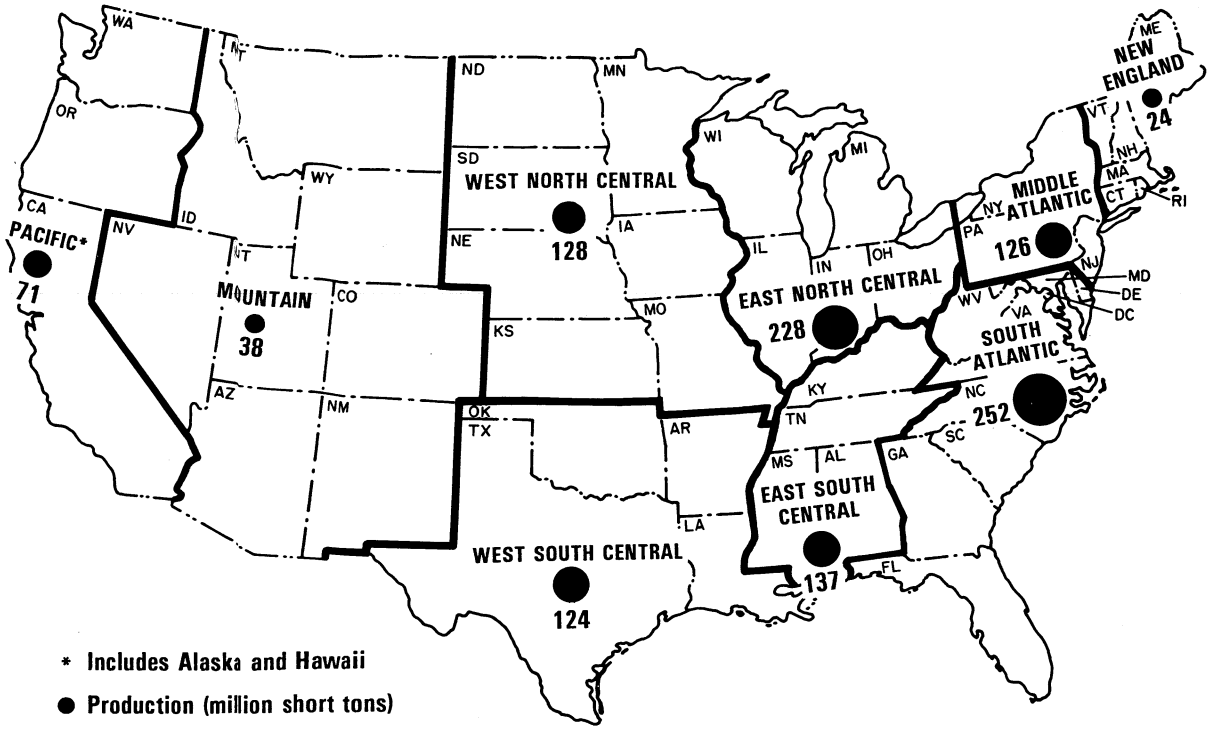
[5]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons into metric tons, multiply short tons by 0.907185.

[6]Total quantity and total value in thousand metric tons and thousand dollars.

Source: Bureau of the Census.

FIGURE 1

PRODUCTION OF CRUSHED STONE IN THE UNITED STATES IN 1992, BY GEOGRAPHIC REGION



DIMENSION STONE

By Harold A. Taylor, Jr.

Mr. Taylor, a physical scientist with 27 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 decreased 15% to 1.09 million short tons valued at $183 million. More than one-half of the dimension stone produced was granite. Limestone, marble, sandstone, and slate were also produced.

Exports of dimension stone decreased 15% in value to $55 million. The value of dimension stone imports for consumption decreased 15% to $404 million, equivalent to 221% 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. The survey of dimension stone producers was not conducted in 1992. A sample survey based on the first 9 months of data was used to generate State annual preliminary estimates. Of the 296 dimension stone operations surveyed for 1991 and 1990, including those that were idle, 256, or 86%, responded, representing 94% of the estimated value shown in table 1. The final 1990 data are based on data from the 1991 survey, and updated 1990 preliminary data for nonrespondents were estimated using preliminary production reports, adjusted prior-year 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 environmmental 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 mineralological 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 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 contain 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 calcity 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 esthetic 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 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, often at the quarry site, for final cutting and finishing operations.

Processing.—Stone-sawing equipment includes large circular saws 10 feet or more in diameter, some with diamond inserts and some using other abrasives; 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

The dimension stone industry faced several environmentally related issues this year, primarily noise and crystalline silica. The most universal was noise pollution from the handheld burners used in many granite quarries. The operators of these burners, in particular, can be affected by the high noise level. This burner is now used only where the alternate methods using the automatic self-propelled burner, the diamond wire saw, or drill and blast with Primacord cannot be used.

Stone primary and waste products are not toxic, nor are the supplies utilized in their production. However, sufficient exposure to crystalline silica-rich stone dust can cause silicosis. The firms are required to saw with water and have employee face masks to protect against silica-containing stone dust. Water and air filtration systems specifically designed for dimension stone operations are beginning to be installed in the industry.

Although these issues were primarily or exclusively Federal in origin, other environmental requirements do vary from State to State and are often a cause of conflict between State or local governments and the quarry operators.

The dimension stone-consuming industry does recycle some postconsumer waste, and the producing industry in Vermont is trying to reduce energy and water consumption. A high proportion of granite curbing, about 80%, is recovered and reused again as curbing. Monuments, mausoleums, and tombstones stay in place for centuries, unless disturbed. However, building products usually end up in a landfill. The granite-producing industry in Vermont is conserving energy by installing more efficient lighting and motors and insulating its plants more. It is also conserving water and eliminating stream pollution by reusing clean water from its recently installed settling ponds.

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 176 companies at 288 quarries in 34 States. Leading States, in order of tonnage, were Indiana, Georgia, and Vermont, together producing 44% of the Nation's total. Of the total production, 50% was granite, 29% was limestone, 12% was sandstone, 3% was slate, 3% was marble, and the remaining 3% was miscellaneous stone. Miscellaneous stone included quartzite 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 (1990-91).

Granite.—Dimension granite includes all coarse-grained igneous rocks. Production decreased 4% to 615,000 tons and decreased slightly in value to $108.8 million in 1992. Granite was produced by 75 companies at 110 quarries in 19 States. Georgia continued to be the leading State, producing 26% of the U.S. total, followed by Vermont and Massachusetts. These three States together produced about 48% of the U.S. total. Cold Spring Granite, Rock of Ages, and Fletcher Granite Co. were the leading producers and accounted for 48% of U.S. production.

Swenson Granite Co. bought the quarries of Coggins Granite Inc. of Elberton, GA, on January 29, 1992. Swenson Granite of Concord, NH, also owns Rock of Ages Corp. of Barre, VT, the major quarrier in Vermont and the owner in turn of an operation in Quebec, Rock of Ages Canada Ltd. In early 1992, Rock of Ages Canada Ltd. purchased 49.9% of Carrieres Norgranit, Inc. and a minority interest in Groupe Polycor, both Quebec granite quarriers. Rock of Ages Corp. sold its 50% interest in Whetstone Granite Co., a granite quarrier in South Dakota and Minnesota, to co-owner Dakota Granite Co., while retaining some interest in quarry properties.

Coggins also sold its Chapel Rose Quarry in Oklahoma and its Radiant Red Quarry in South Carolina to Swenson Granite Co. The Georgia quarries sold include the Royalty Blue, the Berkeley Blue, and the Millstone, plus nine idle quarries and 2,800 acres of land in three Georgia counties. A few of the idle quarries may be reopened, but a finishing plant is not planned. Swenson has placed these assets with a subsidiary, Royalty Granite Corp.

Keystone Granite Co. and Childs & Childs Granite Co. Inc. formed a joint venture to buy out Matthews International's quarry division, including its North Carolina plant and quarry and two South Carolina quarries. The new venture is called Carolina Quarries Inc. and will emphasize exporting rough blocks.

Two Pacific Coast quarries were announced. One was a white granite quarry south of San Diego, CA, owned by M. W. Mihelich & Associates. The other was a black granite (gneiss) quarry in northeastern Washington owned by Black Star Stone Co. Associated finishing facilities were said to allow or shortly will allow the firms to sell polished or finished products.

Fletcher Granite Corp. tested a prototype water-jet technology for cutting stone at a quarry near Chelmsford, MA.

Limestone.—Dimension limestone includes bituminous, dolomitic, and siliceous limestones. Indiana, the leading State, produced 190,000 tons in 1992 compared with 189,010 tons in 1991 and 198,242 tons in 1990. Wisconsin, usually the second or third largest producer, produced 56,612 tons (revised) valued at $3,560,400 (revised) in 1991 and 53,500 tons valued at $4,402,000 in 1990. Kansas produced 30,807 tons (revised) valued at $3,128,000 (revised) in 1991 and 30,315 tons valued at $3,142,000 in 1990. Alabama Limestone Co. was purchased by Cathedral Stoneworks, Ltd. of New York City from bankruptcy. The new owner planned to modernize the operation.

Marble.—Omya, Inc. began to dissolve its Vermont Marble Co. dimension marble operations late in the year. It hoped to lease its Danby White Quarry and sell its other dimension stone quarries.

Sandstone.—Dimension sandstone includes calcareous- and siliceous-cemented sandstones or conglomerates. Quartzite may be described as any siliceous-cemented sandstone. Ohio produced 47,031 tons (revised) of sandstone valued at $2,443,000 (revised) in 1991 and 33,976 tons valued at $2,201,625 in 1990. In 1991, Pennsylvania produced 14,542 tons of sandstone valued at $1,599,000 (revised) and Utah and Arizona combined totaled 19,630 tons valued at $902,000.

In addition to the quantities shown in table 7, dimension quartzite totaled 35,877 tons (revised) worth $2,946,000 (revised) in 1991. Utah and Idaho combined totaled 13,206 tons valued at $1,127,000 in 1991.

Waller Bros. Stone Co. of Scioto County, OH, bought Briar Hill Stone Co. also of Ohio, from the United Bank of Canton, OH. The company is now back in production at a significant level.

A group of Canadian investors bought Cleveland Quarries Co. of Amherst, OH. It is also producing at a significant level. The investors are planning a new $5 million finishing plant that will use water-jet cutting technology. *(See tables 3 and 4.)*

Consumption and Uses

Dimension stone was marketed over wide areas. Industry stockpiles were not monitored, and production during the year was assumed to equal consumption.

Consumption of domestic dimension stone decreased 15% to 1.09 million tons valued at $182.8 million in 1992 compared with 1.28 million tons valued at $211.5 million (revised) in 1991 and 1.23 million tons valued at $232.1 million in 1990.

Consumption of domestic granite decreased to 615,000 tons valued at $108.8 million in 1992 compared with 632,100 tons valued at $105.3 million in 1991 and 628,400 tons valued at $120.8 million in 1990.

Domestic limestone consumption was 368,000 tons valued at $40.0 million in 1992 compared with 367,100 tons valued at $49.5 million (revised) in 1991 and 360,600 tons valued at $51.0 million in 1990.

Domestic marble consumption, including travertine, totaled 43,000 tons valued at $26.0 million in 1992 compared with 42,980 tons valued at $26.1 million in 1991 and 29,203 tons valued at $24.3 million in 1990.

Consumption of domestic slate totaled 32,800 tons valued at $17.5 million in 1992 compared with 32,800 tons valued at $17.5 million in 1991 and 35,980 tons valued at $17.5 million in 1990. *(See tables 5, 6, 7, 8, 9, and 10.)*

Prices

The average price for dimension stone increased to $168 per ton, up slightly from $166 in 1991.

Foreign Trade

Exports.—Exports of dimension stone, about 50% of which was granite, decreased 15% in value.

Imports.—Imports for consumption of dimension stone decreased 15% in value to $404 million, mostly because of decreases in imports of all major categories of dimension stone. On a value basis, marble accounted for 54% of imports, followed by granite, 29%. *(See tables 11, 12, 13, 14, and 15.)*

World Review

Some production of dimension stone occurred in most countries of the world. As usual, Italy produced about one-half of the world's total. Other significant producers were Brazil, China, Finland, India, Norway, Portugal, Spain, Sweden, Turkey, and the United States.

A major dimension stone outlook article was published by an Italian dimension stone specialist. In general, this is a time of weak economies and many uncertainties. World dimension stone production has probably topped out for a while; even hitherto fast-growing Spain had a 5% decrease in production. World dimension stone trade fell even more. It is predicted that it will get worse: dimension stone use in construction lags behind the economy. Conditions in the major markets can be summarized as follows: the Middle Eastern market has been improving along with rebuilding from the Gulf War. The American market was in the worst shape. The European market experienced moderate but slowing growth, ranging from mild negative growth for the United Kingdom to solid positive growth for Germany; Italy had no growth. Japan and the rest of the Far East had extremely strong markets.[1]

Australia.—Although the industry dates back into the 19th century, it only became sizable in the 1980's. The most important stone is granite, the quarry production of which averages 350,000 cubic feet. Next in importance is sandstone; marble, limestone, and slate are minor. A total of 24 exporters of dimension stone are individually listed.[2]

Brazil.—The Brazilian Government published its 1991 production statistics; production of rough dimension stone in 1991 (preliminary) totaled 1.65 million tons (77% granite and 23% marble), compared with 1.42 million tons in 1990 and 1.65 million tons in 1989.

Canada.—Newfoundland Slate Inc. completed its facility at Bourgoynes Cove and began limited production this year. The plant and quarry cost about $6 million and has a capacity of 5,500 tons per year of roofing slate product. Technology for the plant and European marketing was the responsibility of Ardoisieres d'Angers SA, France's leading slate producer. The product will also be marketed in North America and Japan. The firm is one-half owned by McAsphalt Industries Ltd. of Ontario and one-half owned by a private party.

Italy.—A battle has been raging between the marble quarriers and finishers of Carrara and the local council (government) supported by the Tuscan regional administration. The government wants to develop a park in the higher elevations of the Apuan Alps behind Carrara, above approximately 4,000 feet. Quarrying is banned inside the park boundaries, and three quarries already have had to close. The marble industry is the direct and indirect source of employment for most of the local inhabitants. The council felt that the park and concurrent stronger enforcement of environmental regulations were long overdue.

Japan.—The nation's largest marble deposit has been discovered in Nyukawa, Gifu Prefecture, when it had been thought that all marble deposits were exhausted. Resources total 53.5 million tons over an area of 0.8 square mile, probably enough for 300 years of domestic consumption. The marble ranges from red to gold and is so hard that it will probably be mostly used in flooring. Quarry production is scheduled to begin in 1995 with an initial product capacity of 1,320 tons per year. Although total domestic demand is expected to grow rapidly, some displacement of European imports is likely.

The U.S. Bureau of Mines dimension stone specialist wrote an experience-based article on the huge Japanese market for granite.[3] Although the huge market for monumental granite reportedly has almost no growth, the smaller market for building granite has grown rapidly enough to catch up. Domestic production goes almost entirely to the monumental market, while rough granite imports go to both markets. Imports have been mostly rough granite, but imports of finished granite are rapidly closing the gap. Although Japanese buyers are reportedly very demanding, the expected growth

makes the market very attractive to granite producers.

Spain.—A comprehensive recent article covered the fast-growing Spanish dimension stone industry.[4] Spain has very large granite and marble industries and is the world's largest exporter of slate roofing. Production in 1990 totaled 3.41 million tons, of which 1.86 million tons as block was marble, 1.09 million tons as block was granite, and 0.46 million tons was roofing slate. In addition, 1.28 million tons of other stone products was produced, almost one-half of it marble. Domestic consumption was apparently about 87% of production; by end use, 36% was consumed as paving and 22% as outdoor building cladding.

A slowdown in domestic construction began in the second half of 1991 as preparations for the Seville World's Fair and the Olympic Games were completed. The largest producers continue to be the Ingemar Group (granite and marble) and the Cupire-Padesa Group (slate). The outlook for the Spanish dimension stone industry is for much slower growth. Spain, as part of the European Committee for Standardization, is helping to prepare Europewide dimension stone standards, terminology, and test methods.

United Kingdom.—A recent article on the slate industry indicated that demand for slate in 1991 dropped drastically owing to a recession-triggered slump in construction. Domestic slate production dropped 24% while imports were halved. Penrhyn Quarries Ltd., a subsidiary of Alfred Mc Alpine PLC in Wales, remains the largest producer and, in turn, has U.S. and Irish subsidiaries. Burlington Slate Ltd. is the largest producer in the English Lake District.[5] Later in the year, both Penrhyn Quarries and Burlington Slate laid off 20% of their employees because of the worsening recession in building.

Current Research

Several helpful publications were released last year. In particular, the Marble Institute of America published The Dimension Stones of the World, Volume I. It lists the physical and chemical properties and has a colored photograph of each of many major U.S. and world stones. This volume will be of great assistance to those interested in individual stones and those in charge of selecting stones.[6]

Another publication is a bibliographic guide to the literature on dimension stone. It lists more than 270 publications on stone use in buildings, monuments, and art, plus geology, technology, history, trade names, and markets. The publications often cover only one State or quarrying area.[7]

An article describing stone selection and specification was published. It describes how to prepare a successful bid for a job, the adequate preparation leading up to it, and the painstaking followthrough that has to occur.[8]

An article pointed out that installation of thin stone veneer on buildings was not associated with an increased knowledge of stone properties. It therefore requires careful engineering and testing throughout the design and construction phase. The testing should cover strength, durability, permability, and other factors, including environmental.[9]

An innovative tile product sold by Granite & Marble World Trade (GMWT) uses water-jet cutting technology to help create inlay patterns and textured surfaces on stone tiles. Creative Edge of Fairfield, IA, GMWT's joint venturer, makes the tile and is presently cutting a 15-foot by 30-foot granite mural of the Chicago skyline for GMWT. Inlay work has traditionally been done entirely by hand.

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 should be 35,000 tons in 1995 and 37,000 tons in the year 2000. This relatively slow rate reflects a major drop in the market for building stone in 1989-91 and a welcomed major recovery later in the 1990's. Certain segments will continue to grow rapidly, such as uses in kitchens and bathrooms. The supply will be adequate and is likely to shift in favor of domestic producers.

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[1]Napoli, S. International Trends in the Stone Industry. Dimensional Stone, v. 8, No. 9, Sept. 1992, pp. 36-40.

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TABLE 1
SALIENT U.S. DIMENSION STONE STATISTICS

(Thousand short tons and thousand dollars)

		1988	1989	1990	1991	1992
Sold or used by producers:						
Quantity	thousand short tons[1]	e1,159	1,238	r e1,232	r1,275	e1,086
Quantity	thousand metric tons[2]	1,051	1,123	1,118	1,157	985
Value[1]		e$207,489	$210,878	r e$232,130	r$211,494	e$182,825
Exports (value)		$42,668	$34,610	$54,019	$64,947	$54,904
Imports for consumption (value)		$517,835	$525,052	$586,243	r$474,914	$403,922

eEstimated. rRevised.

[1]Includes Puerto Rico for 1990, 1991, and 1992.

[2]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

TABLE 2

U.S. IMPORT DUTIES ON DIMENSION STONE

Tariff item	HTS number	Most favored nation (MFN) Jan. 1, 1993	Non-MFN Jan. 1, 1993
Slate: Rough blocks or slabs	2514.00.0000	3.7% ad valorem	25% ad valorem.
Rough blocks or slabs of marble, travertine, and other calcareous monumental or building stone	2515.00.0000		
Marble and travertine:			
Crude or roughly trimmed	2515.11.0000	$3.46 per cubic meter	$22.95 per cubic meter.
Marble, merely cut	2515.12.0010	2.1% ad valorem	13% ad valorem.
Travertine, merely cut	2515.12.0020	6% ad valorem	50% ad valorem.
Other calcareous stone, alabaster	2515.20.0000	6% ad valorem	50% ad valorem.
Rough blocks or slabs of granite, porphyry, basalt, sandstone, and other monumental or building stone	2516.00.0000		
Granite:			
Crude or roughly trimmed	2516.11.0000	Free	$8.83 per cubic meter.
Merely cut	2516.12.0000	4.2% ad valorem	60% ad valorem.
Sandstone:			
Crude or roughly trimmed	2516.21.0000	Free	$5.30 per cubic meter.
Merely cut	2516.22.0000	6% ad valorem	50% ad valorem.
Other monumental or building stone	2516.90.0000	6% ad valorem	50% ad valorem.
Setts, curbstones, and flagstones	6801.00.0000	4.2% ad valorem	60% ad valorem.
Worked monumental or building stone	6802.00.0000		
Tiles and cubes under 7 square cm, granules	6802.10.0000	6.9% ad valorem	40% ad valorem.
Other stone and articles with a flat or even surface:			
Marble, travertine, and alabaster:	6802.21.0000		
Travertine	6802.21.1000	6% ad valorem	50% ad valorem.
Other	6802.21.5000	2.1% ad valorem	13% ad valorem.
Other calcareous stone	6802.22.0000	6% ad valorem	50% ad valorem.
Granite	6802.23.0000	4.2% ad valorem	60% ad valorem.
Other stone	6802.29.0000	7.5% ad valorem	30% ad valorem.
Other:			
Marble, travertine, and alabaster:	6802.91.0000		
Marble:			
Slabs	6802.91.0500	2.8% ad valorem	15% ad valorem.
Other	6802.91.1500	6% ad valorem	50% ad valorem.
Travertine:			
Articles of subheading 6802.21.1000 that have been dressed or polished, but not further worked	6802.91.2000	6% ad valorem	50% ad valorem.
Other	6802.91.2500	5.3% ad valorem	40% ad valorem.
Alabaster	6802.91.3000	5.3% ad valorem	50% ad valorem.
Other calcareous stone	6802.92.0000	6% ad valorem	50% ad valorem.
Granite	6802.93.0000	4.2% ad valorem	60% ad valorem.
Other stone	6802.99.0000	6.5% ad valorem	40% ad valorem.
Worked slate and articles:	6803.00.0000		
Roofing slate	6803.00.0010	6.6% ad valorem	25% ad valorem.
Other	6803.00.0050	3.7% ad valorem	25% ad valorem.

TABLE 3

DIMENSION STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES,[1] BY STATE

State	1990[e]		1991		1992[e]	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Alabama	W	W	9,552	$2,449	W	W
California	r45,547	r$4,946	44,757	5,254	23,292	$4,148
Colorado	r5,483	W	W	W	6,454	252
Connecticut	14,156	7,113	r16,545	1,739	W	W
Georgia	r 2200,531	r 220,451	r 2216,938	r 221,282	2159,093	213,138
Idaho	7,121	749	r10,883	970	W	W
Indiana	r 2198,242	r 228,565	r 2189,010	r 227,596	190,412	26,767
Kansas	r 230,315	r 23,142	r 230,807	r 23,128	W	W
Maryland	r12,479	r1,079	r12,355	r1,067	11,365	1,024
Massachusetts	r54,566	r9,684	69,332	11,646	65,836	9,292
Minnesota	r54,705	r19,487	45,795	13,962	36,192	11,436
New Hampshire	r46,559	r6,910	34,803	5,013	37,647	5,460
New York	r20,981	r3,918	r17,959	r3,162	18,217	2,779
North Carolina	r36,163	r9,758	r37,056	r10,568	25,369	7,469
Ohio	r 233,976	r 22,202	r 247,031	r 22,443	35,059	2,244
Oklahoma	r 24,267	r 2153	r 23,777	2596	5,182	706
Pennsylvania	r46,788	r10,894	r41,983	r10,459	41,728	10,822
South Carolina	8,929	848	8,829	854	W	W
South Dakota	r55,396	r21,587	W	W	W	W
Tennessee	r3,460	r292	3,460	260	3,400	320
Utah	17,559	1,109	23,079	1,429	W	W
Vermont	r106,265	r33,522	r92,658	31,013	125,000	34,639
Virginia	W	W	11,046	3,061	W	W
Wisconsin	r 257,525	r 27,191	r 260,890	r 26,221	36,166	4,227
Other[3]	r170,889	r38,528	r246,837	r47,324	265,660	48,102
Total[4]	r1,231,902	r232,130	r1,275,382	r211,494	1,086,072	182,825
Total[5 6]	1,117,563	232,130	1,157,007	211,494	985,268	182,825

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

[1]Includes Puerto Rico.

[2]Totals only include Georgia granite, Indiana limestone, Kansas limestone, Ohio sandstone, Oklahoma granite, and Wisconsin granite and limestone; other stone included with "Other."

[3]Includes data for Arizona, Arkansas, Illinois, Iowa, Maine, Michigan, Missouri, Montana, New Mexico, Puerto Rico, Texas, and Washington.

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

[5]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[6]Total quantity and total value in metric tons and thousand dollars.

TABLE 4
DIMENSION GRANITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1990e		1991		1992e	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Georgia	r200,531	r$20,451	r216,938	r$21,282	159,093	$13,138
Massachusetts	r54,466	r9,614	69,232	11,576	65,836	9,292
New Hampshire	r46,559	r6,910	34,803	5,013	37,647	5,460
North Carolina	W	W	32,812	9,586	32,800	9,600
Oklahoma	r4,267	r153	r3,777	596	5,182	706
Pennsylvania	r14,055	r3,269	12,354	3,275	13,500	13,230
South Carolina	W	W	8,829	854	7,097	697
South Dakota	r55,396	r21,587	W	W	W	W
Vermont	r85,987	r17,448	72,537	W	72,540	W
Wisconsin	W	W	4,278	2,661	W	W
Other[1 2]	r167,161	r41,330	r176,515	r50,475	221,465	56,636
Total[3]	r628,422	r120,764	r632,075	r105,316	615,160	108,759
Total[4 5]	570,095	120,764	573,409	105,316	558,064	108,759

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data; included with "Other." XX Not applicable.
[1]Includes California, Colorado, Connecticut, Maine, Minnesota, Missouri, New York, Texas, and Virginia.
[2]Missouri includes a small amount of other dimension stone for 1992.
[3]Data may not add to totals shown because of independent rounding.
[4]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.
[5]Total quantity and total value in metric tons and thousand dollars.

TABLE 5
DIMENSION STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES,[1] BY USE

Use	1990e		1991	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Rough stone:				
Rough blocks for building and construction	281,440	$27,140	r287,289	r$25,680
Irregular-shaped stone[2]	106,017	7,110	r112,270	r5,498
Monumental	258,312	33,715	r249,693	r31,461
Other[3]	14,733	2,284	r15,753	r2,395
Dressed stone:				
Ashlars and partially squared pieces	221,939	55,674	r237,933	r42,645
Slabs and blocks for building and construction	67,669	30,632	r67,831	r27,217
Monumental	47,320	31,285	r51,307	r29,610
Curbing	104,470	18,452	r117,137	r22,268
Flagging	35,798	4,355	r42,776	r3,107
Flagging (slate)	8,366	843	6,646	754
Roofing (slate)	12,859	9,021	12,093	9,271
Structural and sanitary	3,486	2,682	3,307	2,577
Flooring (slate)	6,672	2,890	6,155	2,804
Other[4]	62,820	6,047	r65,192	r6,206
Total[5]	1,231,902	232,130	r1,275,382	r211,494
Total[e 6 7]	1,117,563	232,130	1,157,007	211,494

eEstimated. rRevised.
[1]Includes Puerto Rico.
[2]Includes rubble.
[3]Includes rough stone used for flagging and unspecified uses.
[4]Includes a minor amount of slate used for billiard tabletops, blackboard, bulletin boards, and school slates, and unspecifed uses.
[5]Data may not add to totals shown because of independent rounding.
[6]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.
[7]Total quantity and total value in metric tons and thousand dollars.

TABLE 6

DIMENSION GRANITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1990e		1991	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Rough stone:				
Rough blocks for building and construction	123,173	$12,808	r126,688	r$11,708
Irregular-shaped stone[1]	3,389	275	r3,364	r275
Monumental	255,794	33,552	r247,173	r31,253
Dressed stone:				
Ashlars and partially squared pieces	81,422	26,686	78,717	16,796
Slabs and blocks for building and construction	21,912	8,560	21,730	4,479
Monumental	38,580	21,670	r41,927	r19,789
Curbing	96,980	16,852	r105,370	r20,553
Other[2]	7,172	361	7,106	462
Total	628,422	120,764	r632,075	r [3]105,316
Total[4 5]	570,095	120,764	573,409	105,316

eEstimated. rRevised.
[1]Includes rubble and a minor amount of uses not specified.
[2]Includes unspecified uses for dressed stone.
[3]Data do not add to total shown because of independent rounding.
[4]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.
[5]Total quantity and total value in metric tons and thousand dollars.

TABLE 7

DIMENSION LIMESTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1990e		1991	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Rough stone:				
Rough blocks for building and construction	144,261	$12,518	r136,749	r$11,687
Irregular-shaped stone	37,579	2,797	47,076	2,611
Other[1]	16,046	2,155	r16,815	r2,268
Dressed stone:				
Ashlars and partially squared pieces	85,579	20,741	r87,830	r20,386
Slabs and blocks for building and construction	30,388	9,150	r28,252	r8,906
Flagging	7,682	940	r7,910	r686
Other[2]	39,041	2,703	r42,468	r2,961
Total	360,576	51,004	r367,100	r [3]49,504
Total[4 5]	327,109	51,004	333,028	49,504

eEstimated. rRevised.
[1]Includes rubble, monumental, rough sawed stone, and uses not specified.
[2]Includes dressed monumental stone and unspecified uses.
[3]Data do not add to total shown because of independent rounding.
[4]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.
[5]Total quantity and total value in metric tons and thousand dollars.

TABLE 8

DIMENSION MARBLE SOLD OR USED BY PRODUCERS IN THE UNITED STATES,[1] BY USE

Use	1990e		1991	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Rough stone:				
Rough blocks for building and construction	7,447	$1,226	r17,388	$1,820
Other[2]	1,778	170	2,343	248
Dressed stone:				
Ashlars and partially squared pieces	2,135	W	r2,428	W
Slabs and blocks for building and construction	9,216	12,295	r11,693	13,160
Other[3]	8,627	10,617	9,131	10,903
Total	29,203	[4]24,307	r42,983	26,131
Total[5 6]	26,493	24,307	38,994	26,131

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

[1]Includes Puerto Rico.

[2]Includes rubble, irregular-shaped stone, monumental stone, and uses not specified.

[3]Includes stone used for monumental purposes, a small amount of flagging, and unspecified uses.

[4]Data do not add to total shown because of independent rounding.

[5]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[6]Total quantity and total value in metric tons and thousand dollars.

TABLE 9

DIMENSION SANDSTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1990e		1991	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Rough stone:				
Rough blocks for building and construction	3,101	$317	r2,708	r$181
Irregular-shaped stone[1]	52,498	1,776	r48,253	r1,715
Other[2]	182	29	r139	r20
Dressed stone:				
Ashlars and partially squared pieces	38,389	2,722	r52,808	r2,834
Slabs and blocks for building and construction	6,098	586	r6,076	r612
Flagging	16,520	1,537	r18,292	r1,171
Other[3]	16,938	2,334	r20,376	r2,203
Total[4]	133,726	[4]9,302	r148,652	r8,736
Total[5 6]	121,314	9,302	134,855	8,736

eEstimated. rRevised.

[1]Includes rubble.

[2]Includes monumental stone and uses not specified.

[3]Includes dressed monumental stone, curbing, and unspecified uses.

[4]Data do not add to total shown because of independent rounding.

[5]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[6]Total quantity and total value in metric tons and thousand dollars.

TABLE 10

DIMENSION SLATE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1990e		1991	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Flagging	8,366	$843	6,646	$754
Roofing slate	12,859	9,021	12,093	9,271
Structural and sanitary	3,486	2,682	3,307	2,577
Flooring slate	6,672	2,890	6,155	2,804
Other[1]	4,597	2,068	4,573	2,109
Total[2]	35,980	17,502	32,774	17,516
Total[3 4]	32,641	17,502	29,732	17,516

eEstimated.
[1]Includes a minor amount of slate used for billiard tabletops, blackboards, school slates, and unspecified uses.
[2]Data may not add to totals shown because of independent rounding.
[3]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convent short tons to metric tons, multiply short tons by 0.907185.
[4]Total quantity and total value in metric tons and thousand dollars.

TABLE 11

U.S. EXPORTS OF DIMENSION STONE, BY TYPE

(Thousand short tons and thousand dollars)

Type	1991		1992		Major destination in 1992, percent[1]
	Quantity	Value	Quantity	Value	
Marble, travertine, alabaster worked	25	2,560	21	2,839	Canada, 31.
Marble, travertine—crude or roughly trimmed	9	2,548	4	1,154	Italy, 23.
Marble, travertine—merely cut, by sawing or otherwise	9	6,380	4	2,070	Japan, 25.
Granite, crude or roughly trimmed	r68	11,414	66	12,253	Italy, 38.
Granite, merely cut by sawing or otherwise	r37	13,838	52	18,444	Japan, 43.
Granite, dressed, worked	28	12,702	13	6,010	Canada, 90
Sandstone, crude or roughly trimmed	1	203	1	138	Canada, 92.
Sandstone, merely cut, by sawing or otherwise	8	1,453	7	1,221	Canada, 96.
Slate, worked and articles of slate	NA	8,412	NA	7,695	Bahamas, 30
Slate, whether or not roughly trimmed or merely cut	NA	646	NA	380	Canada, 82.
Other calcareous monumental or building stone; alabaster	27	2,767	6	918	Canada, 41.
Other monumental or building stone	10	2,024	12	1,782	Canada, 59.
Total	NA	64,947	NA	54,904	

rRevised. NA Not available.
[1]By value.

Source : Bureau of the Census.

TABLE 12

U.S EXPORTS OF ROUGH DIMENSION GRANITE,[1] BY COUNTRY

(Thousand short tons and thousand dollars)

Country	Crude, roughly trimmed		Cut by sawing, otherwise	
	Quantity	Value	Quantity	Value
1991:				
Australia	—	—	2.2	925
Belgium-Luxembourg	1.7	369	1.4	527
Canada	12.1	1,807	1.3	566
Italy	21.9	3,526	2.4	1,005
Japan	20.8	4,371	16.4	5,382
Korea, Republic of	1.3	270	.1	38
Mexico	.2	83	1.4	511
Taiwan	5.5	288	6.7	2,887
United Kingdom	(2)	34	1.1	586
Other	4.2	666	3.5	1,411
Total	67.7	11,414	36.5	13,838
Total[3 4]	61.4	11,414	33.1	13,838
1992:				
Australia	—	—	(2)	48
Belgium-Luxembourg	2.0	456	0.4	151
Canada	16.4	2,580	1.2	518
Italy	28.5	4,602	4.1	1,646
Japan	11.4	2,639	23.1	7,929
Korea, Republic of	1.6	344	2.2	1,088
Mexico	.2	78	.2	139
Taiwan	1.9	615	18.1	3,292
United Kingdom	—	—	(2)	33
Other	3.7	939	2.7	3,600
Total	65.7	12,253	52.0	18,444
Total[3 4]	59.6	12,253	47.2	18,444

[1]Does not include granite articles.

[2]Less than 1/2 unit.

[3]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[4]Total quantity and total value in thousand metric tons and thousand dollars.

Source: Bureau of Census as modified by the U.S. Bureau of Mines.

TABLE 13

U.S IMPORTS FOR CONSUMPTION OF DIMENSION GRANITE, BY COUNTRY

(Thousand cubic feet and thousand dollars)

Country	Rough granite[e] [1]		Dressed granite[e]					
			Stone and articles		Worked		Total	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
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	(2)	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
Total[3 4]	102	34,907	30	31,347	129	128,019	159	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	(2)	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
Total[3 4]	51	19,222	36	24,272	141	151,699	177	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
Finland	5	94	(2)	3	(2)	79	(2)	82
India	9	304	285	781	559	11,065	844	11,846
Italy	166	2,485	436	10,232	2,468	72,535	2,904	82,767
Japan	2	20	1	82	10	297	11	379
Mexico	6	66	(2)	2	8	56	8	58
Norway	3	159	9	57	20	185	29	242
Portugal	450	1,418	22	160	60	1,038	82	1,198

See footnotes at end of table.

TABLE 13—Continued

U.S IMPORTS FOR CONSUMPTION OF DIMENSION GRANITE, BY COUNTRY

(Thousand cubic feet and thousand dollars)

Country	Rough granite[e 1]		Dressed granite[e]					
			Stone and articles		Worked		Total	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1991—Continued:								
Saudi Arabia	11	102	1	35	15	509	16	544
South Africa, Republic of	40	1,287	—	—	8	406	8	406
Spain	10	29	29	748	312	9,790	341	10,538
Other	36	384	9	241	100	3,338	109	3,579
Total	1,427	12,278	985	16,977	4,305	125,655	5,290	142,632
Total[3 4]	40	12,278	28	16,977	122	125,655	150	142,632
1992:								
Argentina	7	92	10	179	48	1,221	58	1,400
Brazil	211	526	127	1,596	465	7,235	592	8,831
Canada	237	2,967	29	2,036	161	12,366	190	14,402
China	42	157	17	328	99	2,024	116	2,352
Finland	2	37	—	—	(2)	134	(2)	134
India	25	852	560	1,395	788	14,181	1,348	15,576
Italy	80	1,205	200	4,701	1,767	47,198	1,967	51,899
Japan	9	87	1	47	4	103	5	150
Mexico	21	228	(2)	(2)	3	22	3	22
Norway	1	74	—	—	5	45	5	45
Portugal	160	507	9	62	46	798	55	860
Saudi Arabia	14	134	4	118	16	521	20	639
South Africa, Republic of	56	1,642	1	55	5	253	6	308
Spain	53	153	16	399	215	6,429	231	6,828
Other	56	600	8	203	81	2,560	89	2,763
Total[5]	974	9,261	982	11,120	3,703	95,090	4,685	106,210
Total[3 4]	28	9,261	28	11,120	105	95,090	133	106,210

[e]Estimated.

[1]Includes crude or roughly trimmed, and merely cut by sawing or otherwise.

[2]Less than 1/2 unit.

[3]To convert cubic feet to cubic meters, multiply cubic feet by 0.02831685.

[4]Total quantity and total value in thousand cubic meters and thousand dollars.

[5]Data may not add to totals shown because of independent rounding.

Sources: Bureau of the Census for values and the U.S. Bureau of Mines for quantity.

TABLE 14

U.S IMPORTS FOR CONSUMPTION OF MAJOR CATEGORIES OF DIMENSION MARBLE AND OTHER CALCAREOUS STONE, BY COUNTRY

Country	Dressed marble slabs		Dressed marble—other		Dressed marble and other calcareous stone[1]		Rough marble[2]	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
1990:								
Total	137,546	$147,082	71,227	$80,169	126,244	$75,242	9,528	$5,997
Total[3 4]	124,780	147,082	64,616	80,169	114,527	75,242	8,644	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
Total[3 4]	62,195	73,627	57,629	71,173	135,243	86,735	3,252	4,095
1992:								
China	1,645	1,118	1,367	1,302	3,261	1,357	463	175
France	197	239	855	699	9,769	12,546	31	47
Greece	8,588	8,112	3,756	4,196	4,118	2,923	306	58
India	115	174	482	907	169	180	24	22
Italy	29,030	28,589	33,398	35,428	26,215	25,966	1,633	1,280
Mexico	530	515	1,039	1,207	23,776	8,499	148	94
Portugal	1,868	1,748	1,004	886	6,241	4,211	118	112
Spain	2,683	2,973	3,859	4,368	22,621	22,017	148	166
Other	9,433	8,842	13,646	16,127	30,252	7,188	494	429
Total	54,089	52,310	59,406	65,120	126,422	84,887	3,365	2,383
Total[3 4]	49,069	52,310	53,892	65,120	114,688	84,887	3,053	2,383

[1]HTS No. 6802.92.0000: 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.

[2]Marble—merely cut by sawing or otherwise.

[3]One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[4]Total quantity and total value in metric tons and thousand dollars.

Source: Bureau of the Census as modified by the U.S. Bureau of Mines.

TABLE 15

U.S. IMPORTS FOR CONSUMPTION OF DIMENSION STONE, BY TYPE

Type		1991		1992		Major source for 1992, percent[1]
		Quantity	Value (thousands)	Quantity	Value (thousands)	
Calcareous stone—other[2]	short tons	r4,883	r$2,291	3,186	$2,831	France, 29.
Marble, travertine alabaster and other	do.	6,324	6,985	4,817	4,921	Italy, 51.
Sandstone, merely cut, by sawing or otherwise	do.	250	211	347	181	India, 21.
Slate, roofing	million square feet	5.0	2,948	5.1	2,958	Spain, 51.
Slate, whether or not roughly trimmed or merely cut		NA	1,845	NA	2,051	Italy, 86.
Slate, worked and articles of slate, and other		NA	15,889	NA	16,638	Italy, 51.
Stone, worked monumental or building stone—other	short tons	36,073	41,662	36,287	40,745	Italy, 30.
Travertine, monumental or building stone and articles thereof	do.	3,243	2,117	5,537	2,419	Italy, 91.
Travertine, worked monumental or building stone	do.	12,035	7,308	9,044	6,460	Italy, 91.
Other monumental or building stone	do.	6,935	2,173	14,198	3,487	South Africa, Republic of, 5.
Other stone—monumental or building stone—articles thereof	do.	1,310	945	2,352	1,060	Mexico, 62.

rRevised. NA Not available.
[1]By value.
[2]HTS No. 6802.22.0000.

Source: Bureau of the Census.

STRONTIUM

By Joyce A. Ober

Mrs. Ober, a physical scientist with 15 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 world production table was prepared by Virginia A. Woodson, international data coordinator.

World production of celestite, strontium ore, has grown significantly over the past several years in response to increased demand for strontium carbonate, the most important strontium compound derived from celestite. Trade statistics from the U.S. Bureau of the Census show large increases in imports of both celestite and strontium compounds in 1992. These figures, along with decreased exports of strontium compounds, indicate that domestic consumption of strontium remains strong. Although quantities may fluctuate from year to year, the general consumption trends continue to increase.

Chemical Products Corp. (CPC) of Cartersville, GA, was the only U.S. producer of strontium compounds from celestite. CPC produced strontium carbonate from imported ore 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 and sales 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 11 operations to which a survey request was sent, all responded. The information collected from this survey and the information provided by the U.S. Bureau of the Census on strontium trade were the basis for the end use estimates shown in table 2. *(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 1992 by one company in the United States. CPC was the only domestic company that produced strontium chemicals from celestite. All 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 as 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.

Several U.S. companies produced strontium metal and compounds from strontium carbonate. Calstron Corp. of Memphis, TN, produced strontium metal, 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.[1] 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.[2]

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 strontium compounds possess unique properties, technologies have been 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 are 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. The 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 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 $68 per ton ($61 per short ton), 12% less than the average value in 1991. Mexico was the source of nearly 100% of celestite imports in 1991. Imports of very small quantities of high-valued celestite were reported from Denmark, France, and Madagascar. The exceptionally high unit value and small shipment sizes indicated that these imports were for mineral specimens, not for conversion to strontium carbonate.

The average unit customs value of imported strontium carbonate was $0.59 per kilogram and the average value for strontium nitrate was $0.97 per kilogram; the values for both compounds were slightly lower than the average values reported for 1991.

Foreign Trade

According to reports from the U.S. Bureau of the Census, exports of strontium compounds decreased 34% from the levels reported in 1991. Imports of celestite increased 35% from the levels reported in 1991.

Mexico was once again the most important source for imported strontium compounds; Germany was second. Imports of strontium carbonate in 1992 were 39% higher than those in 1991, with imports from Mexico comprising 82% of total carbonate imports. Imports of strontium nitrate were about the same as those in 1991. *(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; a few operations use froth flotation or gravity separation to beneficiate 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 located in countries from which specific mineral information is not easily obtained.

Capacity.—Two types of strontium capacity exist, ore production capacity and compound production capacity. Strontium compound capacity is deemed a better indicator of the status of the strontium industry 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 10 countries mined celestite in 1992. 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 more complicated and sophisticated processing facilities. Therefore, strontium carbonate production capacity, reported in terms of contained strontium, is usually selected for tabulation. Strontium carbonate capacity has increased because of the continued growth in international sales of color television sets.

Capacity information, compiled from published reports, establishes worldwide strontium carbonate production capacity at about 245,000 tons per year, but estimates place the capacity utilization at between 70% and 75% due to a current overcapacity situation. It is likely that some of the existing capacity will be shut down in the near future, bringing supply capabilities more in line with demand requirements.

Algeria.—Celestite was mined in Algeria from a surface deposit near Beni Mansour. Estimated reserves were more than 1 million tons. The deposit was mined by Enterprise des Produits Non-ferreux et des Substances Utilès (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 Germany. Although the celestite was relatively low grade, only about 70% strontium sulfate, it contained low concentrations of barite, gypsum, iron, and silica, making it possible to concentrate the ore to acceptable levels using only gravity separation.[3]

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, Carro 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.[4]

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 located at Lake 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,[5] but none as significant as the deposit in Nova Scotia.

Timminco Metals was the largest producer of strontium metal in the world. 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 of high grade and close enough to the surface for open pit mining.[6] Import data indicate that strontium chemical plants must exist, but no specific details were available. Strontium carbonate from China has been reported in the United States, and reports also indicated that Japan imports strontium carbonate from China.

Germany.—Kali-Chemie AG of Hannover, a subsidiary of Belgium's Solvay SA, produced strontium carbonate from imported celestite at its plant in Bad Hoenningen. The company, with its joint venture and partial interests in other countries, is the largest strontium carbonate producer in the world, and this plant is the single largest strontium operation in the world. The production facility uses the black ash method and was renovated in 1991 to increase the strontium carbonate production capacity from 15,000 to about 70,000 tons per year.[7] Kali-Chemie imported most of its celestite from Spain and Turkey; it exported nearly all 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.[8]

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 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 has no overburden.[9] Most of the celestite produced from this deposit was exported to the former U.S.S.R., but the economic and political situation in that part of the world has limited markets for the Iranian celestite. The company is trying to establish new markets for its celestite throughout the world.

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.[10] Societa Bario e Derivati, a

subsidiary of Kali-Chemie AG, produced strontium nitrate at Massa. Production and capacity figures were not available; most of the production is exported to the United States. The plant was closed in 1992 because the cost was too high to meet new environmental requirements.[11]

Japan.—Although celestite was not mined in Japan, it has been the largest consumer of strontium carbonate in the world, mostly due to its large television and electronics industry. Four companies produced strontium carbonate from imported celestite. Honjo Chemical Corp. operated a production facility for 11,000 tons per year of carbonate at Neyagawa in Osaka and another of the same capacity at Okayama in Okayama using celestite from Spain and China. There have been strong indications that Honjo may close at least one or both of these operations owing to less expensive imports and the shift of television tube production to other countries.[12]

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 Dowa 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.[13]

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 at Onsan. The plant began operation in 1990 with combined production capacity of 40,000 tons per year of strontium carbonate and barium carbonate. The production was marketed to the growing television industry in that country. The black ash method was used.[14]

Mexico.—Mexico has become a major supplier of both celestite and strontium carbonate. Vast celestite deposits provide abundant raw material for the strontium carbonate producers in Mexico and throughout the world. Since Mexican strontium carbonate production began in 1987, capacity has expanded tremendously, making the country the largest producer worldwide with nearly 40% of the world's total production capacity.

Cia. Minera La Valenciana SA (CMV) bought the strontium carbonate processing equipment when a major U.S. strontium carbonate and strontium nitrate producer (FMC Corp.) closed its California plant in 1984. 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 where production began in 1987. The plant capacity has been upgraded to 50,000 tons per year.

CPC operated a strontium carbonate plant in Reinosa, Tamaulipas, close to the U.S. border, which began production at the end of 1991. Capacity was reported at about 22,000 tons per year. Sales y Oxidos (SYOSA), 86% owned by Kali-Chemie, operated a black ash strontium carbonate plant near Monterrey with the capacity of 15,000 tons per year.[15] Quimica Dinamica SA de CV operates an 8,000-ton-per-year strontium carbonate and strontium nitrate plant in Monterrey. Planning to install a larger black ash plant in the future, the company used the soda ash process for strontium carbonate production. The company had announced plans to increase capacity to more than 50,000 tons, but that development will depend on the continued strength of strontium demand. Quimica Dinamica is currently a major force in the strontium nitrate market.[16]

Mexico was the world's largest producer of celestite in 1992. The most recent Directory of Mexican Non-Metallic Minerals Trust lists 11 companies currently mining celestite. The newest mine, operated by Minera La Roja SA, began production in 1990 from the La Ilusion Mine in Coahuila. Proven reserves are 500,000 tons with total reserves of almost 3 million tons. The ore is upgraded through flotation to a minimum 95% strontium sulfate.[17]

CMV mined celestite from the San Augustín 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 Augustín Mine have been estimated at more than 725,000 tons. SYOSA and Quimica Dinamica operated mines in Coahuila. Other small operations occur in Aguascalientes, Chihuahua, and Nuevo Leon. In most cases, Mexican celestite is very 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.[18]

Morocco.—A joint venture between CPC and Kali-Chemie has established Mobar SA, a project to mine celestite in northern Morocco at Ksar El Kebir. Heavy-media separation is necessary to produce 94% strontium sulfate. The operation was in the startup phase.[19]

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.[20] 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.[21] Other deposits with 500,000 tons of reported reserves have been identified in the Punjab Province.[22]

Spain.—Spain traditionally has been one of the largest celestite producers worldwide. Celestite was produced from the Montevive 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 production from Montevive is exported to Japan, some remains in Spain, and the rest is exported to Germany.[23] Another deposit at Escúzar near Montevive is operated by Kali-Chemie Iberia SA. The ore is upgraded to 95% strontium sulfate by heavy-media preconcentration and flotation. Production from this site is shipped to other Kali-Chemie operations in Germany and Korea.[24]

Promotora de Industria del Sur (Proinsur SA) produced strontium carbonate and strontium nitrate at a combined facility near Granada until the end of 1991 when market conditions prompted its closure. The plant had a design capacity of 8,000 tons per year of carbonate but never reached capacity. Strontium carbonate was produced by the soda ash method. The plant also had a production capacity of about 3,000 tons per year of nitrate, which was not fully utilized.[25] Plans to improve Proinsur's process have been developed, but have been shelved until market conditions improve.

Turkey.—Turkey competes with Iran, Mexico, and Spain 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 was operated on a seasonal basis, usually from May to October. Another mine near Sivas formerly was operated by Bilfer Madencilik AS, which reestablished concessions for future 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 Korea and Germany.[26]

Former 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 Bucharia to the shores of the Sea of Aral. Reserves are believed to be very large, but the ore grade is probably not high.[27] No details are available concerning the production of strontium carbonate in the former U.S.S.R. except that there has been production in the past, probably from domestic celestite as well as from imports from Iran and Turkey. Recent changes in the political and economic situation in this region may have caused disruptions in production as indicated by attempts by traditional celestite suppliers to establish new markets, but as with many former Soviet industries, details remain a mystery.

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 U.K. celestite never regained its prominence. Celestite deposits, occurring in the Bristol area, were mined by Bristol Minerals Co. Ltd. This was one of the few sites in the world where celestite deposits are not in remote locations. The ore was crushed, washed, and graded to achieve a product with 95% strontium sulfate.[28] The Bristol deposits were finally exhausted in 1992, and mining was curtailed. The company developed a spiraling and flotation process for handling mine tailings and keep the operation going until the tailings have been reprocessed.[29] *(See table 6.)*

OUTLOOK

The strontium carbonate capacity situation has clouded the picture for the future of the industry, but for the most part, the future continues to look bright for the near term. Changes have occurred regarding leading celestite and strontium carbonate producers, but production and consumption continue to expand.

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 noted[1])

	1988	1989	1990	1991	1992
United States:					
Production, strontium minerals	—	—	—	—	—
Imports for consumption:					
Strontium minerals	18,100	12,000	21,500	14,600	19,700
Strontium compounds	7,800	11,300	11,800	r9,550	13,000
Exports (compounds)	[2]3,000	[2]3,200	700	1,080	650
Shipments from Government stockpile excesses	—	—	—	—	—
Price, average value of mineral imports at port of exportation, dollars per ton	85	76	86	77	68
World production[3] (celestite)	r226,483	r275,264	r259,527	r193,752	e217,100

eEstimated. rRevised.
[1]The strontium content of celestite is 43.88%, which was used to convert units to celestite.
[2]Export data are obtained from the Journal of Commerce Port Import/Export Reporting Service.
[3]Excludes China and the former U.S.S.R.

Source: Bureau of the Census.

TABLE 2
U.S. ESTIMATED DISTRIBUTION OF PRIMARY STRONTIUM COMPOUNDS, BY END USE

(Percent)

End use	1989	1990	1991	1992
Electrolytic production of zinc	4	3	2	2
Ferrite ceramic magnets	10	9	7	12
Pigments and fillers	3	4	6	5
Pyrotechnics and signals	10	11	13	11
Television picture tubes	70	70	70	67
Other	3	3	2	3
Total	100	100	100	100

TABLE 3
U.S. EXPORTS OF STRONTIUM COMPOUNDS, BY COUNTRY

	1991		1992	
	Kilograms	Value[1]	Kilograms	Value[1]
Strontium carbonate-precipitated:				
Canada	57,113	$73,140	109,581	$107,432
Japan	—	—	287,141	291,624
Mexico	44,544	27,209	70,000	20,773
Peru	18,000	12,600	—	—
Taiwan	1,628,891	1,304,028	371,056	328,624
United Kingdom	4,702	29,880	1,360	5,976
Total	1,753,250	1,446,857	839,138	754,429
Strontium oxide, hydroxide, and peroxide:				
Canada	2,874	3,277	3,767	2,720
Germany	[2]27,890	[2]71,400	25,613	225,169
Greece	—	—	2,992	18,999
Israel	(2)	(2)	—	—
Italy	108	4,407	—	—
Japan	1,153	18,731	—	—
Korea, Republic of	2,963	19,230	1,550	61,270
Mexico	1,649	6,630	5,947	20,378
Norway	368	6,884	467	18,522
Portugal	—	—	113	27,000
Taiwan	5,342	158,515	5,400	141,145
United Kingdom	—	—	301,272	923,076
Venezuela	4,624	29,362	—	—
Total	46,971	318,436	347,121	1,438,279

[1]Customs value.
[2]Shipments to Germany were erroneously reported as shipped to Israel in 1991.

Source: Bureau of the Census.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM MINERALS,[1] BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)
Mexico	33,203	$2,558	44,810	$3,026
Other	1	19	—	—
Total	33,204	2,577	44,810	3,026

[1]Celestite (strontium sulfate).
[2]Customs value.

Source: Bureau of the Census.

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM COMPOUNDS, BY COUNTRY

	1991		1992	
	Kilograms	Value[1]	Kilograms	Value[1]
Strontium carbonate:				
China	87,000	$51,674	85,000	$43,394
Germany	2,953,552	1,980,685	3,665,089	2,420,747
Italy	7,400	22,960	8,505	19,811
Japan	7,287	38,482	3,606	11,978
Mexico	11,798,625	6,938,072	16,841,523	9,659,110
United Kingdom	16	12,810	3	2,704
Total	14,853,880	9,044,683	20,603,726	12,157,744
Strontium nitrate:				
Italy	35,400	33,600	17,500	16,048
Japan	—	—	160	2,315
Korea, Republic of	1,000	4,500	—	—
Mexico	1,721,039	1,702,576	1,749,172	1,701,305
Spain	18,000	17,280	—	—
Total	1,775,439	1,757,956	1,766,832	1,719,668

[1]Customs value.

Source: Bureau of the Census.

TABLE 6

STRONTIUM MINERALS: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Algeria[e]	5,400	5,400	5,400	5,400	5,400
Argentina	2,241	1,193	[e]1,200	1,200	1,200
Iran (celestite)[3]	39,194	56,849	34,140	[r]28,500	30,000
Mexico (celestite)	51,626	67,658	66,254	[r]62,180	80,000
Pakistan	488	956	1,799	[r]1,472	1,500
Spain[4]	[r]41,981	[r]32,323	[r]31,000	[r]28,000	28,000
Turkey (celestite)[e]	[r]60,000	[r]90,000	[r]95,000	[r]65,000	70,000
United Kingdom	25,553	20,885	24,734	[r]2,000	1,000
Total	[r]226,483	[r]275,264	[r]259,527	[r]193,752	217,100

[e]Estimated. [r]Revised.

[1]Table includes data available through June 1, 1993.

[2]In addition to the countries listed, China and Poland produce strontium minerals, but output is not reported quantitatively, and available information is inadequate to make reliable estimates of output levels.

[3]Data are for year beginning Mar. 21 of that stated.

[4]Sr_2O_4 content.

SULFUR

By Joyce A. Ober

Mrs. Ober, a physical scientist with 15 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 Doug Rhoten, International Data Section.

Although both production and consumption decreased for the third consecutive year, the United States retained its position as the world's leading producer and consumer of sulfur and sulfuric acid. The quantity of sulfur was recovered during the refining of petroleum, and the processing of natural gas was greater than any time since the U.S. Bureau of Mines began reporting statistics for this type sulfur. The production of sulfur through the Frasch process, however, was lower than it had been for more than 50 years. Low Frasch production was a result of production cutbacks of one of the three mines that operated throughout 1992 and the slower-than-expected startup at a new mine that began operation during the year. Total production and shipments of sulfur from all sources were slightly lower than they had been in 1991.

Sulfur production from a major salt dome on Federal lease block Main Pass 299 in the Gulf of Mexico began at the end of April. 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.

Shipments of recovered elemental sulfur were nearly three times higher than Frasch shipments, and total shipments were slightly lower than those in 1991. 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 emissions, supplied a significant quantity of sulfuric acid to the domestic merchant acid market. Marketing continued to be difficult for some producers because smelters were near western copper mines and far from major sulfuric acid markets.

Worldwide, sulfur production decreased about 5% compared to that in 1991, with a 19% decrease in Frasch production and a slight increase in the amount recovered from petroleum and natural gas processing. Frasch production was lower because only three mines operated in the United States for the full year, Mexican and Polish mines operated at low rates, Iraq had not resumed full production following the war in the Persian Gulf, and political and economic problems continued in Eastern Europe and the former U.S.S.R. Recovered elemental production increased in Asia, the Middle East, North America, and Western Europe; decreased in Eastern Europe and the former U.S.S.R.; and remained about the same in the rest of the world. About two-thirds 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 an estimated 7%. Consumption in fertilizer production decreased and 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 1.2 million metric tons, about 8% below levels recorded in 1991. Although U.S. sulfur inventories decreased about 32% from yearend 1991, worldwide producers' stocks of elemental sulfur increased nearly 5%. *(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 177 operations to which a survey request was sent, 173 responded, representing 98% of the total production shown in table 1. Production data for the nonrespondents were estimated using prior-year reported production.

BACKGROUND

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.

Also known as brimstone, "the stone that burns," sulfur 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 commonly used 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 20-centimeter 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 a 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 1992, world sulfur production and consumption amounted to 52.4 million and 53.1 million metric tons, respectively. The United States was the world's largest producer and consumer; however, the United States was a net importer of sulfur. Canada and the former U.S.S.R. produced nearly equal quantities of sulfur in 1992, but the former U.S.S.R. was a net importer, while Canada was the world's largest exporter of elemental sulfur. Poland, the fifth largest producer, ranked second among 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 former 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 pyrrhotite) 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 include 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 former U.S.S.R.; substantial deposits occur in the mountain and gulf coast regions of the United States and in Germany, France, 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. However, the steep price reductions in the past 2 years have confused the issue of price

leadership. Canada's role is still very important, but the oversupply of sulfur in Europe, Poland, and Saudi Arabia also has had an effect on prices.

In the United States, the quoted liquid Frasch sulfur price, f.o.b. terminal Tampa, FL, has traditionally been the benchmark price. Toward the end of 1992, the industry seemed to be abandoning this practice. Although a Tampa Frasch price was published weekly in trade publications, reports in those publications indicated that contract prices were becoming less dependent on these posted prices, and in fact only one Frasch producer was posting its prices weekly. 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 at least $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 that 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 figure 2.)*

Operating Factors

Increasing environmental concerns have had an impact on the sulfur industry, as they have had on most other industries. The effects on the sulfur industry can be interpreted as both positive and negative as far as sulfur is concerned, but certainly positive in terms of decreasing pollution.

Even before the Clean Air Act became law in 1977, oil refineries and natural gas processors realized the necessity of removing sulfur from their products and offgases. The U.S. Bureau of Mines began collecting data on recovered sulfur in 1939, and references were made to this type of sulfur prior to that, but with no official data to quantify the recovery. At first, recovered sulfur was considered a waste material, not a commercial byproduct. As time went on, the importance of recovered sulfur increased as sulfur demand increased faster than the supply of Frasch and other native sulfur. Recovered sulfur became the primary domestic source of elemental sulfur in 1982.

The Clean Air Act set limits on the quantity of pollutants that could be released into the atmosphere. Sulfur dioxide was identified as one of the most common pollutants and one of the major contributors of acid rain, known to damage both natural and artificial environments. New gas-cleaning apparatus removed as much sulfur dioxide as was technologically possible from offgases. Petroleum refiners and gas processors were able to recover a greater percentage of sulfur from the gas stream as elemental sulfur, metal smelters (especially nonferrous metals) recovered byproduct sulfuric acid, and coal and oil burning electric powerplants recovered byproduct gypsum (calcium sulfate), cutting emissions dramatically. The type of byproduct recovered was determined by the sulfur content of the gas stream; elemental sulfur was recovered when the sulfur dioxide content was relatively high.

Amendments to the Clean Air Act of 1990 required a 50% reduction of sulfur dioxide emissions by the year 2000, and electric power stations are believed to be the source of 70% of all sulfur dioxide emissions. For this reason the 1990 amendments will concentrate on the further reduction of emissions from electric utilities. Existing technology to recover elemental sulfur from powerplant offgases has a cost estimated to be 50% higher than the cost of recovering byproduct gypsum. Although some byproduct gypsum is consumed in the same end uses as natural gypsum, much of it is disposed as waste. Although no utilities currently are recovering commercial quantities of elemental sulfur in the United States, as landfill costs become higher elemental sulfur recovery becomes a more attractive alternative to byproduct gypsum production.

Over the years, larger quantities of sulfur have been recovered for a number of reasons, including increased petroleum refining and natural gas processing, more stringent limitations on sulfur dioxide emissions, and higher sulfur contents of the crude oil refined. Other contributing factors are lower sulfur content limits set on petroleum-based fuels. As a result, recovered sulfur production increased about 6% in 1992, although refinery production grew only about 1% in 1992.

As sulfur supplies, either as elemental sulfur or byproduct sulfuric acid, have grown due to increased environmental awareness, the demand for sulfur has decreased in some consuming industries for the same reason. Some industries (i.e., uranium processing) have contracted or completely disappeared owing to concerns regarding environmental damage caused by their processes. Other industries, such as titanium dioxide production, have converted to more environmentally "friendly" processes that do not use sulfuric acid. In addition, many consumers who continue to use sulfuric acid are putting new emphasis on regenerating or recycling spent acid.

Another area where improved air quality has had an impact on sulfur use is in agriculture. As reduced sulfur dioxide emissions decreased acid rain, sulfur content of soils also has decreased. Sulfur is now recognized as an important plant nutrient, necessary for the most efficient use of other nutrients and optimum plant growth. Because many soils are now deficient in sulfur, a demand for sulfur-containing fertilizers has been created, and farmers must now buy a nutrient that previously had been available at no cost.

Increased environmental awareness has created a dilemma for sulfur producers. While pollution reduction requirements have created increased supplies of sulfur and sulfur products, similar requirements have caused a decrease in demand. This situation will persist and the imbalance between supply and demand could increase. Disposing of excess sulfur, recovered while cleaning the air to protect the environment, may create

another environmental problem.

ANNUAL REVIEW

Legislation and Government Programs

The 1990 amendments to the Clean Air Act required a 50% reduction from 1980 levels of sulfur dioxide emission nationwide by the year 2000. The 1990 Act contains an innovative measure to control emissions through market-based incentives rather than more traditional, strict, inflexible rules. The Emission Allowance Market (EAM) will make it possible for companies that have been able to reduce emissions at their operations to sell unneeded allowances to companies that have not been able to meet pollution reduction requirements.

Other types of pollutants will eventually be controlled by this process, but sulfur dioxide will be managed first. Because electric powerplants are believed to be the source of about 70% of all sulfur dioxide emissions in the United States, the EAM will concentrate on that industry. The Environmental Protection Agency has chosen the Chicago Board of Trade (CBoT) to administer allowance sales.

Utilities will be assigned emission allowances based on historic fuel consumption and sulfur dioxide emission data. These assigned allowances will decrease over time to meet the goal of 50% reduction. Additional allowances will be available for purchase on the open market. Each utility must buy its assigned allowances directly from the Government at a predetermined price. If a specific power station finds it cannot meet its pollution requirements, it must buy additional allowances on the open market or from another utility that has reduced its emissions and thus possesses emission allowances that are in excess of its needs. Additional allowances may be purchased directly from companies offering them for sale or through auctions at the CBoT. All of the Government's unassigned allowances will be sold through CBoT.

Phase 1 of the EAM program will affect the 10 largest power stations in 21 Eastern and Midwestern States. Compliance will be required by January 1, 1995, with sales of future emission allowances beginning at the CBoT in March 1993. Phase 2 will encompass approximately 700 remaining smaller utilities with compliance required by January 1, 2000. As time passes, all emission allowances will be purchased through auction or on the open market, with none through direct sale from the Government.

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 1992, the United States had three Frasch mines operating in Louisiana and Texas; another mine in Louisiana began operating during the year. Mines in Texas were Pennzoil Sulphur Co., at Culberson, and Texasgulf Inc. (TG), at Boling Dome in Wharton County. Freeport Sulphur Co. owned and operated two mines in Louisiana. The Caminada Pass mine 14 kilometers offshore in the Gulf of Mexico operated throughout the year, and Main Pass, 27 kilometers offshore, began operating in April.

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 about 50 million tons of sulfur on its Federal lease block, Main Pass 299, which is offshore in the Gulf of Mexico, 27 kilometers 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 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, and production of natural gas, oil, and sulfur began in 1992. The company expects to reach full capacity of about 2 million tons per year sometime in 1994. The estimated cost of the project was more than $750 million. The startup at Main Pass was somewhat slower than expected owing to some technical problems as well as low sulfur prices. The company chose to concentrate on oil and gas production until sulfur prices improved.

Frasch sulfur output decreased 550,000 tons from the quantity produced in 1991 and was only about one-third of what it was in 1981. Shipments to domestic and overseas consumers were 17% lower in 1992 than they were in 1991. Frasch sulfur accounted for 22% of domestic production in 1992. 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 $120 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 two-thirds of the total domestic output of sulfur in all forms compared with 66% in 1991. Production and shipments of recovered sulfur were 6% higher, reaching alltime high levels owing to record production from the Nation's petroleum refineries. Production and shipments from petroleum refineries were 7% and 6% higher, respectively, and from natural gas processing plants, about 5% and 6% higher, respectively, than those 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 22 reporting an annual production exceeding 100,000 tons. By source, 52% was produced at 3 coking plants and 85 refineries or satellite plants treating

refinery gases. The remainder was produced by 27 companies at 60 natural gas treatment plants. The five largest recovered-sulfur producers in 1992 were Exxon Co. U.S.A., Standard Oil Co. (California), Standard Oil Co. (Indiana), Shell Oil Co., and Mobil Oil Corp. The 52 plants owned by these companies accounted for 55% of recovered elemental sulfur output during the year. *(See tables 2, 3, and 4.)*

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 78% 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 1992 total. *(See table 5.)*

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 figure 3.)*

Consumption and Uses

Domestic consumption of sulfur in all forms was slightly lower in 1992 than it was in 1991. In 1992, 79% of the sulfur consumed was obtained from domestic sources compared with 77% in 1991 and 80% in 1990. The sources of supply were domestic recovered elemental sulfur, 51%; domestic Frasch sulfur, 18%; and combined domestic byproduct sulfuric acid, pyrites, hydrogen sulfide, and sulfur dioxide, 10%. The remaining 21% 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 59 companies, and shipments of sulfuric acid were reported by 50 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 86% of reported 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.

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. consumption of sulfur in sulfuric acid (100% basis) decreased by about 4% in 1992 owing to decreases in demand for sulfuric acid in industrial uses. Demand for sulfuric acid for the production of phosphoric acid, the largest single end use, was virtually unchanged from that of 1991. Sulfuric acid demand for copper ore leaching, the second largest end use, decreased about 6% as reported by sulfuric acid producers. Reported shipments of sulfuric acid for petroleum refining and other petroleum and coal products were not significantly different from those of 1991, but reported consumption of elemental sulfur in those end uses was nearly double.

According to the 1992 canvass reports, company receipt of spent or contaminated sulfuric acid for reclaiming totaled 2.7 million tons. The largest source of this spent acid continued to be the petroleum refining industry, which accounted for 49% of the total returned. About 1.2 million tons of spent acid was reclaimed from chemical producers. The remaining reclaimed acid was from manufacturers of ferrous and nonferrous metals, paper, storage batteries, and some unidentified sources.

The largest use of sulfur in all forms, for agricultural purposes, increased from 9.0 million tons in 1991 to about 9.3 million tons. The estimated quantity of sulfur needed to manufacture exported agricultural chemicals decreased by about 550,000 tons to 4.1 million tons, indicating that sulfur consumption for fertilizers intended for domestic consumption increased more than 500,000 tons. Although consumption of sulfur for phosphatic fertilizer production experienced little change in 1992 and exports of fertilizer decreased, domestic consumption of fertilizer was relatively stable. Low export demand resulted in increased producers' stocks of phosphatic fertilizers. *(See tables 6, 7, and 8 and figure 4.)*

Stocks

Yearend inventories held by Frasch and recovered elemental sulfur producers decreased 32% from those of 1991, which would normally indicate a tightness of supply, but this was not the case in 1992. Because of low world demand and increased competition for domestic markets, at least one Frasch producer chose to cut production and ship from inventory to reduce expenses. Combined yearend stocks amounted to approximately a 23-day supply compared with a 34-day supply in 1991, a 40-day supply in 1990, a 37-day supply in 1989, and a 32-day supply in 1988 based on apparent consumption of all forms of sulfur. *(See table 9.)*

Markets and Prices

The posted price for liquid sulfur exterminal Tampa, FL, began the year at $98 and dropped to $88 per ton in October. 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 $87.05 to $58.15 per ton. The average value, f.o.b. plant, for shipments of recovered elemental sulfur varied widely by geographic region; the national average value for the year was $45.20 per ton, almost $20 per ton less than the average for 1991. The average value for all elemental sulfur was $49.17 per ton in 1992, 31% lower than that in 1991. *(See table 10.)*

Foreign Trade

Exports of elemental sulfur from the United States, including the U.S. Virgin Islands, decreased 19% in quantity and 42% in value. According to the Bureau of the Census, exports from the west coast were 568,000 tons or 77% of total U.S. exports.

The United States continued to be a net importer of sulfur; imports exceeded exports by about 1.8 million tons in 1992. Frasch sulfur from Mexico and recovered elemental sulfur from Canada, both delivered to U.S. terminals and consumers in the liquid phase, furnished 99% of all U.S. sulfur import requirements. Total elemental sulfur imports decreased 10% in quantity; imports by rail from Canada increased 11%, while waterborne shipments from Mexico were 33% lower than those in 1991. Imports from other sources, very small compared to those from Canada and Mexico, decreased 77%.

The United States also had significant trade in sulfuric acid. Sulfuric acid exports decreased about 6% from those of 1991. Imports, which were significantly greater than exports, were mostly by rail from Canada. The tonnage increased 8% from the quantity reported in 1991; the value of imported sulfuric acid increased 19%. Approximately 456,000 tons of acid was imported into the Tampa, FL, area, about 18% less than the Tampa acid imports of the previous year. Two sulfuric acid terminals had been established there in 1989. *(See tables 11, 12, 13, and 14.)*

World Review

With production, consumption, and prices down for the second consecutive year, 1992 was a disappointing year for the global sulfur industry. Frasch producers experienced production cutbacks, and as consumption decreased, international competition for available markets became more intense.

Industry Structure.—In 1992, the sulfur industry remained 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 1992, involuntary sources represented almost 64% of the elemental sulfur produced worldwide.

Large quantities of Frasch sulfur were produced from mines in only five countries: Iraq, Mexico, Poland, the former U.S.S.R, and the United States. Poland and the former 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 southern Africa, China, much of Eastern Europe, Finland, and Spain and were an important source in Scandinavia and the former U.S.S.R.

Recovered elemental sulfur was the predominant sulfur source in Canada, France, Germany, Saudi Arabia, and the United States. Additionally, recovered elemental sulfur was an important source in Iran, Japan, and the former U.S.S.R. Sulfur production in Iraq and Kuwait was beginning to recover from the effects of the Gulf War, but was significantly lower than that in previous years. Production levels in Iraq will affect world markets minimally until economic sanctions are lifted by the United Nations.

International sulfur trade was dominated by a limited number of exporting countries; exports from Canada, Poland, Saudi Arabia, the United States, Mexico, and Germany, in descending order of the quantity shipped, accounted for 86% of sulfur trade in 1992. Major sulfur importers in 1992 were the United States, Morocco, India, Tunisia, Brazil, the Republic of Korea, and the United Kingdom, in descending order of importance, all with imports of more than 500,000 tons.

Capacity.—The data in table 15 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, 1992. 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 15.)*

Canada.—Production in Canada was 6.35 million tons, slightly higher than that of the previous year. Canada was the world's largest sulfur exporter, with nearly 90% of production exported. Sulfur recovered from natural gas processing represented 76.8% of total Canadian production, with 7.6% 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 annual tons of sulfur capacity should be operational by early 1993; full production capacity is expected to be reached by the end of that year. An estimated 25 million tons of sulfur is contained in this deposit, which has an average hydrogen sulfide content of 35.3%.

Shell completed a pilot-scale project to determine the feasibility of producing sulfur from a deposit containing more than 90% hydrogen sulfide as well as elemental sulfur. The Bearberry sulfur resources were estimated at 40 million tons, and because of the corrosiveness of the material, presented significant challenges to designing a successful recovery process. Suitable materials were developed, and the pilot project proved successful. However, because the cost of construction of a full-scale plant would be prohibitive, especially with sulfur prices at current lows, the operation was shut down after proving its success.

China.—The third largest sulfur consumer and fourth largest sulfur producer was nearly self-sufficient in sulfur. China is the largest pyrites producer, representing more than one-half of all pyrites production and large pyrites reserves. This was the only country in which pyrites production is growing; this trend is expected to continue.

Former U.S.S.R.—Production of sulfur in all forms decreased substantially for the fifth consecutive year. 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.

Considered the world's last oil and gas frontier, many oil companies were interested in forming joint ventures in the former U.S.S.R. The potential exists for large sulfur recovery capacity when new oil and gas operations are commissioned.

Sulfur production began at the Tengiz oil and gas condensate field in the Republic of Kazakhstan in 1991. Since that time, Chevron reached an agreement with the Government of Kazakhstan for a 50% interest in the further development of the Tengiz and Korolov oilfields and gasfields. Tengiz was believed to have huge oil reserves and associated sour gas. Korolov was much smaller, but with a higher sulfur content.

Originally, four production phases were planned for Tengiz, but for the time being, only Tengiz I and Tengiz II are expected to be completed. Tengiz II was expected to come on-stream in 1992, but experienced delays. If all phases of the project are completed, sulfur recovery capacity could be more than 3 million tons per year when oil production reaches its peak in the year 2010.

Negotiations were proceeding with the Government of Kazakhstan and a British and Italian joint venture to develop the Karachaganak oil and sour gas condensate field. This field also has a large sulfur-producing potential due to its 22% hydrogen sulfide content.

The Astrakhan sour gas field in the

Russian Republic began producing in 1987, but serious environmental problems forced its shutdown in 1989 for repairs and improvements. It was restarted in 1992 and gradually approached its capacity to recover 1.8 million tons of sulfur per year. The second phase of production, Astrakhan II, was expected by the end of 1993.

Iraq.—Iraq's Frasch sulfur operation suffered no damage during the war in the Persian Gulf, but sulfur production and exports were believed to be low due to the United Nation's trade embargo that remained in effect. Reports from Iraq stated that production at Mishraq had reached 2 million tons per year. It was doubtful that output was that high, but Iraq represents a significant additional source of supply when sanctions are lifted.

Kuwait.—Oil production resumed at the end of 1991 after oil well fires were extinguished and some refineries repaired following the Gulf War. Refinery repairs were slower than expected, and sulfur recovery was possible at only one refinery before the end of 1992. Sulfur recovery was expected at the other refineries in Kuwait by the end of 1993.

Mexico.—Frasch sulfur production decreased for the fourth consecutive year to about 820,000 tons. Four mines were operating at the beginning of the year, but Azufrera Panamericana S.A. (APSA), operator of the Coachapa/Otopan and Jaltipan Mines, was declared bankrupt and the mines were closed in November. The remaining mine, Texistepec, owned by Compania Exploradora del Istmo S.A. and Texasgulf, was expected to close in 1993, reducing the number of major Frasch-producing countries to four.

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 2.5 million tons in 1992, a 20% increase from approximately 2.1 million tons imported in 1992.

Poland.—Frasch production was 33% lower than it was in 1991 and 44% lower than the annual average for the 1980's. Economic problems in Eastern Europe and the former U.S.S.R. took their toll on the Polish sulfur industry. In the past, the majority of Polish sulfur exports was to this region, but Polish exports in 1992 were about 2.5 million tons, 14% less than those in 1991. Africa was Poland's largest customer, receiving 42% of exports, followed by Eastern Europe and the former U.S.S.R., taking 21%.

Poland was the largest world producer of native sulfur, with major mines at Jeziorko, Grzybow, and Machow. Due to high production costs, Machow closed during the year. The construction of the new Osiek Mine was beset by financial problems, and startup, which had been expected in 1992, was delayed until 1993. *(See table 16.)*

OUTLOOK

The future of the sulfur industry seems clearer than it has for the past few years. Unfortunately, the outlook is not very positive. Sulfur production and consumption will continue a general upward trend, but growth of consumption will lag behind production increases. Production will decrease from Frasch deposits, but growth of recovered production will more than compensate for any increased demand. As a result, stocks will build.

World sulfur demand, from 1993 to 1997, is forecast to increase at an annual rate of about 1% per year. From 1997 to the year 2002, growth is expected to be higher, at almost 2%. World demand is projected to attain 55.9 million tons in 1997 and increase to about 61 million tons in the year 2002. In the short term, U.S. sulfur demand is forecast to increase from 12.7 million tons consumed in 1992 to 13.5 million tons in 1997 and 14.0 million tons in the year 2002.

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 1992. World demand for phosphate fertilizers is forecast to increase at an annual rate of about 2% 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 1992, an estimated 4.1 million tons of sulfur was required to manufacture the phosphatic fertilizers exported from the United States compared with 4.2 million tons of sulfur for domestic phosphoric fertilizer use. However, this may be misleading. Domestic fertilizer consumption appears to have grown significantly in 1992, but in reality, producers built up their own stocks because exports were depressed and production continued at capacity. Domestic phosphate production will probably decrease in 1993 owing to large producers' inventories; sulfur demand will decrease accordingly. Sulfur demand for domestically consumed phosphates is forecast to increase slightly through 1997 and remain relatively stable thereafter.

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. Although 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 over the next 10 years, reaching 23 million tons in the year 2002.

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, about 55 million tons. In 1992, these same sources supplied only 36% of world production, 52.4 million tons.

It is anticipated that in the short term, owing to decreased production at Frasch operations, world sulfur supply and demand will be closely balanced. However, a number of new production facilities that will be completed soon, are under development, or are in the planning stage will create tremendous new supply sources. The completion of the Caroline Gasfield should increase Canadian capacity by 1.2 million tons in 1993. The completion 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 annual production capacity. Freeport McMoRan's new Main Pass 299 Mine came on-stream in 1992 and could be producing at a rate of more than 2 million tons per year sometime in 1994, increasing U.S. Frasch capability by 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 through the year 2002, keeping prices low. World sulfur production may attain a level of 60 million tons in 1997 and exceed 62 million tons in the year 2002.

OTHER SOURCES OF INFORMATION

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TABLE 1
SALIENT SULFUR STATISTICS

(Thousand metric tons, sulfur content, and thousand dollars unless otherwise specified)

	1988	1989	1990	1991	1992
United States:					
Production:					
Frasch	3,174	3,888	3,726	2,869	2,320
Recovered[1]	6,444	6,510	6,536	6,645	7,048
Other forms	1,128	1,194	1,298	1,306	1,295
Total	10,746	11,592	11,560	10,820	10,663
Shipments:					
Frasch	4,341	3,780	3,676	3,120	2,600
Recovered[1]	6,470	6,475	6,483	6,682	7,094
Other forms	1,128	1,194	1,298	1,306	1,295
Total	11,939	11,449	11,457	11,108	10,989
Exports, elemental[2]	1,223	1,024	972	1,196	966
Imports, elemental	1,996	2,260	2,571	3,020	2,725
Consumption, all forms	12,712	12,685	13,056	12,932	12,747
Stocks, Dec. 31: Producer, Frasch and recovered	1,112	1,301	1,423	1,194	809
Value:					
Shipments, f.o.b. mine or plant:					
Frasch	$430,814	$378,712	$335,189	$271,599	$151,195
Recovered[1]	$498,368	$509,582	$479,011	$428,816	$315,438
Other forms	$88,181	$104,304	$117,139	$112,218	$76,125
Total	$1,017,363	$992,598	$931,339	$812,633	$542,758
Exports, elemental[3 4]	$131,863	$107,126	$109,327	r$119,713	$69,662
Imports, elemental[4]	$185,864	$209,465	$206,450	r$241,749	$129,894
Price, elemental, dollars per metric ton, f.o.b. mine or plant	$85.95	$86.62	$80.14	$71.45	$48.14
World: Production, all forms (including pyrites)	r59,160	r59,298	r58,082	r55,041	e52,409

eEstimated. rRevised.
[1]Includes Puerto Rico and the U.S. Virgin Islands.
[2]Includes exports from the U.S. Virgin Islands to foreign countries.
[3]Includes value of exports from the U.S. Virgin Islands to foreign countries.
[4]Declared customs valuation.

TABLE 2
PRODUCTION OF SULFUR AND SULFUR-CONTAINING RAW MATERIALS IN THE UNITED STATES

(Thousand metric tons)

	1991		1992	
	Gross weight	Sulfur content	Gross weight	Sulfur content
Frasch sulfur	2,869	2,869	2,320	2,320
Recovered sulfur[1]	6,645	6,645	7,048	7,048
Byproduct sulfuric acid (100% basis) produced at copper, lead, molybdenum, and zinc plants	3,984	1,302	3,948	1,292
Other forms[2]	10	4	8	3
Total	XX	10,820	XX	10,663

XX Not applicable.
[1]Includes Puerto Rico and the U.S. Virgin Islands.
[2]Includes hydrogen sulfide, liquid sulfur dioxide, and pyrites.

TABLE 3
RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1991			1992		
	Production	Shipments		Production	Shipments	
		Quantity	Value		Quantity	Value
Alabama	362	360	29,928	421	419	24,263
California	714	720	27,210	699	702	18,389
Florida	37	37	W	47	47	W
Illinois	240	240	17,485	267	269	12,285
Louisiana	692	692	61,123	732	731	42,936
Michigan and Minnesota	174	174	12,402	184	185	7,708
Mississippi	695	686	45,710	659	679	32,001
New Mexico	54	54	2,774	54	55	1,424
North Dakota	88	89	4,382	82	82	1,723
Ohio	48	48	3,941	43	44	2,813
Pennsylvania	66	66	3,446	56	57	2,688
Texas	1,733	1,735	113,118	2,008	2,010	99,323
Wyoming	1,074	1,072	50,355	1,056	1,067	31,712
Other[1]	669	711	56,942	740	746	38,173
Total[2]	r6,645	r6,682	428,816	7,048	7,094	315,438

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Includes Arkansas, Colorado, Delaware, Indiana, Kansas, Kentucky, Montana, New Jersey, Utah, Virginia, Washington, Wisconsin, Puerto Rico, the U.S. Virgin Islands, and data indicated by symbol W.
[2]Data may not add to totals shown because of independent rounding.

TABLE 4

RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY PETROLEUM ADMINISTRATION FOR DEFENSE (PAD) DISTRICT

(Thousand metric tons)

District and source	1991		1992	
	Production	Shipments	Production	Shipments
PAD 1:				
Petroleum and coke	302	304	317	318
Natural gas	37	37	47	47
Total[1]	338	340	364	365
PAD 2:				
Petroleum and coke	653	653	698	699
Natural gas	90	89	85	85
Total	743	742	783	784
PAD 3:[2]				
Petroleum	2,402	2,440	2,620	2,639
Natural gas	1,213	1,213	1,352	1,354
Total	3,615	3,653	3,972	3,993
PAD 4 and 5:				
Petroleum	886	886	889	901
Natural gas	1,064	1,062	1,041	1,052
Total[1]	1,950	1,948	1,930	1,952
Grand total[1]	r6,645	r6,682	7,048	7,094

rRevised.
[1]Data may not add to totals shown because of independent rounding.
[2]Includes Puerto Rico and the U.S. Virgin Islands.

TABLE 5

BYPRODUCT SULFURIC ACID[1] PRODUCED IN THE UNITED STATES

(Thousand metric tons, sulfur content, and thousand dollars)

Year	Copper plants[2]	Zinc plants[3]	Lead and molyb-denum plants[3]	Total	Value
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
1992	1,093	139	59	1,291	86,743

[1]Includes acid from foreign materials.
[2]Excludes acid made from pyrites concentrates.
[3]Excludes acid made from native sulfur.

TABLE 6
CONSUMPTION OF SULFUR[1] IN THE UNITED STATES

(Thousand metric tons)

	1988	1989	1990	1991	1992
Frasch:					
Shipments	4,341	3,780	3,676	3,120	2,600
Exports	464	330	348	448	362
Imports	1,079	1,086	1,129	1,259	845
Total	4,956	4,536	4,457	3,931	3,083
Recovered:					
Shipments[2]	6,470	6,475	6,483	6,682	7,094
Exports	759	694	624	748	604
Imports	917	1,174	1,442	1,760	1,877
Total	6,628	6,955	7,301	7,694	8,368
Total elemental	11,584	11,491	11,758	11,625	11,451
Pyrites, shipments	W	W	W	W	W
Byproduct sulfuric acid, shipments	1,125	1,190	1,294	1,302	1,292
Other forms, shipments[3]	3	4	4	4	4
Total, all forms[4]	12,712	12,685	13,056	12,932	12,747

W Withheld to avoid disclosing company proprietary data; included with "Other forms, shipments."
[1]Crude sulfur or sulfur content.
[2]Includes Puerto Rico and the U.S. Virgin Islands.
[3]Includes consumption of hydrogen sulfide, liquid sulfur dioxide, and data indicated by symbol W.
[4]Data may not add to totals shown because of independent rounding.

TABLE 7

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	
		1991	1992	1991	1992	1991	1992
102	Copper ores	—	—	688	648	688	648
1094	Uranium and vanadium ores	—	—	19	8	19	8
10	Other ores	—	—	68	46	68	46
20	Food and kindred products	W	W	—	—	W	W
26, 261	Pulpmills and paper products	24	27	279	296	303	323
28, 285, 286, 2816	Inorganic pigments, paints and allied products, industrial organic chemicals, other chemical products[2]	r103	140	r724	425	r827	565
281	Other inorganic chemicals	124	124	177	192	301	316
282, 2822	Synthetic rubber and other plastic materials and synthetics	W	W	272	278	272	272
2823	Cellulosic fibers, including rayon	—	—	r68	43	r68	43
283	Drugs	—	—	13	15	13	15
284	Soaps and detergents	W	W	59	50	59	50
286	Industrial organic chemicals	—	—	308	196	308	196
2873	Nitrogenous fertilizers	—	—	218	227	218	227
2874	Phosphatic fertilizers	—	—	8,311	8,300	8,311	8,300
2879	Pesticides	—	—	9	3	9	3
287	Other agricultural chemicals	r595	756	40	38	r635	794
2892	Explosives	—	—	13	12	13	12
2899	Water-treating compounds	—	—	203	131	203	131
28	Other chemical products	(3)	—	161	146	r161	146
29, 291	Petroleum refining and other petroleum and coal products	r149	308	383	385	r532	693
331	Steel pickling	—	—	33	31	33	31
333	Nonferrous metals	—	—	15	30	15	30
33	Other primary metals	—	—	1	1	1	1
3691	Storage batteries (acid)	—	—	36	31	36	31
	Exported sulfuric acid	—	—	r63	14	r63	14
	Total identified[4]	r995	1,356	r12,161	11,547	r13,156	12,901
	Unidentified	r679	729	680	793	r1,359	1,522
	Grand total[4]	r1,674	2,084	r12,842	12,340	r14,515	14,423

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

[1]Does not include elemental sulfur used for production of sulfuric acid.

[2]No elemental sulfur was used in inorganic pigments and paints and allied products.

[3]Revised to zero.

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

TABLE 8
SULFURIC ACID FROM SMELTERS SOLD OR USED IN THE UNITED STATES, BY END USE

(Thousand metric tons of 100% H_2SO_4)

SIC	Use	1991	1992
102	Copper ores	1,917	1,844
1094	Uranium and vanadium ores	17	15
10	Other ores	68	93
26, 261	Pulp mills and other paper products	129	94
2816	Inorganic pigments	W	W
281	Other inorganic chemicals	89	81
2823	Cellulosic fibers	W	W
283	Drugs	W	W
2873	Nitrogenous fertilizers	W	W
2874	Phosphatic fertilizers	625	580
287	Other agricultural chemicals	79	59
2899	Water-treating compounds	209	161
28	Other chemical products	24	4
291	Petroleum refining	25	15
331	Steel pickling	W	W
333	Nonferrous metals	16	7
3691	Storage batteries (acid)	29	18
	Unidentified	661	779
	Total domestic	3,888	3,750
	Exports	W	W
	Grand total	3,888	3,750

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

TABLE 9
YEAREND SULFUR STOCKS OF U.S. PRODUCERS

(Thousand metric tons)

Year	Frasch	Recovered	Total[1]
1988	954	158	1,112
1989	1,109	193	1,301
1990	1,177	245	1,423
1991	979	216	1,194
1992	642	167	809

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

TABLE 10
REPORTED SALES VALUES OF SHIPMENTS OF SULFUR, F.O.B. MINE OR PLANT

(Dollars per metric ton)

Year	Frasch	Recovered	Average
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
1992	58.15	44.47	48.14

TABLE 11

U.S. EXPORTS[1] OF ELEMENTAL SULFUR, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1991		1992	
	Quantity	Value	Quantity	Value
Australia	1	1,253	2	1,344
Belgium	150	18,527	—	—
Brazil	142	14,216	268	17,087
Canada	10	2,420	9	2,498
China	5	411	(2)	67
Colombia	9	972	12	755
France	50	6,505	1	75
Greece	—	—	17	1,158
India	149	12,715	—	—
Korea, Republic of	23	4,388	11	4,923
Mexico	178	15,984	109	8,252
Senegal	67	7,034	104	7,812
South Africa, Republic of	11	1,040	97	4,950
Taiwan	7	1,331	12	1,476
Tunisia	112	11,328	125	6,419
Other	282	21,589	199	12,846
Total	1,196	119,713	966	69,662

[1]Includes exports from the U.S. Virgin Islands.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 12
U.S. EXPORTS OF SULFURIC ACID (100% H_2SO_4), BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	64	$62	362	$49
Canada	79,826	6,670	84,725	6,701
China	—	—	31	39
Columbia	—	—	199	179
Costa Rica	—	—	991	325
Dominican Republic	397	87	1,172	62
Ecuador	2,004	114	1,049	64
Greece	—	—	138	5
Honduras	—	—	786	260
Israel	13,235	532	7,466	407
Korea, Republic of	1,920	774	2,039	859
Liberia	92	15	—	—
Mexico	14,169	814	26,241	999
Morocco	—	—	15	24
Netherlands Antilles	3,010	182	17	13
Panama	3,838	187	2,705	135
Saudi Arabia	1,483	126	509	71
Spain	7	8	—	—
Taiwan	2,558	476	2,385	493
Thailand	74	75	90	92
Trinidad and Tobago	816	49	1,842	86
United Kingdom	149	15	87	6
Venezuela	5,091	191	1,195	39
Other	20,139	1,428	5,412	913
Total[1]	148,872	11,806	139,456	11,822

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

Source: Bureau of the Census.

TABLE 13
U.S. IMPORTS OF ELEMENTAL SULFUR, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1991		1992	
	Quantity	Value[1]	Quantity	Value[1]
Canada	1,670	$103,647	1,857	$57,397
Mexico	1,259	130,840	845	69,693
Other[2]	90	7,262	21	2,804
Total[3]	3,020	241,749	2,725	129,894

[1]Declared customs valuation.
[2]Includes Congo, Dominican Republic, France, Germany, Japan, Monaco, Netherlands, and United Kingdom in 1991; Belgium, France, Germany, Japan, Netherlands, and Venezuela in 1992.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 14

U.S. IMPORTS OF SULFURIC ACID (100% H_2SO_4), BY COUNTRY

Country	1991		1992	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Algeria	7,518	$271	—	—
Argentina	4,175	54	3,609	$318
Australia	38,756	137	—	—
Canada	1,276,767	46,869	1,340,329	50,866
Chile	—	—	7,758	196
France	10,484	210	(3)	5
Germany	185,077	3,392	158,037	4,918
Italy	21,957	441	7,259	211
Japan	76,977	814	100,584	2,397
Mexico	146,741	3,348	156,381	4,046
Netherlands	5,916	20	28,883	631
Norway	10,007	637	—	—
Spain	10,987	115	23,731	589
Sweden	152	4	51,816	1,568
Switzerland	—	—	10,509	376
Trinidad and Tobago	—	—	8,583	175
United Kingdom	49,585	1,394	87,933	2,196
Other	126	20	(3)	3
Total[2]	1,845,225	57,727	1,985,414	68,496

[1]Declared c.i.f. valuation.
[2]Data may not add to totals shown because of independent rounding.
[3]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 15

WORLD SULFUR ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1992, RATED CAPACITY, SULFUR IN ALL FORMS[1]

(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.[2]	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[e]	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

[e]Estimated.

[1]Includes capacity at operating plants as well as plants on standby basis.

[2]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

TABLE 16

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1988	1989	1990	1991	1992e
Algeria: Byproduct, natural gas and petroleume	20	20	20	20	20
Australia:e					
Byproduct:					
Metallurgy	200	200	200	200	200
Petroleum	9	10	10	10	10
Total	209	210	210	210	210
Austria:					
Byproduct:					
Metallurgy	11	12	12	e12	12
Natural gas and petroleum	36	37	30	e27	30
Total	r47	49	42	e39	42
Bahrain: Byproduct, petroleume	48	48	48	48	48
Belgium: Byproduct, all sourcese	310	320	310	300	300
Bolivia: Native	7	8	2	3	3
Bosnia and Herzegovina: Byproduct, metallurgy[4]	—	—	—	—	5
Brazil:					
Frasch	6	6	6	e6	6
Pyrites	103	72	46	e50	50
Byproduct:					
Metallurgy	152	164	166	e166	166
Petroleum	61	60	58	e60	60
Total	322	302	276	e282	282
Bulgaria:e					
Pyrites	70	70	70	r60	60
Byproduct, all sources	60	60	60	r50	50
Total	130	130	130	r110	110
Canada:					
Byproduct:					
Metallurgy	856	809	r790	r872	896
Natural gas	5,415	5,183	5,210	r5,460	5,563
Petroleume	152	r149	207	r230	235
Tar sands	485	491	r503	r540	552
Totale	6,908	6,632	r6,710	r7,102	7,246
Chile:					
Native:					
Refined	17	15	28	e20	22
From caliche	21	1	(6)	(6)	(6)
Byproduct, metallurgye	r416	400	400	400	400
Total	r454	416	428	420	422
China:e					
Native	300	300	320	320	320
Pyrites	3,900	4,270	4,400	r4,700	5,000
Byproduct, all sources	550	600	650	650	650
Total	4,750	5,170	5,370	r5,670	5,970

See footnotes at end of table.

TABLE 16—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1988	1989	1990	1991	1992[e]
Colombia:					
Native	43	46	32	r47	46
Byproduct, petroleum[e]	5 8	8	8	r9	10
Total[e]	5 51	54	40	r56	56
Croatia: Byproduct[4]					
Metallurgy	—	—	—	—	5
Petroleum	—	—	—	—	1
Total	—	—	—	—	6
Cuba: Byproduct, petroleum[e]	r7	r7	r7	r7	7
Cyprus:[7] Pyrites	51	26	—	—	—
Czechoslovakia:[e]					
Native	6	6	6	6	6
Pyrites	60	50	50	50	50
Byproduct, all sources	40	40	40	40	40
Total	106	96	96	96	96
Denmark: Byproduct, petroleum	14	r19	12	e12	12
Ecuador:[e]					
Native	5	4	4	4	4
Byproduct:					
Natural gas	5	5	5	5	5
Petroleum	5	5	5	5	5
Total	15	14	14	14	14
Egypt: Byproduct, natural gas and petroleum[e]	8	8	8	8	8
Finland:					
Pyrites	313	306	357	e369	370
Byproduct:					
Metallurgy[e]	240	180	237	227	225
Petroleum	47	41	e42	e40	40
Total[e]	600	527	636	636	635
France:					
Byproduct:					
Natural gas	775	647	666	794	750
Petroleum[e]	226	239	233	225	225
Unspecified[e]	180	150	150	180	180
Total[e]	1,181	1,036	1,049	1,199	1,155
Germany:					
Byproduct:					
Eastern states, all sources[e]	r350	r334	r280	r100	120
Western states:					
Metallurgy [8]	r344	r362	r375	r340	145
Natural gas	952	r947	858	r905	900
Petroleum[e]	r215	r210	r257	r174	100
Unspecified[e]	r292	r283	r280	r225	150
Total[e]	r2,153	r2,136	r2,050	r1,744	1,415

See footnotes at end of table.

TABLE 16—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1988	1989	1990	1991	1992[e]
Greece:					
Pyrites	r59	r57	r41	r35	25
Byproduct:[e]					
Natural gas	185	185	185	195	180
Petroleum	5	5	5	5	5
Total	r249	r247	r231	r235	210
Hungary:[e]					
Pyrites	1	1	1	1	1
Byproduct, all sources	10	10	10	r8	8
Total	11	11	11	r9	9
India:					
Pyrites	30	39	r94	r128	100
Byproduct:[e]					
Metallurgy	125	125	125	r130	130
Petroleum	10	r4	5 10	r12	13
Total[e]	165	168	r229	r270	243
Indonesia:[7] Native	4	4	4	e4	4
Iran:[e]					
Byproduct:					
Metallurgy	25	40	45	50	50
Natural gas and petroleum	206	460	635	650	700
Total	231	500	680	700	750
Iraq:[e]					
Frasch	5 958	960	800	r250	500
Byproduct, natural gas and petroleum	5 227	370	r380	r50	70
Total	5 1,185	1,330	r1,180	r300	570
Israel: Byproduct, natural gas and petroleum	68	68	e64	r66	60
Italy:[e]					
Pyrites	308	323	290	285	200
Byproduct, petroleum	310	315	297	315	280
Total	618	638	587	600	480
Japan:					
Pyrites	71	62	53	r e30	35
Byproduct:					
Metallurgy	1,268	r1,321	1,336	r e1,350	1,350
Petroleum	1,093	1,176	1,268	e1,300	1,250
Total	2,432	2,559	2,657	r e2,680	2,635
Korea, North:[e]					
Pyrites	200	200	200	210	210
Byproduct, metallurgy	30	30	30	30	30
Total	230	230	230	240	240
Korea, Republic of:[e]					
Byproduct:					
Metallurgy	55	55	55	55	55
Petroleum	35	36	36	37	37
Total	90	91	91	92	92

See footnotes at end of table.

TABLE 16—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1988	1989	1990	1991	1992[e]
Kuwait: Byproduct, natural gas and petroleum[e]	360	r375	300	r—	75
Libya: Byproduct, natural gas and petroleum[e]	14	r14	r14	r14	14
Macedonia:[4]					
Pyrites	—	—	—	—	(5)
Byproduct, metallurgy	—	—	—	—	10
Total	—	—	—	—	10
Mexico:					
Frasch	1,628	1,528	1,441	r1,040	820
Byproduct:					
Metallurgy[e]	240	286	290	280	280
Natural gas and petroleum	510	555	701	r754	500
Total[e]	2,378	2,369	2,432	r2,074	1,600
Namibia: Pyrites[e]	115	100	70	r65	82
Netherlands: Byproduct, petroleum[e]	215	260	285	290	290
Netherlands Antilles: Byproduct, petroleum[e]	60	60	60	r120	120
New Zealand: Byproduct, all sources	4	1	3	r(5)	1
Norway:					
Pyrites	152	122	e125	e121	125
Byproduct:[e]					
Metallurgy	80	575	75	75	75
Petroleum	10	13	15	15	15
Total[e]	242	210	215	211	215
Oman:[e]					
Byproduct:					
Metallurgy	30	32	31	30	30
Natural gas and petroleum	17	25	r30	40	40
Total	47	57	r61	70	70
Pakistan:					
Native	1	—	(5)	(5)	(5)
Byproduct, all sources[e]	25	25	25	26	26
Total[e]	26	25	25	26	26
Peru:[e]					
Native	(5)	(5)	(5)	(5)	(5)
Byproduct, all sources	66	66	66	66	60
Total	66	66	66	66	60
Philippines:					
Pyrites	e160	e195	134	e150	150
Byproduct, metallurgy[e]	150	185	185	150	150
Total[e]	310	380	319	300	300
Poland:[9]					
Frasch	4,411	4,276	4,027	r3,302	2,300
Native	589	588	637	r633	600
Byproduct:[e]					
Metallurgy	150	150	140	140	130
Petroleum	30	20	20	20	20
Gypsum[e]	20	20	10	10	10
Total[e]	5,200	5,054	4,834	r4,105	3,060

See footnotes at end of table.

TABLE 16—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1988	1989	1990	1991	1992e
Portugal:					
Pyrites	110	91	e95	e96	95
Byproduct, all sources e	5	3	3	4	4
Total e	115	94	98	100	99
Qatar: Byproduct, natural gas e	r55	52	52	52	52
Romania: e					
Pyrites	370	359	300	300	200
Byproduct, all sources	380	375	350	350	250
Total	750	734	650	650	450
Saudi Arabia: Byproduct, natural gas and petroleum	1,378	1,423	1,435	r2,000	2,000
Serbia and Montenegro: [4]					
Pyrites	—	—	—	—	(6)
Byproducts:					
Metallurgy	—	—	—	—	130
Petroleum	—	—	—	—	(6)
Total	—	—	—	—	130
Singapore: Byproduct, petroleum e	r—	r—	r—	r—	—
Slovenia: Byproduct, petroleum [4]	—	—	—	—	1
South Africa, Republic of:					
Pyrites	507	461	452	293	5384
Byproduct:					
Metallurgy e	r110	100	111	104	100
Petroleum e [10]	120	r120	r120	120	120
Total [11]	738	r682	683	517	5603
Spain:					
Pyrites	1,057	938	748	e800	800
Byproduct: e					
Coal (lignite) gasification	2	2	2	2	2
Metallurgy	110	110	100	100	100
Petroleum	8	8	8	8	8
Total e	1,177	1,058	858	910	910
Sweden:					
Pyrites	286	233	r231	r83	50
Byproduct: e					
Metallurgy	125	125	125	120	120
Petroleum	45	40	40	40	40
Total e	456	398	r396	r243	210
Switzerland: Byproduct, petroleum e	4	4	4	4	4
Syria: Byproduct, natural gas and petroleum e	40	40	530	29	29
Taiwan: Byproduct, all sources	86	76	96	r126	120
Trinidad and Tobago: Byproduct, petroleum e	r4	r4	r4	r4	4

See footnotes at end of table.

TABLE 16—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1988	1989	1990	1991	1992e
Turkey:					
Native	30	r22	20	r21	22
Pyrites	75	96	r e93	r e94	94
Byproduct:					
Petroleum	16	13	r14	e15	15
Unspecified e	5	49	r7	r5	5
Total e	126	r180	r134	r135	136
U.S.S.R.: e 12					
Frasch	1,100	1,100	1,000	900	800
Native	2,400	2,350	2,000	1,800	1,600
Pyrites	2,150	2,150	1,900	1,700	1,400
Byproduct:					
Metallurgy	1,375	1,350	1,200	1,100	900
Natural gas	3,290	2,500	2,500	2,200	2,200
Petroleum	450	450	425	400	350
Total	10,765	9,900	9,025	8,100	7,250
United Arab Emirates: Abu Dhabi: e					
Byproduct:					
Natural gas	100	70	80	r64	65
Petroleum	10	10	10	10	10
Total	110	80	90	r74	75
United Kingdom:					
Byproduct:					
Metallurgy	55	60	66	e45	40
Petroleum	129	118	129	e120	125
Total	184	178	195	e165	165
United States:					
Frasch	3,174	3,888	3,726	2,869	2,320
Pyrites	W	W	W	W	W
Byproduct:					
Metallurgy	1,125	1,190	1,294	r1,302	1,291
Natural gas	2,501	2,537	2,336	2,403	2,525
Petroleum	3,943	3,973	4,200	4,242	4,524
Unspecified	3	4	4	4	3
Total	10,746	11,592	11,560	r10,820	10,663
Uruguay: Byproduct, petroleum e	2	2	2	2	2
Venezuela: Byproduct, natural gas and petroleum	125	e125	r106	r83	80
Yugoslavia: 13					
Pyrites and pyrrhotite	252	296	222	e200	—
Byproduct: e					
Metallurgy	170	175	175	160	—
Petroleum	3	4	3	2	—
Total e	425	475	400	362	—
Zaire: Byproduct, metallurgy e	32	29	r24	16	11

See footnotes at end of table.

TABLE 16—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1988	1989	1990	1991	1992[e]
Zambia:					
Pyrites	r31	r29	30	30	30
Byproduct, metallurgy[e]	r78	r73	r70	70	70
Total[e]	r109	r102	r100	100	100
Zimbabwe:[e]					
Pyrites	18	r21	r29	r31	31
Byproduct, all sources	5	5	5	5	5
Total	23	r26	r34	r36	36
Grand total[11]	r59,160	r59,298	r58,082	r55,041	52,409
Of which:					
Frasch	11,277	r11,758	11,000	r8,367	6,746
Native	r3,423	r3,344	r3,053	r2,858	2,627
Pyrites	r10,449	r10,567	r10,031	r9,881	9,542
Byproduct:					
Coal (lignite) gasification	2	2	2	2	2
Metallurgy	r7,552	r7,638	r7,657	r7,524	7,106
Natural gas	r13,278	r12,126	11,892	r12,078	12,240
Natural gas and petroleum, undifferentiated	3,009	r3,520	r3,753	r3,741	3,626
Petroleum	r 7,294	r 7,431	r 7,842	r 7,901	7,986
Tar sands	485	491	503	r540	552
Unspecified sources	r2,371	r2,401	r2,339	r2,139	1,972
Gypsum	20	20	10	10	10

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data; included with "Byproduct: Unspecified sources."

[1]Table includes data available through July 26, 1993.

[2]In addition to the countries listed, a number of nations may produce limited quantities of either elemental sulfur or compounds (chiefly H_2S or SO_2) 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 also may 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.

[3]The 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.

[4]Formerly part of Yugoslavia; data were not reported separately until 1992.

[5]Reported figure.

[6]Less than 1/2 unit.

[7]In addition, may produce limited quantities of byproduct sulfur from oil refining.

[8]Includes only the elemental sulfur equivalent of sulfuric acid produced as a byproduct from metallurgical furnaces; additional output may be included under "Byproduct: Unspecified sources."

[9]Official 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.

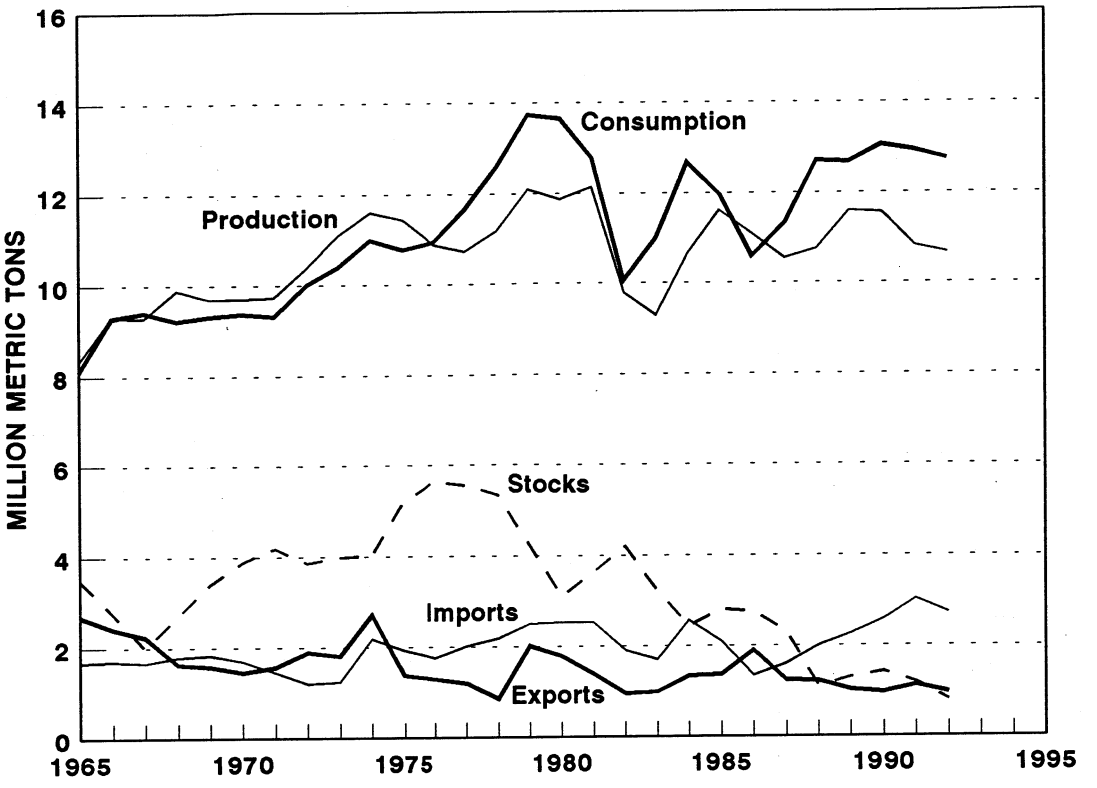
[10]Estimates for 1988-92 include byproduct production from synthetic fuels.

[11]Detail may not add to totals shown because of independent rounding.

[12]Dissolved in Dec. 1991. This commodity is believed to be produced in Azerbaijan, Belarus, Estonia, Kazakhstan, Russia, Turkmenistan, Ukraine, and Uzbekistan; however, information is inadequate to formulate reliable estimates of individual country production.

[13]Dissolved in Apr. 1992.

FIGURE 1
TRENDS IN THE SULFUR INDUSTRY IN THE UNITED STATES



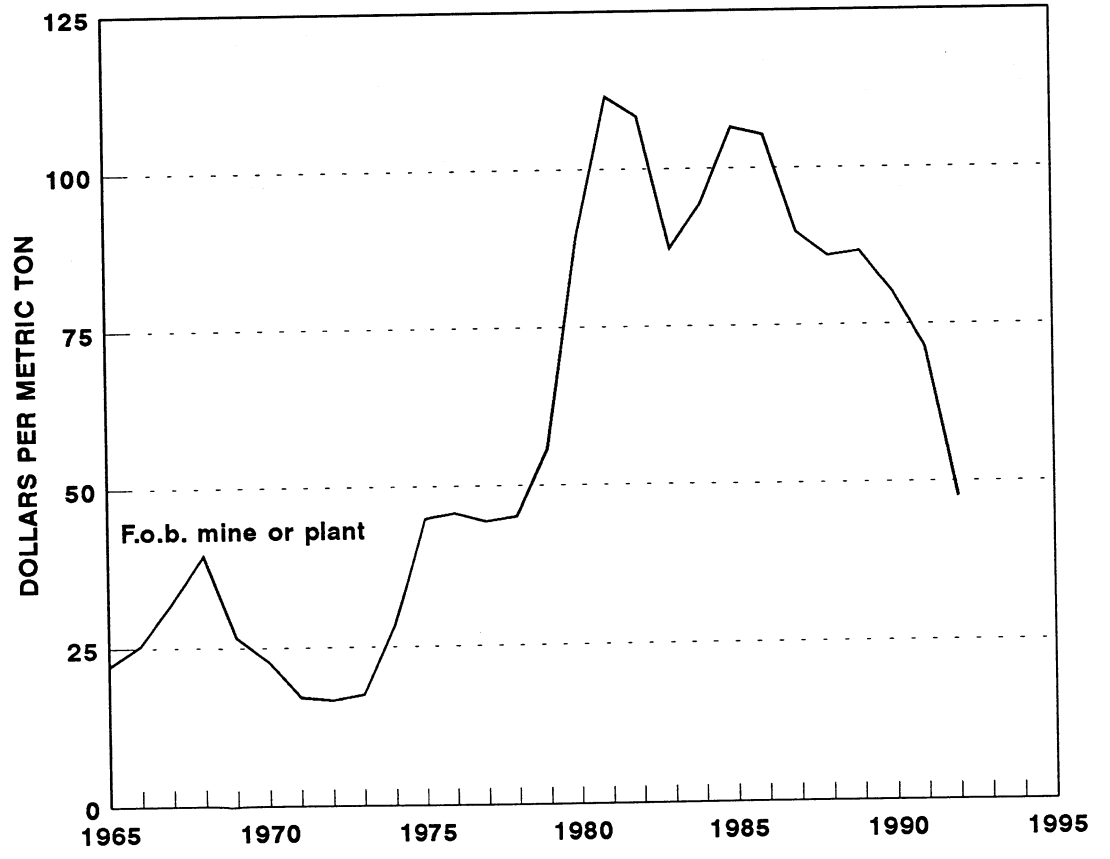
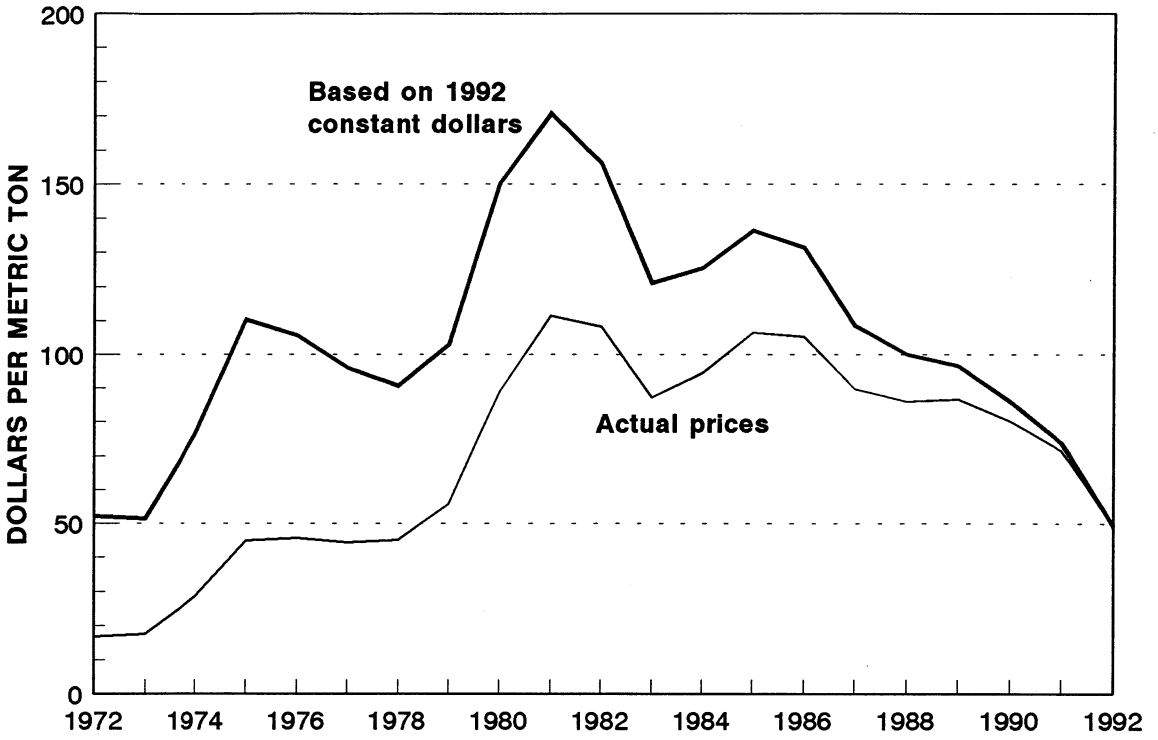


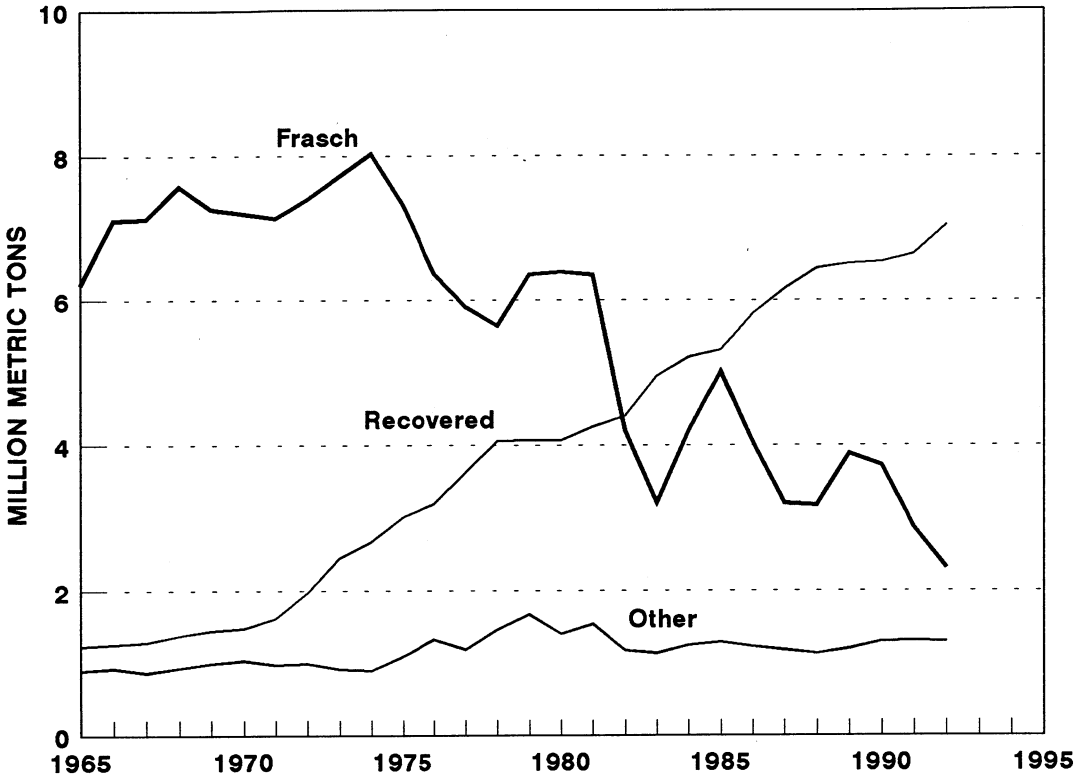
FIGURE 2
TIME-PRICE RELATIONSHIPS FOR SULFUR



Based on the average reported prices for elemental sulfur (Frasch and recovered), f.o.b. mine and/or plant, these prices reflect approximately 90% of the shipments of sulfur in all forms during 1973-92.

FIGURE 3

TRENDS IN THE PRODUCTION OF SULFUR IN THE UNITED STATES



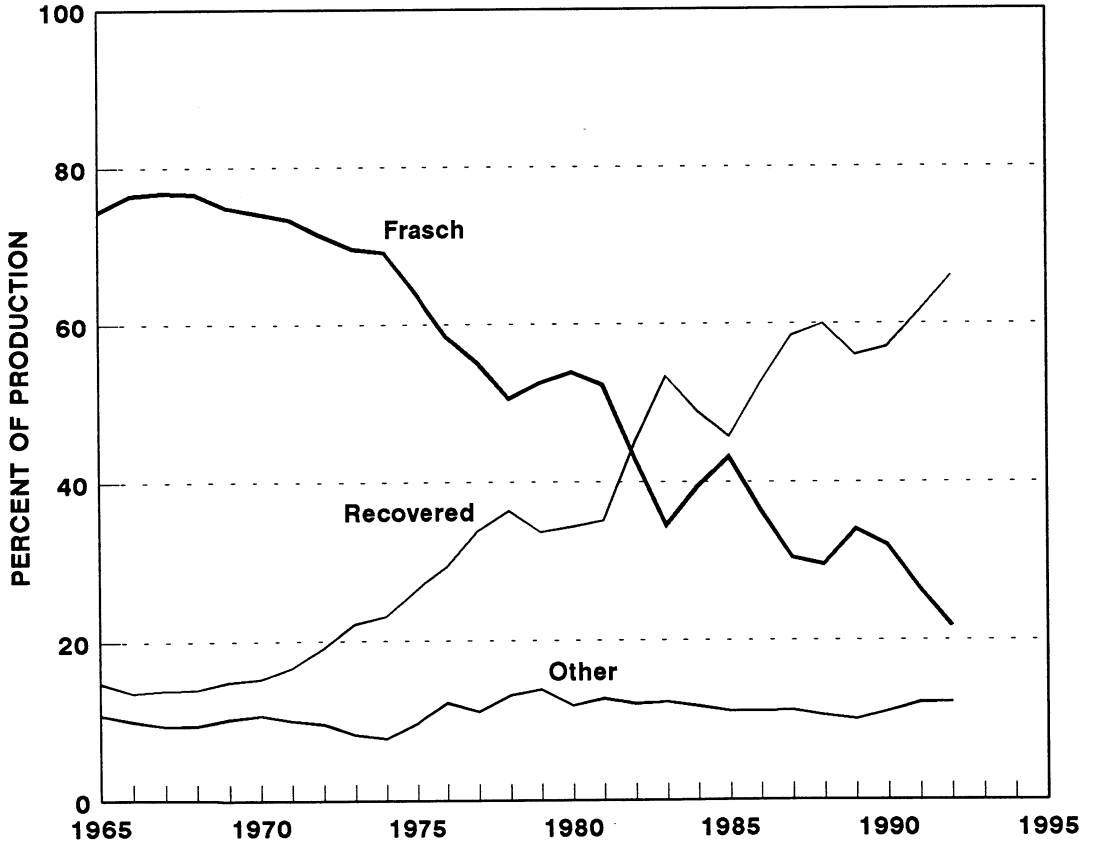
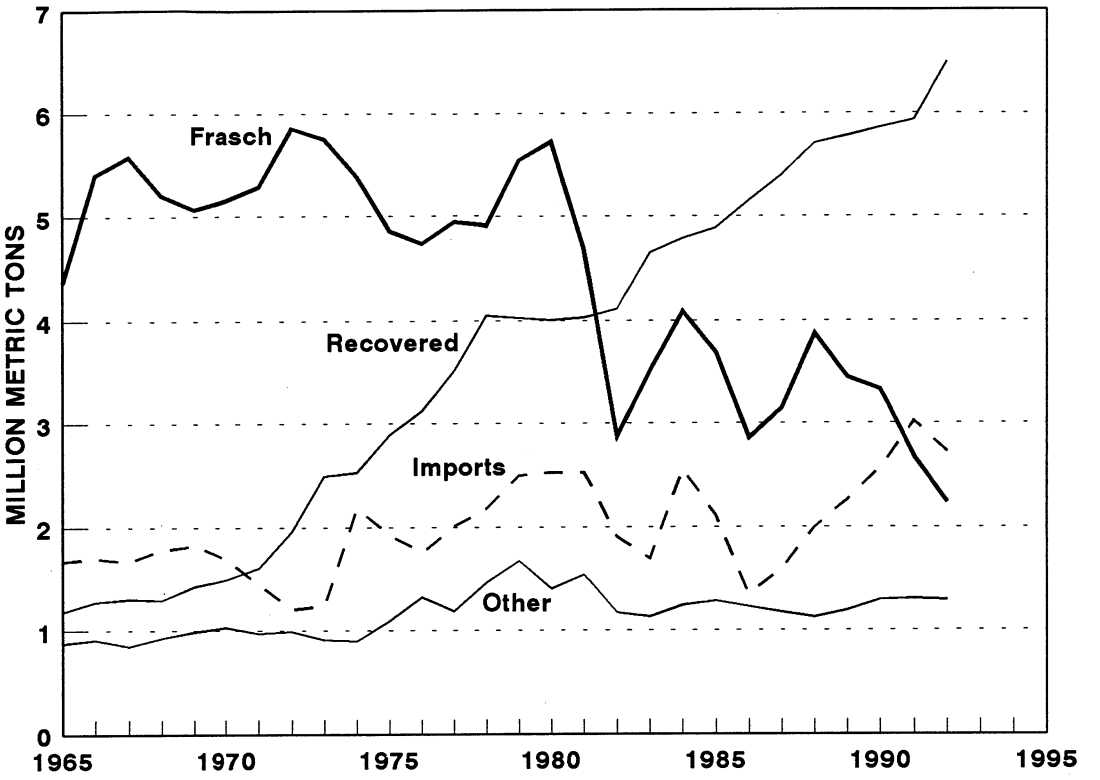
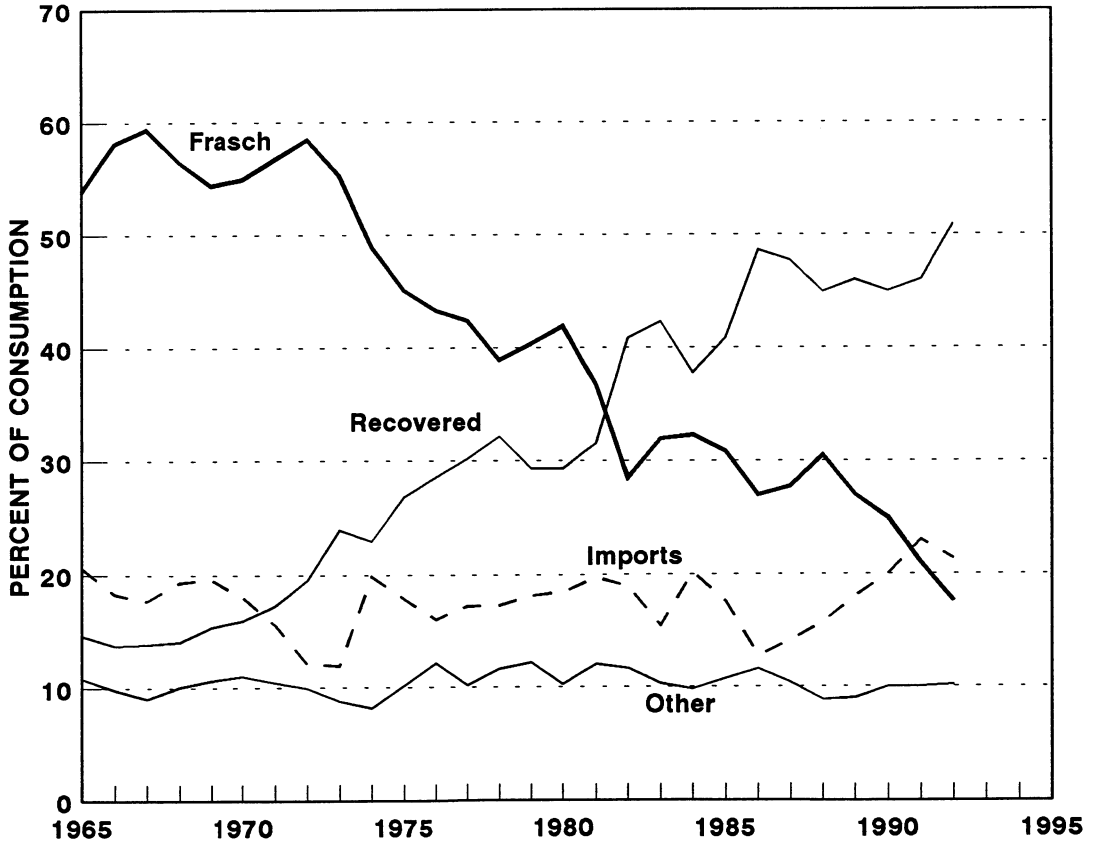


FIGURE 4

TRENDS IN THE CONSUMPTION OF SULFUR IN THE UNITED STATES





TALC AND PYROPHYLLITE

By Robert L. Virta

Mr. Virta, a physical scientist with 17 years of 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 Jeremy Tidwell, international data assistant.

Domestic production of talc decreased 4% from 1,037,000 metrics in 1991 to 997,000 tons in 1992. The value of crude ore decreased 2% in value from $32 million to $31 million. Sales of crude and processed talc decreased 5% in tonnage from 864,000 tons to 817,000 tons and increased 15% in value from $83 million to $95 million. Imports for consumption increased 19% in tonnage to 80,000 tons and 4% in value to $12 million. Exports decreased 2% in tonnage to 175,000 tons and increased slightly in value. The major domestic use for talc was in ceramics, which accounted for 35% of the domestic consumption, followed by paper, 20%; paint, 18%; roofing, 9%; plastics, 5%; and cosmetics, 5%. Other applications accounted for 8% of consumption. Production and sales of pyrophyllite were unchanged from those of 1991. The major uses for pyrophyllite were in ceramics, refractories, insecticides, paint, plastics, paper, and rubber, in decreasing order of consumption.

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 45 mines and mills. Twelve companies that account for approximately 90% of the domestic production responded to the survey. Production data for the nonrespondents were 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 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."[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

One issue that continues to attract attention 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 and OSHA. Under OSHA's Hazard Communication Standard, products containing more than 0.1% crystalline silica must be labeled. Additionally, OSHA-regulated sites that receive and/or use these products must comply with OSHA's Hazard Communication Standard.

Production

Talc.—Twelve companies operating 17 mines in 7 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 Luzenac America Inc., Dal Minerals, Gouverneur Talc Co., Montana Talc Co., and Pfizer (Minerals Technologies Corp.). 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.

Pfizer Inc. reorganized its minerals operations under a subsidiary company called Minerals Technologies Corp. The subsidiary will control the precipitated calcium carbonate, limestone, talc, and refractory operations.[3]

The sale of Cyprus Minerals Co.'s talc mines and mills to RTZ Corp. PLC was completed. The mines and mills will operate under the name Luzenac America Inc.

U.S. mine production of crude talc decreased 4% in tonnage to 997,000 tons and decreased 2% in value to $31 million. *(See table 1.)* This is the lowest production level since 1984, following several years of growth. Producers in Montana, New York, and Texas reported increases in production, corresponding with increased sales to the ceramics, paint, and paper industries. Talc production in California, Oregon, and Virginia was unchanged while that of Vermont decreased. Mines that operated in Montana, New York, Texas, and Vermont accounted for 98% of domestic talc production. Montana led all States in the tonnage and value of talc produced. *(See table 2.)*

Pyrophyllite.—Pyrophyllite was mined by two companies operating three mines in North Carolina and one company operating one mine in California. 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 was unchanged from that of 1991.

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 5% in tonnage to 817,000 tons and increased 15% in value to $95 million in 1991. *(See table 1.)* The major consumer of talc was the construction industry, where it is used in ceramic tile and sanitaryware, joint compounds, paint, and roofing. The end-use distribution was ceramics, 35%; paper, 20%; paint, 18%; roofing, 9%; cosmetics, 5%; plastics, 5%; and insecticides, refractories, rubber, and other, 8%. *(See table 3.)*

Sales to the ceramics, cosmetics, paint, and rubber industries increased slightly. Sales to the paper industry increased 14% despite a poor year for the paper industry in 1992. The largest decreases in reported sales were in plastics and roofing. Reported sales to the plastics industry decreased 28%, contrary to current trends in plastics manufacturing. Some talc classified as "Other" in table 3 and imported talcs undoubtedly were used by the plastics industry. It is likely that domestic consumption of talc in plastics actually increased slightly in 1992 rather than decreased. Consumption of talc by the roofing industry decreased from 88,000 tons to 70,000 tons. As with plastics, some of the sales to the roofing industry may have been classified as "Other" in table 3. A modest decrease in consumption of talc for roofing was expected based on the state of the construction industry.

Approximately 76% of the data presented in table 3 was reported by the companies; the remainder was estimated from reported prior-year data adjusted by trends in employment and other guidelines. Approximately 80,000 tons of imported talc was not included in this end-use breakdown. The imported talc was purchased primarily by mineral brokers who do not participate in the U.S. Bureau of Mines survey. Imports represent slightly less than 10% of the total reported domestic sales by U.S. talc producers.

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 was unchanged from that of 1991. The largest portion of domestically produced ground pyrophyllite was used in ceramics, followed by refractories, insecticides, paint, plastics, paper, and rubber.

Markets and Prices

Talc prices varied depending on the

quality and the degree and method of processing. The unit value of crude talc based on data reported by producers was $31 per ton. The average reported unit value of processed talc was $116 per ton. The average unit value of crude and processed pyrophyllite was less than that of 1991. Unit values for imported crude and ground talc ranged from $35 per ton to $584 per ton for shipments exceeding 100 tons. Unit values for cut or sawed talc ranged from $467 per ton to $1,273 per ton for shipments exceeding 100 tons. The average unit value for all imported talc was $156 per ton. Unit values for exported crude and ground talc ranged from $38 per ton to $557 per ton for shipments exceeding 100 tons and averaged $172 per ton for all exports.

Prices, quoted by the American Paint & Coatings Journal, December 28, 1992, in U.S. dollars per metric ton for paint-grade talc in carload lots ranged from $99 to $220. Approximate equivalents, in dollars per metric ton, of price ranges quoted in Industrial Minerals (London), December 1992, for talc, c.i.f. main European ports, ranged from $112 to $352. *(See table 4.)*

Foreign Trade

Talc exports decreased 2% in tonnage to 175,253 and increased slightly in value to $30,069,590. Canada was the largest importer of talc, followed by Belgium-Luxembourg, Taiwan (9,451 tons), Germany (8,582 tons), and Japan. *(See table 5.)* Talc imports increased 19% in tonnage to 79,560 tons and 4% in value to $12,408,496. Canada and China supplied 76% of all talc imports. *(See table 6.)*

World Review

China is 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. *(See table 7.)*

Austria.—One open pit mine and three underground talc mines operated in Styria. The open pit mine produced about 100,000 tons per year or about 75% of the country's production. Owing to difficulties in mining underground in highly altered rock, one of the underground mines switched from top slicing to underhand cut-and-fill mining. This method, which uses a cement and gravel or waste rock backfill, successfully resolved several rock mechanics problems. Tests also were being conducted to determine the practicality of using mechanical cutting equipment to replace drilling and blasting.[4]

China.—A new pyrophyllite deposit was discovered through a joint United Nations and Chinese mineral exploration project. The deposit, which is in the Fujian Province, is the largest discovered in China. The deposit contains approximately 16 million tons of pyrophyllite.[5]

Italy.—Construction began on Talco Sardinia's talc processing facility near Orani. The company is building a new 40,000-ton-per-year mill. The company will supply talc for the Italian talc market and for export to European countries.[6]

Netherlands.—Westmin Talc BV acquired complete ownership of the talc mill operated by Jan de Poorter BV in Amsterdam, Netherlands. The plant has a milling capacity of 40,000 tons per year. Westmin Talc will use the plant to supply the European talc market.[7]

Current Research

The U.S. Bureau of Mines conducted a study of an underground talc mine in which rock falls, pillar sloughing, and other ground control problems were observed. The principal ground control problem and the greatest hazard was pillar instability. This was attributed to the steeply dipping orientation of the foliation in the talc ore body. Artificial support and more uniform pillar design would have minimized pillar sloughing. A boundary element model showed that uneven loads on the irregularly shaped pillars could have been reduced by better pillar design. Measurement of roof convergence and pillar loading failed to detect significant changes during mining. This suggested that the hanging wall could support large spans between pillars and permit high extraction ratios.[8]

OUTLOOK

The past 15 years has been a period of change for the talc and pyrophyllite industries. Several mines were closed in response to environmental issues, many small mines closed for economic reasons, and several large mining operations were sold as major corporations changed their business strategies. Twenty-eight companies mined talc and pyrophyllite in 13 States in 1978. By 1992, these numbers had dropped to 15 and 8, respectively.

Domestic consumption of talc and pyrophyllite during this period has ranged from a low of 744,000 tons in 1982 to a high of 1,054,000 tons in 1988 and 1990. Consumption declined during the recession of the early 1980's and increased again through 1990. The economic downturn of the late 1980's did not affect the talc and pyrophyllite industries until 1991, when consumption dropped below 1 million tons.

Despite these changes, demand for talc and pyrophyllite should remain strong. Domestic consumption can be expected to range from 900,000 tons to 1,000,000 tons per year in the near future. Ceramics will continue to be the major domestic end use for talc, followed by consumption in paper, paint, roofing, plastics, and cosmetics, in descending order. For pyrophyllite, the major domestic end uses will continue to be in ceramics and refractories.

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[2]———. Mine Safety and Health Administration. Air Quality, Chemical Substances, and Respiratory Protection Standards. V. 56, No. 39, Feb. 27, 1991, pp. 8168-8171.

[3]Chemicalweek. Pfizer Separates its Minerals Business. V. 151, No. 8, Aug. 26, 1992, p. 6.
[4]Moser, P. Mines and Mining in Austria. BHM, V. 137, 1992, pp. 107-117.
[5]Industrial Minerals (London). New Pyrophyllite Find in China. No. 293, Feb. 1992, p. 63.
[6]Loughbrough, R. Italy's Industrial Minerals. Ind. Miner. (London), No. 301, Oct. 1992, pp. 35-57.
[7]Industrial Minerals (London). Westmin Talc Acquires Final Share of Talc Plant. No. 297, June 1992, p. 10.
[8]Moebs, N., and G. Sames. Geotechnical Aspects of Roof and Pillar Stability in a Georgia Talc Mine. BuMines RI 9404, 1992, 29 pp.

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TABLE 1
SALIENT TALC AND PYROPHYLLITE STATISTICS

(Thousand metric tons and thousand dollars)

	1988	1989	1990	1991	1992
United States:					
Mine production, crude:					
Talc	1,136	1,172	1,185	1,037	997
Pyrophyllite	97	81	82	W	W
Total	[1]1,234	1,253	1,267	1,037	997
Value:					
Talc	$29,364	$27,731	$31,068	$32,051	$31,307
Pyrophyllite	$1,820	W	W	W	W
Total	$31,184	$27,731	r$31,068	$32,051	$31,307
Sold by producers, crude and processed:					
Talc	940	1,065	1,021	864	817
Pyrophyllite	93	79	80	W	W
Total	1,033	[1]1,145	1,101	864	817
Value:					
Talc	$115,899	$114,453	$110,585	$82,579	$94,739
Pyrophyllite	$4,164	W	W	W	W
Total	$120,063	$114,453	$110,585	$82,579	$94,739
Exports[2] (talc)	260	319	238	178	175
Value	$21,391	$28,949	$32,909	$30,050	$30,070
Imports for consumption (talc)	80	78	65	67	80
Value	$12,268	$12,128	$11,056	$11,925	$12,408
Apparent consumption[3]	1,054	1,012	1,054	926	902
World: Production	r8,811	r9,239	r9,410	r9,001	e8,864

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data; not included in total.
[1]Data do not add to total shown because of independent rounding.
[2]Excludes powders—talcum (in package), face, and compact.
[3]Production, 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	1991		1992	
	Quantity	Value	Quantity	Value
Montana (talc)	365	15,741	407	16,162
Texas (talc)	213	4,561	236	5,720
Oregon (talc)	(1)	68	(1)	67
Other[2 3]	459	11,682	354	9,358
Total[3]	1,037	[4]32,051	997	31,307

[1]Less than 1/2 unit.
[2]Includes California, New York, Vermont, and Virginia.
[3]Does not include quantity and value for pyrophyllite.
[4]Data do not add to total shown because of independent rounding.

TABLE 3

END USES FOR GROUND TALC AND PYROPHYLLITE

(Thousand metric tons)

Use	1991			1992		
	Talc	Pyrophyllite	Total	Talc	Pyrophyllite	Total
Ceramics	255	W	255	269	W	269
Cosmetics[1]	37	—	37	38	—	38
Insecticides	14	W	14	8	W	8
Paint	135	W	135	141	W	141
Paper	133	—	133	151	—	151
Plastics	53	W	53	38	W	38
Refractories	4	W	4	3	W	3
Roofing	88	—	88	70	—	70
Rubber	16	W	16	17	W	17
Other[2]	77	W	77	29	W	29
Total[3]	811	W	811	764	W	764

W Withheld to avoid disclosing company proprietary data.
[1]Incomplete data. Some cosmetic talc known to be included in "Other."
[2]Includes art sculpture, asphalt filler and coatings, crayons, floor tile, foundry facings, rice polishing, stucco, and other uses not specified.
[3]Data may not add to totals shown because of independent rounding.

TABLE 4
PRICE OF TALC

(U.S. dollars per metric tons)

	Value
United Kingdom:	
300 mesh, exworks	112
Canada: Fine micron, Hegman No. 6	205
Montana: Ultrafine grind, Hegman No. 6	220
New York:	
Nonfibrous, bags, mill:	
98% through 325 mesh	99
99.6% through 325 mesh	115
Trace retained on 325 mesh	180
Norwegian:	
Ground (exstore)	224-240
Micronized (exstore)	264-352
French, fine-ground	192-304
Finnish, micronised	224-320
Italian, cosmetic-grade	280
Chinese, normal (exstore):	
UK 200 mesh	83
UK 325 mesh	92
New York, paint, minimum 20-ton lot	165

Sources: American Paint & Coatings Journal, Dec. 28, 1992, and Industrial Minerals (London), Dec. 1992.

TABLE 5
U.S. EXPORTS OF TALC[1]

(Thousand metric tons and thousand dollars)

Year	Belgium		Canada[2]		Japan		Mexico		Other[3]		Total[4]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
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	e82	e8,006	37	7,566	238	32,909
1991	46	6,023	42	7,767	20	2,338	28	3,791	42	r10,131	178	30,050
1992	28	4,636	47	8,066	7	912	22	2,992	70	13,464	175	30,070

eEstimated. rRevised.

[1]Excludes powders—talcum (in package), face, and compact.

[2]Probably includes shipments in transit through Canadian ports.

[3]Includes 61 countries in 1992.

[4]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)
1990:	r14,653	$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[2]	31	28	3,283	1,183	246	571	3,560	1,782
Total[1]	r25,021	1,758	38,141	6,683	3,629	3,484	66,791	11,925
1992:								
Brazil	—	—	225	47	243	141	468	188
Canada	58	9	31,598	4,888	2,080	2,040	33,736	6,936
China	25,598	932	437	64	784	576	26,819	1,572
France	5,225	436	768	272	16	23	6,009	731
Japan	—	—	2,225	1,106	—	—	2,225	1,106
Other[3]	9,713	904	183	99	407	872	10,303	1,875
Total[1]	40,594	2,280	35,436	6,476	3,530	3,651	79,560	12,408

rRevised.

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

[2]Includes 23 countries.

[3]Includes 17 countries.

Source: Bureau of the Census.

TABLE 7

TALC AND PYROPHYLLITE: WORLD PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992e
Argentina:					
Pyrophyllite	671	1,310	e1,300	e1,200	1,100
Steatite e	250	250	250	250	240
Talc	26,108	26,658	e26,000	e25,000	24,500
Australia:					
Pyrophyllite	3 5,750	5,000	5,000	6,000	5,000
Talc	3 199,631	195,000	200,000	210,000	210,000
Austria: Steatite	132,974	133,078	133,971	r 161,425	160,000
Brazil:[4]					
Agalmatolite	122,531	r —	r —	r —	—
Pyrophyllite	60,070	r 243,365	r 183,400	r 186,000	187,200
Talc	378,463	r 380,647	r 286,938	r 292,270	292,800
Burma: Steatite	r —	r —	r —	r —	—
Canada (shipments): Pyrophyllite, soapstone, talc	146,443	144,828	137,290	r 123,000	107,000
Chile: Talc	1,070	835	898	r 536	600
China: Unspecified e	1,900,000	2,100,000	r 2,545,000	r 2,600,000	2,650,000
Colombia: Pyrophyllite, soapstone, talc	12,800	9,196	10,113	r 11,064	11,000
Egypt: Pyrophyllite, talc, soapstone, steatite	7,268	7,146	6,340	r 9,091	9,000
Finland: Talc	379,000	398,000	385,000	r 361,000	350,000
France: Talc	e 320,000	329,960	r 328,100	e 300,000	300,000
Germany: Talc (marketable)	r 19,525	r 20,520	r 21,378	r e 21,500	20,000
Greece: Steatite	1,587	r 10,518	r 1,444	r 790	700
Hungary: Talc e	13,000	12,000	12,000	10,000	10,000
India:					
Pyrophyllite	64,923	97,264	e 80,000	r 84,577	85,000
Steatite	417,493	414,268	r e 406,000	r e 424,000	425,000
Iran: Talc[5]	29,261	11,039	31,087	r 6,676	10,000
Italy: Steatite and talc	158,722	146,000	r 151,566	r 161,200	160,000
Japan:					
Pyrophyllite	1,244,491	1,233,600	1,213,036	r 1,228,896	1,064,000
Talc	49,797	55,665	61,550	r 65,633	59,000
Korea, North: Unspecified e	r 100,000	r 100,000	170,000	170,000	170,000
Korea, Republic of:					
Pyrophyllite	673,776	770,298	657,611	r 573,208	600,000
Talc	146,478	162,098	181,600	r 170,563	160,000
Macedonia: Talc[6 7]	—	—	—	—	16,500
Mexico: Talc	13,645	r 13,534	r 13,477	r 11,883	12,000
Nepal: Talc[8]	4,430	6,728	1,798	r 3,500	3,000
Norway: Talc e	100,000	100,000	100,000	r 80,000	80,000
Pakistan: Pyrophyllite	37,429	38,290	30,177	r 33,643	35,000
Paraguay: Unspecified	150	200	e 200	e 200	200
Peru:					
Pyrophyllite	3 9,200	7,500	7,500	r 8,000	8,000
Talc	3 1,450	1,500	1,500	r 2,100	2,000
Philippines: Talc	27	—	—	—	—
Portugal: Talc	7,187	8,063	7,926	e 8,000	8,000

See footnotes at end of table.

TABLE 7—CONTINUED

TALC AND PYROPHYLLITE: WORLD PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Metric tons)

Country[2]	1988	1989	1990	1991	1992[e]
Romania: Talc[e]	50,000	[3]45,638	40,000	40,000	40,000
South Africa, Republic of:					
Pyrophyllite	3,162	3,942	2,759	4,448	[3]2,957
Talc	10,111	11,596	11,179	[r]8,235	[3]13,758
Spain: Steatite	[3]68,979	75,000	75,000	70,000	70,000
Sweden: Talc	[r]16,550	[e]16,000	[e]16,000	[r]20,000	20,000
Taiwan: Talc	21,603	22,559	22,123	[r]18,518	18,000
Thailand:					
Pyrophyllite	37,285	39,799	29,290	[r]42,960	40,000
Talc	4,843	7,242	4,360	[r]5,575	5,500
Turkey	5,397	[r]6,280	[e]6,000	[e]6,000	6,000
U.S.S.R.: Talc[e 9]	530,000	530,000	500,000	450,000	400,000
United Kingdom: Talc	14,182	15,413	14,781	[r]10,818	10,000
United States:					
Pyrophyllite	97,000	81,301	82,025	W	W
Talc	1,136,347	1,171,871	1,185,142	1,037,196	997,268
Uruguay: Talc[e]	1,600	1,600	1,600	1,600	1,600
Yugoslavia: Talc[7 10]	27,566	24,590	17,984	[e]17,000	—
Zambia: Talc	73	114	160	[r]89	100
Zimbabwe: Talc	976	1,513	1,787	[r]1,676	1,700
Total	[r]8,811,274	[r]9,238,816	[r]9,409,640	[r]9,000,503	8,863,723
Of which:					
Pyrophyllite	2,233,757	[r]2,521,669	[r]2,292,098	[r]2,168,932	2,028,257
Steatite	[r]621,283	[r]633,114	[r]616,665	[r]652,040	655,940
Talc	[r]3,508,320	[r]3,576,663	[r]3,480,368	[r]3,104,976	3,066,326
Unspecified	[r]2,447,914	[r]2,507,370	[r]3,020,509	[r]3,074,555	3,113,200

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]Table includes data available through May 18, 1993.

[2]In addition to the countries listed, Czechoslovakia produces talc, but information is inadequate to make reliable estimates of output levels.

[3]Reported figure.

[4]Total of beneficiated production, salable direct shipping production, and that consumed by producers.

[5]Data based on Iranian fiscal year beginning Mar. 21 of year stated.

[6]Formerly part of Yugoslavia.

[7]All production in Yugoslavia from 1988-91 came from Macedonia.

[8]Data based on Nepalese fiscal year beginning mid-July of year stated.

[9]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

[10]Dissolved in Apr. 1992.

TIN

By James F. Carlin, Jr.

Mr. Carlin, a physical scientist with the Branch of Metals, has been the commodity specialist for tin for 13 years. Domestic survey data were prepared by Elsie Isaac, statistical assistant; and international data tables were prepared by Ivette Torres, 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 1992, 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 99.98% 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 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, P.T. Timah in Indonesia, the Malaysia Mining Corp., 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 price 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 International Tin Council. 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. Although 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 tinplate-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 tinplate and the solder industries have undergone considerable consolidation. Although there are a number of companies in the tin chemical field, one firm dominates.

The other domestic tin-using industries are diverse, such as the brass, bronze, 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 (SnO_2), 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 Mohs 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 also may 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 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°C 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 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 plastic 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 NDS continued in its fourth year of being managed by the Department of Defense, with day-to-day operations guided by the Defense Logistics Agency (DLA).

The DLA sold 8,815 tons of tin from the stockpile in 1992. DLA continued its tin swap program with the ferroalloy upgraders through their broker-agents and also continued its direct 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 increased by seven compared with the four locations used in 1991. The pickup points were: Point Pleasant, WV; Curtis Bay, MD; Hammond, IN; Stockton, CA; Sommerville, NJ; New Haven, IN; Gulfport, MS; Baton Rouge, LA; Anniston, AL; Granite City, IN; and Warren, OH. This year as an innovation, DLA tin customers were allowed to select their tin by brand. Brands such as Banka, Longhorn, and Pass were available.

The DLA had authority from Congress to dispose of 12,000 tons of tin in fiscal 1992. At yearend 1992, the NDS inventory was 153,896 tons of tin and the stockpile goal was 42,674 tons. DLA also announced it had awarded its fiscal 1993 ferroalloy upgrading contracts to Elkem and Macalloy. Payment for each contract would be 25% tin, 35% payment in kind, and 40% other commodities.

Throughout the year, no substantive action was taken on the bill (S. 391) calling for either a ban or reduction in the use of lead in certain products, but the bill did remain active. 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 bronze fittings for naval gear. 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; therefore, 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 (compared to recent years) and the prospect of the same or even faster paced sales 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 January, hearings were held for two days at the International Trade Commission in Washington, DC, at which interested tin industry officials were invited to express their concerns over proposed U.S. Government action that would raise sharply the tariffs on tin, bauxite, some steel items, and a variety of nonmineral goods imported from China. The punitive tariffs were to be in retaliation for violation of U.S. intellectual property rights. Shortly after these January 6-7 hearings, the Office of the U.S. Trade Representative announced that an accord had been reached with China on the matter and that the tariffs would not be imposed.

The chairman of the Pig Tin Task Group for the ASTM announced an initiative to institute a new low-lead Grade A specification for tin metal used for tinplate. The revised specification called for a maximum lead content of 0.020%, compared with 0.050% in the current Grade A specification. The ASTM B-2 Committee accepted the

proposed new specifications. By yearend, the ASTM membership had not yet voted on the issue.

Production

The Lost River Mining Corp., in Alaska, operated the only mine in the United States to produce any amount of tin concentrates. It produced a very small amount. This mine has operated intermittently as a tin producer for many decades. The tin output from the mine amounted to only a small fraction of domestic tin requirements.

Alco-Met Corp., Boston, MA, reportedly was satisfactorily completing its first full year of producing 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 was 100 tons annually of 99.9999%-pure tin. Such purities were favored for certain electronic applications.

MIDCO Inc., St. Louis, MO, announced the startup of its new tin smelter designed to produce Grade A tin from secondary sources. The tin was to be sold in ingot form, with expected production at the rate of 3,000 tons annually. The MIDCO brand of tin was sanctioned by the London Metal Exchange. Before this year, MIDCO had been producing a tin-lead solder at this facility.

Consumption and Uses

Primary tin consumption decreased slightly in 1992. The major consumption category of tinplate registered a fairly significant decline, which was partly offset by a modest increase in the solder category.

Tinplated steel and tin-free steel accounted for 27% of the 131 billion cans shipped domestically; aluminum accounted for 73%. This compared to 1991 figures showing steel accounting for 27% of the 129 billion cans shipped domestically and aluminum accounting for 73%. Aluminum held an overwhelming advantage in the beverage can market, while steel predominated in the food can and the general-line markets.[3]

Weirton Steel Corp., Weirton, WV, announced it had joined a collaborative effort with Nippon Steel Corp., Japan, and the Sollac Div. of Usinor, France, to work together to develop a lighter weight steel can to increase the competitiveness of the two-piece steel beer and soft drink can. All three firms rank among the world leaders in tinplate production.

The Ball Corp. agreed to purchase Heekin Can Co. for $90 million. Ball was based in Indiana, and Heekin was based in Ohio. Ball had been strongest in using aluminum for beverage cans, while Heekin's strength had been in tinplate for food cans.

During the year, reports from the domestic automotive industry indicated an accelerated conversion from copper-brass radiators to aluminum radiators. Ford led the trend, with 90% of its cars and trucks now fitted with aluminum radiators. General Motors now had about 60% of its cars and trucks fitted with aluminum radiators. Until 1991, Chrysler reportedly used only copper-brass, but started to use aluminum radiators for its new Dodge Caravan and Plymouth Voyager minivans and the new LH-platform Chrysler Concorde, Eagle Vision, and Dodge Intrepid models. Reportedly, most European carmakers were also moving rapidly to aluminum radiators. This is in sharp contrast to Japan's carmakers, who have remained with copper-brass in all their cars made in Japan as well as in their American factories. One of the main driving forces toward aluminum radiators has been the desire and need by carmakers to improve fuel efficiency, and one of the ways to achieve that is to favor lighter weight components such as aluminum radiators. Solder is used to seal copper-brass radiators, so these trends have negative implications for tin usage. *(See tables 2, 3, and 4.)*

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 the tin in this country until they sold it to customers. Foreign-owned trading firms seemed to dominate the field. Most tin dealers were based in or near New York, NY. 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. Foremost among these direct-sale operations was Indo-Metal Corp., which served as the exclusive North American sales outlet for tin metal produced by Indonesia's Government-owned tin production organization. The year was one of continued consolidation following a few years of significant shakeouts in the tin trading community.

The price of tin metal, as published in Metals Week, remained in a fairly narrow band all year, although it experienced a brief spurt in the May through August period. The LME remained the primary trading focus for tin. The Kuala Lumpur Commodities Exchange in Malaysia continued as an active tin trading forum.

Following the startup of the new LME warehouse in Baltimore, MD, the LME announced its approval of three more warehouses in the United States. The new warehouses were in Toledo, OH; St. Louis, MO; and Long Beach, CA; and were expected to accept delivery of aluminum, nickel, tin, and zinc.

Foreign Trade

Brazil supplanted Bolivia as the major source of U.S. tin metal imports. China ranked second, followed by Bolivia, Indonesia, and Malaysia.

Imports declined somewhat, although a part of the slack was absorbed by increased Government stockpile disposals.

Imports of tin in all forms (ore and concentrate, metal, and waste and scrap) remained free of U.S. duty. *(See tables 5, 6, and 7.)*

World Review

The seven ATPC member countries, which accounted for about 60% of world

tin output, agreed to export limits of 87,000 tons in 1992, down from 95,000 tons in 1991. Brazil and China, not members of ATPC, also agreed to restrict exports. The ATPC announced that, in view of the current tin overhang depletion rate, it could continue its export quota program only until 1994. In March, the ATPC estimated world tin stocks to be 37,000 tons (in the 1981-85 period world tin stocks were believed to be as high as 100,000 to 125,000 tons), and they felt a normal stock level of 20,000 tons could be achieved by 1993.

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.

Rebounding from a lengthy period of inactivity in 1991 owing to labor strife, Renison continued mining throughout the year but with a scaled-back work force. Most of Renison's mine output was shipped to either the Datuk Keramat Smelter Co. or Malaysia Smelting Co. tin smelters in Malaysia for refining. The Renison material was an important feedstock for both Malaysian smelters because domestic Malaysian mine output has declined in recent years.

Greenbushes Ltd. continued to mine tin and tantalum near Perth, in Western Australia. This operation produced about 200 to 300 tons of tin-in-concentrate annually in recent years.

Bolivia.—Tin production continued at the higher levels characteristic of the pattern established in recent years. However, Bolivia lost its position as the dominant source of tin for the United States and ranked third in that category.

Corporación Minera de Bolivia (COMIBOL), the Government-owned mining organization, was reportedly expanding its rationalization scheme in response to urging from the World Bank. In recent years, COMIBOL had reduced its work force from 30,000 to about 6,000 people. Reportedly, plans were to change COMIBOL into a mostly administrative function, overseeing the mining contracts of various private firms. 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 tons of tin in concentrate annually, with the output going to the Vinto metallurgical complex of COMIBOL. Another important operation was the Catavi-Siglo tin mine in the Department of Potosí, with reported reserves of 3,900 tons.

The large Brazilian tin-mining company Paranapanema started work on recovering the tin values from the tin tailings and dumpings at the Catavi-Siglo Mine. In 1991, Paranapanema won the bidding for the tin tailings and dumpings at that site. Paranapanema expected to invest $8 million in the recovery at Catavi-Siglo, which had an estimated 21 million tons of dumpings. Catavi-Siglo had been the world's largest underground tin mine before it was closed in 1986.

Compania Minera del Sur (COMSUR) started construction on a 1,000-ton-per-day milling plant at the Bolivar tin-silver-zinc-lead operation. COMSUR was one-third owned by RTZ Ltd. Bolivar was estimated to have 856,000 tons of reserves (1.26% tin) and more than 350,000 tons of tailings (0.76% tin).

Empresa Nacional de Fundiciones (ENAF), the Government-owned smelting organization, announced the signing of long-term contracts to supply two tin trading houses: Toyota Tsusho and Leopold Lazarus. The material involved was reportedly 99.90% tin with low-lead content; low-lead metal was increasingly welcomed in the marketplace. ENAF also signed a contract to toll smelt up to 5,000 tons of tin concentrates from Minsur's tin mine in San Rafael, Peru. This was believed to be ENAF's first contract for toll smelting. Minsur's tin concentrates had been toll smelted in Brazil, Malaysia, and Mexico. In addition, ENAF completed the conversion of its tin smelter from heavy fuel to natural gas. The reduction in operating costs expected to result from the switch from oil to gas would allow ENAF to further reduce its treatment charges.

Landlocked Bolivia was granted access to the Pacific Ocean in a historic bilateral agreement between the Governments of Bolivia and Peru. In the past, the main mining areas of Bolivia had been obliged to transport their exported mineral output to the ports of Arica or Antofagasta in northern Chile. The port of Arica is very small, and shipments to Antofagasta, which is further south, were costly and time consuming. It was believed that access to the Peruvian port of Ilo would result in quicker and cheaper exports of Bolivian tin and concentrates. Ilo was a deep natural port, but expansion was needed and planned. The development of Ilo was to be funded by the InterAmerican Development Bank and would include the construction of a road from LaPaz to Ilo.

Brazil.—Brazil continued its 3-year string of tin mine production at rates considerably below those established in prior years and ranked second in world tin mine output. It ranked third in world tin smelter production. Tin mines and smelters were mostly privately owned, sometimes by foreign firms. 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 Paranapenema 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, Ariquemes, 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 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 was reportedly considering constructing a tin smelter. Total investment at Pitinga was about $115 million.

There were a series of alternating legal decisions about the continued operation of the Bom Futuro Mine near Ariquemes in Rondônia State. During 1991, the Government closed tin-mining operations by independent miners (garimpeiros) on the site. This year, various tribunals issued decrees alternately favoring the garimpeiros and occasionally the Ebesa tin-mining consortium of companies. During the year, tin-mining activity at Bom Futuro was nil except for some possible tin smuggling.

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 tons annually.

Canada.—Rio Algom Ltd. closed its East Kemptville, Nova Scotia, tin mine early in the year owing to continued low tin prices. Discovered as a tin property in 1979, the mine started production in 1985 and had a series of owners. Rio had provisions of $20 million to cover closing costs. Rio was 53% owned by RTZ Ltd., and the demise of this mine represented the end of RTZ's involvement in tin mining; since 1991, RTZ's other tin holdings (all based in the United Kingdom) ceased operations.

China.—For the third consecutive year, China led the world in tin mine output. 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 40,000 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. 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. Several other tin smelters around the world utilized Yunnan's 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.

The Gejiu tin smelter, owned by Yunnan Tin Corp., announced that the London Metal Exchange approved the YT brand as good for delivery. This smelter had an annual output of 12,000 tons. It treated concentrates with a grade of about 40% to 60% tin and produced 99.0% and 99.9% tin purity with a maximum lead content of 0.03%.

France.—CMB Packaging launched a new three-piece tinplate can. The can had a lithographed tinplate body and a full aperture easy-open end. It also had symmetrical vertical flutes that provided stiffening and allowed a down-gauging of the tinplate used from about 0.21 mm to 0.17 mm, providing a weight savings of 20%. A new production plant at CMB's factory in Cambridgeshire, United Kingdom, was to produce the item.

Germany.—Consolidated Tin Smelters, the subsidiary of Amalgamated Metal Corp. (AMC), announced plans to sell its 50.5% ownership in Malaysia's Datuk Keramat Holdings (DKH) owing to Keramat's intention to diversify into banking. AMC would retain its interest in DKH's subsidiary, Datuk Keramat Smelting (DKS). A group of Malaysian businesses were reportedly interested in buying AMC's stake in DKH. DKS had been producing about 20,000 tons of refined tin in recent years. The smelter had an installed capacity of 60,000 tons of concentrates, but effective capacity was considerably lower and still dropping because of the lower quality foreign concentrates DKS blends with the higher quality domestic concentrates. Effective capacity was reported to be about 30,000 tons annually.

Hong Kong.—The Mainland Tin Smelting Co., which owned and operated a 7,200-ton-per-year tin smelter, announced it may add a third furnace to the plant. A Far Eastern firm purchased a 20% stake in Mainland Metals Holdings Ltd., which controls Mainland Tin Smelting, Mainland Alloys, and Mainland Metals. Mainland Tin Smelting had an application before the London Metal Exchange for registration of its tin.

India.—Reports indicated that erratic supplies of tinplate and sharply increasing tinplate prices combined to create turmoil in the country's metal packaging industry. In India, some of the functional advantages of tinplate over other packaging materials were even more pronounced than in other countries owing to the diverse climatic conditions in various parts of the country and some rough transit handling facilities. Based on these considerations, tinplate could be expected to have won market share at the expense of competitive materials; however, the problems of prices and supplies tended to force canmakers from tinplate. Total installed capacity for tinplate production was 300,000 tons, but even though demand was about 435,000 tons annually, production never exceeded 180,000 tons. The main reason for the low production has been the Government's import policy toward tin mill blackplate. In the late 1970's and early 1980's, the cost of imported blackplate was lower than prices charged by Indian producers, and because of the large outflow of foreign exchange, the Government then tried to discourage

imports through import licensing and customs levies. However, domestic capacity remained underutilized, and the domestic producers did not modernize or expand their plants. Adverse exchange rate fluctuations and the high rate of customs duty increased the cost of tinplate to the users, and food packers have been switching to other materials. One of India's three tinplate producers, KR Steelunion, closed its 60,000-ton-per-year plant at Bombay. The two other producers were Steel Authority of India and Tinplate Co. of India. On the positive side, the Government was promoting exports of foodstuffs and accorded priority status to the food processing industry. The ministry of food processing tried to win a further cut in the excise duty on packaging materials and the customs duty on imported materials. These moves could revive India's demand for tinplate.

Indonesia.—This country ranked as the world's third leading tin mine producer and as the world's fourth leading tin smelter producer.

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 output. In recent years, 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. In the past 2 years, P.T. Timah embarked on and generally completed 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 and consolidated all its tin production on Bangka Island. It also moved its headquarters from Jakarta to Bangka Island. This year was one of consolidation for P.T. Timah.

P.T. Timah announced it had begun producing low-lead tin after acquiring a crystallizer from China for its tin smelter. This low-lead tin was intended mostly for users in Japan and the United States. Its major application was for tinplate.

P.T. Timah sold its tin output in the United States exclusively through its subsidiary, Indo-Metal Corp., in New York, NY.

Japan.—Two firms announced the start of mass production of plastic food cans to compete with the steel can. Mitsubishi Kasei Corp. and Mitsubishi Plastics Industries Ltd. launched the joint project after 4 years of testing and evaluation. This newly developed can was molded of multilayered plastics by a process licensed by Hitek Ltd., of Richmond, Victoria, Australia. The can was to be marketed under the name "KP-CAN"; it consisted of two layers of recycled polypropylene and composite layers of gas-sealing ethylene-vinyl alcohol copolymers and a bonding resin, all of which were sandwiched between two polypropylene layers. This plastic can was said to be 40% lighter than the comparable steel can, suitable for use in microwave ovens, and could be made transparent. The cost of the plastic can was said to be about 10% higher than the cost of the comparable steel can. Initial deliveries were made to the Hoko Fishing Co. (Japan). Current production was 18 million plastic cans per year, but Mitsubishi announced plans that could lead to production of 120 million cans annually.

Korea, Republic of.—Lucky Metals Ltd. announced the possibility of closing its Changhang tin smelter this year owing to low tin prices and lack of a steady source of tin concentrates. The Changhang tin smelter, with production of about 1,000 tons annually, depended mostly on tin concentrates from China. But in 1992, that source of concentrates had declined sharply owing to China's preference to export tin metal rather than tin concentrates and to keep its own tin smelters operating at a high rate. The startup in recent years of Mainland Metal's tin smelter in Hong Kong also aggravated tin concentrate sourcing problems for Changhang.

Pohang Iron & Steel Co., one of the world's largest tinplate producers, announced it had reached an agreement with Shanghai No. 10 Iron and Steel Co. (China) to construct a 120,000-ton-per-year electrolytic tinning line. The line was to be constructed at Shanghai's Pudong Industrial Complex. Construction was expected to start in 1993, subject to approval by the Government of China, with a 1995 startup. The line's cost was estimated at $97 million.

Malaysia.—This country ranked only sixth in world tin mine production after leading the world for most of the past century. The country continued to lead the world in tin smelter production.

At midyear, the President of the Malaysian Chamber of Mines decried the sad state of its tin industry. He observed that after 100 years of exploitation, the industry was suffering decline because of very low ore grades. The situation was aggravated by rising costs. Labor costs were cited as a special problem, rising sharply as the tin industry encountered harsh competition for workers from other sectors of a robust economy, such as tourism and construction. Production from the gravel pump sector accounted for 45 of the 49 mines closed this year. The total number of tin mines still operating fell to 92, the lowest number since the 1950's.

Malaysia Mining Corp. (MMC) remained the largest tin producer in the country, but continued low tin prices depressed its operations. MMC continued its movement away from tin, and for the third 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 already had been active in engineering and construction and was preparing to enter the manufacturing field too.

The Sunjei Lembing tin mine was reopened. The mine has had a series of closings and reopenings since the 1940's and was last closed in 1987. Now, a Chinese Malaysian partnership has reopened parts of the mine, with plans to bring the whole complex back into operation.

Malaysia's two large tin smelters raised their tin concentrate treatment charges and were reportedly operating near full capacity. The two smelters, operated respectively by Datuk Keramat Holdings Bhd. and Malaysia Smelting Corp. Bhd., were supplementing declining demand for the refining of local concentrates by absorbing additional foreign tin concentrates. Smelting charges, which had declined sharply in 1991, rose to about $290 per metric ton of contained tin for concentrates grading 70% tin. Datuk refined about 35,000 tons of tin annually, about 85% of which was foreign. Malaysia Smelting refined about 30,000 tons annually, about 60% of which was foreign. The two smelters, both in Penang State, together accounted for about 20% of world tin-smelting capacity. It was believed that Malaysia's importance in tin smelting would increase in future years as depressed tin prices and environmental problems make it more difficult for tin smelters in other countries to compete with Malaysian smelters.

Mexico.—Tin mining was focused in the north-central region adjoining the States of Durango, Zacatecas, and San Luis Potosí. The country's main tin mine, the El Perro Mine, was owned by Cia Mineral Pizzuto.

Estaño Electro S.A. de C.V. operated a tin smelter at Tlalnepantla, near Mexico City. Fundidora de Estaño 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 were imported.

Metales Potosí announced it was operating at full capacity, 4,800 tons per year, for the first time since the international "tin crisis" of late 1985. Potosí toll processed tin concentrates from Australia, Bolivia, Peru, Portugal, and Zaire. In the late 1980's, operating levels had been as low as 40% to 50%, but improved as more tin concentrates became available as a result of tin-smelter shutdowns around the world. Potosí's treatment charges reportedly rebounded to a more normal and profitable level of about $600 to $700 per ton. This year, with sales of $18 million, the smelting operation was unprofitable, but sales were expected to reach $30 million in 1993, signaling a return to profitability. One-half of the tin Potosí produced was used to make the firm's solder, and the remainder was exported to the United States. However, to reduce its dependence on one commodity, the firm began constructing a facility to recover metals from low-grade copper scrap. By yearend 1993, this plant was expected to start treating 10,000 tons of copper scrap annually, producing blister copper, zinc oxide, tin, and lead.

Netherlands.—The large steel producer, Hoogovens, which had acquired a 40% stake in the Norwegian tinplate producer Norsk Blikkvalseverk (NB) in January 1990, agreed to acquire the remaining 60% of the firm. Hoogovens has long been a major tinplate producer. The acquisition added 130,000 tons annually to Hoogoven's yearly production of 670,000 tons of tinplate. Hoogovens now controlled about 20% of the European tinplate market.

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.

Peru.—Minsur negotiated a contract with Bolivia's state-owned smelting organization, ENAF, for the toll treatment of 3,600 tons of tin concentrates. ENAF had excess capacity. Minsur produced about 13,000 tons annually of tin concentrate, grading about 50% tin. Minsur previously had similar deals with Capper Pass (United Kingdom) and Potosí (Mexico) and still had similar contracts with Cesbra (Brazil) and the two Malaysian tin smelters.

Portugal.—Europe's largest tin mine, Somincor's Neves Corvo copper-tin mine in southern Portugal, announced good progress with its tin production. Neves Corvo had total output of 9,000 tons of tin concentrates to yield 6,500 tons of tin. In 1991, grades of the flotation concentrates (which amount to about 25% of total tin production in terms of metal content) ran about 30% tin; after some operating capital improvements, average grades in 1992 ran 45% tin or better. This emphasis on improving concentrate grades was associated with Somincor's agreement on a long-term contract this year with the Zamora tin smelter in Spain. Zamora has traditionally been a processor of high-grade tin concentrates.

Russia.—Tin mining was conducted mostly in the far eastern regions of the country. The country's major tin smelter, the Novosibirsk Integrated Tin Works, actively sought business ties with Western firms. The 35,000-ton-per-year tin smelter sought foreign tin concentrates for smelting and refining because the facility found itself operating below capacity owing to a shortage of feed. The smelter used a variety of feed ranging from 15% to 70% tin, although the average grade tended toward the low side, at 25% to 30% tin. Also, the smelter could handle low-grade residues down to about 1% to 2% tin, although as environmental restrictions are increasing, treatment of low-grade feed may continue only for another few years. The smelter was still owned by the Russian Government, but under an agreement signed 3 years ago, the plant was leased to the operators for 11 years. The smelter, which employed about 2,000 people, produced mostly 99.92% tin but also had a small production of higher purities. The company also produced tin solder and solder paste. Novosibirsk planned to commence production of

organic tin chemicals in 1993 using a process developed in-house. Most of the smelter's tin output was consumed in Russia, but some went to Byelarus, Kazakhstan, and the Ukraine.

Reportedly, tin consumption in Russia was about 38% in solder, 24% in tinplate, 12% in tinning, and the rest in a variety of applications.

Hyundai Resources Development Co. (Republic of Korea) announced plans to start mine development work on the Pravouny tin deposit near the far east city of Khabarovsk. Estimates made by geologists had set reserves at Pravouny at 50 million tons of ore. Mine output would be 1 million tons of tin ore annually or about 5,000 tons of tin-in-concentrate annually. The tin grade was believed to be 0.5%, and some copper was present. Hyundai formed a 50-50 joint-venture with a Khabarovsk firm called Dalgeologia to develop the mine. It was reported the tin concentrates would be shipped to the Solnechny copper smelter near Komsomolsk. With Hyundai's involvement, much of the concentrate could be exported to the Republic of Korea and other countries in Southeast Asia, although some also could be shipped across Siberia to the tin smelter at Novosibirsk in south-central Russia. Hyundai believed that, if its own studies support the earlier Soviet numbers, mine development could commence by yearend. The Hyundai group companies have been among the most aggressive foreign firms in trying to develop natural and mineral resources (including coal and timber) in the former Soviet Far East. Hyundai, which was the first foreign trading firm to establish an office in the port city of Nahodka, this year relocated its base to Vladivostok with the lifting of restrictions on foreign access to the former Soviet naval port.

South Africa, Republic of.—Rooiberg Tin Ltd. announced plans to close part of its tin-mining operations and to focus mining activities on high-grade tin ore reserves. The decision to high grade was motivated by low rand-denominated tin prices that have put the mine under pressure to reduce costs or shut down. Ore production would be cut from the 12,000-ton-per-month level to 6,000 tons. The firm had enough high-grade reserves to last 1 year. Rooiberg's tin smelter, which secured all its feed from the Rooiberg tin mine, produced less than 1,000 tons of tin metal in 1992.

Thailand.—Once the country's largest revenue producer among metals, tin mine and smelter production remained steady this year, but at a much lower level than prevailed a decade ago. Now Thailand ranks only fifth among the world's tin mine producers. Other industries such as tourism, real estate, rubber, palm oil, and shrimp farming continued to draw investment away from tin mining in the south, where most tin reserves were located.

The Thai Pioneer Enterprise tin smelter announced plans to boost annual production at its Pathum Thani plant by 6,000 tons, to 12,000 tons. To cover the cost of raising its output, Thai Pioneer planned to double its capital. Thai Pioneer was owned 60% by Van Waaden and Associates of the Netherlands; the remaining shares were held by local Thai business groups, including Universal Mining.

Thaisarco, the country's major tin smelter, announced the start of a 2-year, $1.2 million exploration program over a large site in the Andaman Sea. Also, Thaisarco announced current discussions with the Offshore Mining Organization (OMO), the Government tin-mining agency, about the possibility of mining for tin in OMO's concession near the site of Thaisarco's own exploration program. The firm's renewed interest in tin mining was attributed to its difficulties in sourcing enough feed. The smelter was running trial lots of tin concentrate from Laos as part of its attempt to make up for the decline in Thailand's mined tin output. The smelter's production of 11,000 tons of tin metal this year was considerably less than its capacity of 38,000 tons.

Turkey.—Although the country has not been a major tin producer in modern times, archaeologists and scientists working on bronze artifacts in Turkey announced evidence that sheds light on how early humans obtained tin. Throughout the Near East, bronze articles from 5,000 years ago attest to the importance of this copper and tin alloy to early cultures. In the past, archaeologists had unearthed many copper mines nearby but had no idea where the tin originated. Some evidence had pointed to mountains in Afghanistan as the nearest possible source, and there had been clues that tin was an active trading item. But recently, tin ore was found at Goltepe, in the mountains near Ankara, Turkey. Radiocarbon dating techniques showed that tin was extracted there about 2500 B.C. It was hypothesized that these ancient people extracted tin using a multistep, low-temperature technique. The findings added evidence to a growing perception that ancient cultures may have depended on small, local mineral deposits more than previously believed.

United Kingdom.—Carnon Consolidated Ltd. announced plans to develop two new levels at its South Crofty tin mine in Cornwall. A decline to service these levels was already in place and was equipped with a conveyance suitable for ore removal and human transport. Carnon planned to invest about $7 million over the next 5 years.

Vietnam.—A joint-venture was announced by Japanese, Taiwanese, and local interests that would establish a new plant for the manufacturing of tin cans in Vietnam by 1994. The joint-venture would be capitalized at $2.5 million and would be 29% owned by the Japanese trading firm of Tomen Corp., 51% by Taiwan's Ton Yi Industrial Corp., and the remainder by a Vietnamese Government-owned corporation. The plant would be in Ho Chi Minh City and would be capable of producing about 70 million tin cans annually. It was expected that Ton Yi would supply the tinplate, and that the cans produced would be intended for pineapples and other fruits, vegetables, and marine products. Exports of canned products would be handled by Tomen with most

shipments to be made to Japan, Russia, and Western Europe. Vietnam promoted the export of its agricultural and fishery products to the West to earn foreign exchange. In recent years, its export sales to these markets were slow because of quality problems with tin cans. Vietnam produced about 30 million tin cans annually. With the additional announced can capacity, the country was expected to meet the entire demand for cans for canned exports.

Current Research

In the United States, 3M Corp.'s Electrical Specialties Div. in Austin, TX, announced development of a new Underwriter's Laboratory Recognized Scotch Foil Shielding Tape #1183 that employs a tin-alloy coating on smooth copper foil to enhance a durable electromagnetic field. This tape was a tin-alloy coated version of the 3M #1181 tape and provided shielding when wrapped around flat and round cable, and cable connectors. The electrically conductive adhesive enabled #1183 tape to make electrical connection across seams and between mating sections of electronic enclosures ranging from small equipment housings to large shielded rooms. The tape also could suppress the energy radiating from seams between the sectors of dish antennas. The tin-alloy coating on both sides of the foil reportedly provided two significant benefits: environmental stability and corrosion resistance, and exceptional solderability for applications such as sealing the seams when the tape was used as a shield around cable connectors.

In France, CMB Packaging announced development of a new three-piece tinplate can. The can had a lithographed tinplate body and a full-aperture, easy-open end. It also had symmetrical vertical flutes that provided stiffening and allowed a down-gauging of the tinplate used from about 0.21 mm to 0.17 mm, providing a weight savings of 20%. A new production plant was being built at CMB's factory in Cambridgeshire, United Kingdom, to make the new item.

In Japan, Sumitomo Metal Mining Co. announced that it had developed, in conjunction with Tohoku Chemical Co., a new type of highly transparent indium-tin oxide film that could be printed like ink onto flat-panel video displays. Currently, forms of indium-tin oxide, a key component of liquid-crystal or electroluminescent displays used on a wide variety of electronic devices, must be sputtered onto the panel, baked, and then etched via standard lithographic methods. The new material offered the potential to produce larger displays while significantly reducing costs.

In the United Kingdom, the International Tin Research Institute (ITRI), based in Uxbridge, announced a widening of the scope of its tin research activity. Since its 1932 founding, the ITRI had limited its research activities for, and funding sources to, its tin producer sponsors. This year, the ITRI established a new limited liability company called ITRA. The facilities of ITRA would be open to commercial firms and to trade or research associations worldwide. Organizations subscribing to ITRA would have the opportunity to participate in cooperative research projects that were of mutual interest to a particular industrial sector or to place specific research contracts with ITRA, with exclusive access to the results. Although ITRA will be a separate organization, with its own subscribers and clients, it would be fully supported by all the facilities of ITRI, including technical expertise and support staff.

The ITRI also announced success in its 2-year effort to develop a cyanide-free plating system for tin-zinc coatings. The new plating electrolyte was claimed to be less corrosive and easier to control and operate than the original plating process, which used hydrofluoric acid. The ITRI said that a patent was being sought and that a number of industrial firms were trying the new plating process. They felt that a new market for tin of at least 1,000 tons yearly worldwide would result from this new development. The next stage would be to adapt the process to continuous strip plating, which would tap the large galvanized steel and automotive markets.

Also in the United Kingdom, two subsidiaries of the Cookson Group, Fry's Metals and Electrovert, announced an Anglo-Canadian partnership for the worldwide manufacture and marketing of fusible alloy core technology. The process was originally developed by Fry and the product made in its Clydebank, Scotland, plant. The process was ordinarily used for making plastic components in the automotive and aerospace industries and allowed components with complicated internal structures to be produced in a single hollow piece. Castings were made using tin-bismuth or tin-lead-antimony alloy molds, which form the internal structure of the plastic form. The low-melting point alloy was carefully melted away to leave a precisely formed casting. This property allowed lightweight, smooth forms to be made from high melting point plastics with good insulating properties that were suitable for auto engine components such as inlet manifolds, water pumps, and thermostat housings. An additional benefit was reportedly the recycling of the tin alloys used in casting. Each casting machine was estimated to use 3 to 5 tons of tin alloy at any one time, of which Fry's estimated less than 1% was lost annually in the process. Fry forecasted a probable market of at least 400 machines of this type.

CMB Closures Ltd., United Kingdom, announced the development of a new microwaveable tinplate cap. The plastic-lined tinplate closure, with a tamper-evident "pop-up" button, was sealed to a specially developed glass bowl-shaped container. CMB started to conduct trials with the new cap in the United States and felt the item could be commercially available by 1993.

British Steel Corp., a major tinplate producer, announced development of a competitive material that does not use tin. Its trade name was Hi-Top, and it was somewhat akin to tin-free steel (TFS, developed 25 years ago) with an electrolytic chromium-chromium oxide coating. The coating on Hi-Top was a duplex structure; 80% of its thickness consisted of chromium metal adjacent to the steel substrate and 20% hydrated

chromic oxide-hydroxide in a layer above the metal. The precise composition was controlled by the processing conditions.

British Steel also brought to market another competitive packaging product called Ferrolite. The product was developed by CMB Packaging Technology PLC, and British Steel became the sole licensee for production of Ferrolite in the United Kingdom for sale worldwide. The product featured a polymer coating on one or both sides of a steel strip. The firm claimed Ferrolite was applicable to most tin mill product applications, including aerosol can components, full aperture easy-open ends, and draw/redraw cans; but technology for welding was not yet commercially available. The firm indicated that a particularly interesting market for Ferrolite was in the production of shallow drawn trays for pet food and ready-meal markets, and claimed testing had shown that Ferrolite trays could be safely used in microwave ovens and provided even heating of the contained food.

OUTLOOK

Supply

The supply of tin for the United States was expected to continue to originate primarily in Asia and South America and to enter the country in the form of refined tin metal. Although some promising tin deposits existed in the United States, primarily in Alaska, these were 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 an important and probably increasing 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 such as Brazil and China appears likely.

Demand

The demand for primary tin in the United States was 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 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.

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[2]Pearce, 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.

[3]Can Manufacturers Institute. Metal Can Shipment Report 1992. Washington, DC, 1992, p. 1-4.

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TABLE 1
SALIENT TIN STATISTICS

(Metric tons unless otherwise specified)

	1988	1989	1990	1991	1992
United States:					
Production:					
Mine	W	W	W	W	W
Smelter	[1]1,467	e1,000	—	—	—
Secondary[e]	15,275	14,340	17,187	13,099	12,970
Exports[2]	1,209	904	658	970	1,888
Imports for consumption:					
Metal	43,493	33,988	33,810	29,102	27,314
Ore (tin content)	2,837	216	—	1	—
Consumption:					
Primary	37,531	36,609	36,770	r35,138	34,953
Secondary	8,072	9,854	8,395	r9,667	10,137
Stocks, yearend, U.S. industry	15,023	14,668	17,304	r13,812	10,714
Prices, average cents per pound:					
New York market	330.91	397.28	287.69	258.75	282.58
Metals Week composite	441.42	520.18	386.29	362.85	402.40
London	NA	[3]382.00	281.00	254.00	277.00
Kuala Lumpur	319.86	387.12	276.02	248.42	271.85
World: Production:					
Mine	r204,654	r233,127	r221,651	r202,723	e179,466
Smelter:					
Primary	r215,163	r222,639	r223,379	r190,147	e182,473
Secondary	r19,112	r19,789	r17,770	r13,041	e8,990
Undifferentiated	105	126	1,468	2,760	e6,560

[e]Estimated. [r]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data; U.S. mine production for 1988-92 was negligible.

[1]Reported figure.

[2]Excludes reexports.

[3]The London Metal Exchange resumed trading as of June 1, 1989.

TABLE 2
U.S. CONSUMPTION OF PRIMARY AND SECONDARY TIN

(Metric tons)

	1988	1989	1990	1991	1992
Stocks, Jan. 1[1]	10,217	9,242	13,551	r12,502	12,034
Net receipts during year:					
Primary	39,421	37,760	38,473	r36,126	34,302
Secondary	12,472	10,901	9,501	r1,622	2,279
Scrap	6,707	8,168	6,534	r8,370	8,412
Total receipts	58,600	56,829	54,508	r46,118	44,993
Total available	68,817	66,071	68,059	r58,620	57,027
Tin consumed in manufactured products:					
Primary	37,531	36,609	36,770	r35,138	34,953
Secondary	8,071	9,854	8,395	r9,667	10,137
Total	45,602	46,463	45,165	r44,805	45,090
Intercompany transactions in scrap	630	424	316	275	267
Total processed	46,232	46,887	45,481	r45,080	45,357
Stocks, Dec. 31 (total available less total processed)	22,586	19,184	r22,578	r13,540	11,670

rRevised.
[1]Includes tin in transit in the United States.

TABLE 3
U.S. CONSUMPTION OF TIN, BY FINISHED PRODUCT

(Metric tons of contained tin)

Product	1991			1992		
	Primary	Secondary	Total	Primary	Secondary	Total
Alloys (miscellaneous)[1]	W	W	W	W	W	W
Babbitt	r596	r345	r941	629	291	920
Bar tin	r436	W	r436	922	W	922
Bronze and brass	r1,227	r1,669	r2,896	1,271	1,645	2,916
Chemicals	6,564	—	6,564	6,301	—	6,301
Collapsible tubes and foil	W	W	W	W	W	W
Solder	r10,700	r5,596	r16,296	11,518	6,924	18,442
Tinning	r1,465	W	r1,465	1,134	123	1,257
Tinplate[2]	11,482	W	11,482	9,821	W	9,821
Tin powder	539	W	539	573	W	573
Type metal	W	W	W	W	W	W
White metal[3]	r868	W	r868	974	W	974
Other	r1,261	r2,057	r3,318	1,810	1,154	2,964
Total	r35,138	r9,667	r44,805	34,953	10,137	45,090

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Includes terne metal.
[2]Includes secondary pig tin and tin acquired in chemicals.
[3]Includes pewter, britannia metal, and jewelers' metal.

TABLE 4
U.S. INDUSTRY YEAREND TIN STOCKS

(Metric tons)

	1988	1989	1990	1991	1992
Plant raw materials:					
Pig tin:					
Virgin[1]	7,013	6,807	10,671	r10,339	6,830
Secondary	1,440	2,253	795	863	646
In process[2]	1,056	1,032	1,101	r1,000	1,268
Total	9,509	10,092	12,567	r12,202	8,744
Additional pig tin:					
Jobbers-importers	3,387	3,536	2,467	742	1,117
Afloat to United States	2,127	1,040	2,270	868	853
Total	5,514	4,576	4,737	1,610	1,970
Grand total	15,023	14,668	17,304	r13,812	10,714

rRevised.
[1]Includes tin in transit in the United States.
[2]Data represent scrap only, tin content.

TABLE 5
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.							
	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1990	$2,086	6,788	$35,291	293,426	$199,036	426	$2,493	8,488	$1,782
1991	r2,516	r6,804	33,132	r284,783	195,659	r340	r2,698	10,109	2,240
1992	2,333	10,567	57,875	295,321	200,534	510	3,883	28,500	7,070

rRevised.

Source: Bureau of the Census.

TABLE 6

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 and pigs		Tin scrap and other tin bearing material except tinplate scrap[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1990	145,396	$78,687	658	$3,344	106,389	$55,921
1991	150,187	89,677	970	5,455	121,359	85,708
1992	272,549	162,302	1,888	8,957	127,191	89,298

[1]Includes bars, rods, profiles, wire, powders, flakes, tubes, and pipes.

Source: Bureau of the Census.

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF TIN, BY COUNTRY

Country	Quantity (metric tons)	Value (thousands)
1991		
Concentrates (tin content):		
Bolivia	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
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
Total[1]	29,102	161,725
1992		
Metal (unwrought tin):		
Australia	300	1,684
Belgium	1	10
Bolivia	4,623	26,269
Brazil	8,167	49,597
Burma	21	112
Chile	521	2,883
China	5,389	31,136
Hong Kong	377	2,082
India	59	348
Indonesia	3,854	23,283
Malaysia	2,799	18,072
Mexico	212	1,310
Singapore	320	1,984
Thailand	427	2,783
United Kingdom	(2)	15
Other	244	1,455
Total	27,314	163,023

[1]Data may not add to totals shown because of independent rounding.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 8

TIN: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1988	1989	1990	1991	1992e
Argentina	446	405	r230	r230	200
Australia	7,009	7,709	r7,377	r5,700	2 6,400
Bolivia	10,504	15,849	17,249	r16,830	15,300
Brazil	44,102	50,232	39,149	r29,253	30,000
Burma	529	501	r653	r518	710
Burundie 3	24	50	r54	r74	72
Cameroone	r3	r3	r3	r3	3
Canada	3,591	2,790	2,828	r4,455	—
Chinae	29,500	40,000	42,000	43,000	43,000
Czechoslovakia	515	562	613	r118	100
Germany: Eastern states	r2,474	r2,413	r1,806	r118	—
Indonesia	29,590	31,263	30,200	30,061	25,000
Kazakhstane 4	—	—	—	—	500
Laose	300	r 2 127	500	r300	300
Malaysia	28,866	32,034	28,468	20,710	2 14,339
Mexico	274	159	7	15	15
Mongolia	e1,200	e1,200	320	r141	2 63
Namibia	1,182	1,120	900	r11	10
Niger	119	71	r38	r20	20
Nigeria	r300	r e250	r e170	r182	200
Peru	4,181	r5,082	5,134	6,559	6,000
Portugal	81	63	r 2 4,779	r 2 8,333	6,500
Russiae 4	—	—	—	—	10,000
Rwandae 5	118	762	734	730	730
South Africa, Republic of	1,377	1,306	1,140	1,042	582
Spain	66	r56	r27	r25	25
Tanzaniae	r2	r15	r15	r6	5
Thailand	14,225	14,922	14,635	14,937	15,000
Ugandae	10	10	r25	r25	25
U.S.S.R.e 6	16,000	16,000	15,000	13,500	—
United Kingdom	3,454	3,846	3,400	r2,326	1,000
United States	W	W	W	W	W
Vietname	700	850	r850	r800	800
Zaire7	2,771	2,346	2,221	r1,635	1,500
Zambia	1	1	r6	r6	7
Zimbabwee	1,140	r1,130	r1,120	r1,060	1,060
Total	r204,654	r233,127	r221,651	r202,723	179,466

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]Contained tin basis. Data derived in part from the Monthly Statistical Bulletin of the International Tin Council, London. Table includes data available through July 26, 1993.

[2]Reported figure.

[3]Concentrates gross weight reported, estimated 47% Sn content.

[4]Formerly part of the U.S.S.R; data were not reported separately until 1992.

[5]Concentrates gross weight reported, estimated 70% Sn content.

[6]Dissolved in Dec. 1991.

[7]Nonduplicated total of content of concentrates plus smelter production.

TABLE 9

TIN: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1988	1989	1990	1991	1992e
Argentina:					
Primary	r323	r311	r180	r180	150
Secondarye	100	100	100	100	100
Totale	r423	r411	r280	r280	250
Australia:					
Primary	439	424	312	268	250
Secondarye	300	300	200	r300	250
Totale	739	724	512	r568	500
Belgium: Secondary	4,972	r5,976	6,063	r4,426	5,260
Bolivia: Primary	5,373	9,448	12,567	r14,663	12,000
Brazil:					
Primary	41,857	44,240	r37,580	r25,776	30,000
Secondarye	250	250	250	250	250
Totale	42,107	44,490	r37,830	r26,026	30,250
Bulgaria[2]	83	64	64	60	60
Burma: Primary	110	r171	r275	r157	300
Canada: Secondarye	200	200	200	200	200
China: Primarye	29,500	29,500	35,000	38,000	38,000
Czechoslovakia: Primary	515	562	613	r118	100
Denmark: Secondarye	100	100	100	100	100
Germany, Federal Republic of:e					
Eastern states: Primary	r3,322	r3,470	r2,862	—	—
Western states: Secondary	r100	300	r400	—	—
Total	r3,422	r3,770	r3,262	r700	4,500
Greece: Secondarye	40	40	40	30	30
India: Secondary	200	200	e200	e200	200
Indonesia: Primary	28,365	29,916	30,389	30,415	24,000
Japan: Primary	846	808	816	r716	[3]821
Korea, Republic of: Primarye	400	800	800	600	400
Malaysia: Primary	49,945	50,874	49,002	42,722	[3]45,680
Mexico: Primary	r1,812	r4,752	r5,004	r2,262	2,500
Netherlands:					
Primary	3,478	4,529	r5,850	r4,800	4,500
Secondarye	180	190	250	r200	150
Totale	3,658	4,719	r6,100	r5,000	4,650
Nigeria: Primary	566	258	r227	r246	220
Norway: Secondarye	55	100	100	90	90
Portugal: Primary and secondary	22	62	1,404	r2,000	2,000
Russia:[4 5]					
Primary	—	—	—	—	10,000
Secondary	—	—	—	—	2,000
Total	—	—	—	—	12,000
Singapore: Primarye	900	600	800	200	—

See footnotes at end of table.

TABLE 9—Continued

TIN: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1988	1989	1990	1991	1992e
South Africa, Republic of:					
Primary	r1,377	r1,306	r1,140	r1,042	3592
Secondarye	r80	r80	r70	r70	60
Totale	r1,457	r1,386	r1,210	r1,112	652
Spain:					
Primary	806	1,767	600	r700	600
Secondarye	200	200	200	200	200
Totale	1,006	1,967	800	r900	800
Thailand: Primary	14,675	14,571	15,512	11,255	11,000
U.S.S.R.:e 5 6					
Primary	18,500	18,000	16,000	13,000	—
Secondary	4,000	4,000	3,700	3,300	—
Total	22,500	22,000	19,700	16,300	—
United Kingdom:					
Primary	9,014	3,584	6,122	r1,661	—
Secondary	7,757	7,184	5,897	r3,575	100
Total	16,771	10,768	12,019	5,236	100
United States:					
Primary	1,467	1,000	—	—	—
Secondary	578	569	W	W	W
Total	2,045	1,569	W	W	W
Vietnam: Primarye	600	800	800	r500	500
Zaire: Primarye	3118	100	90	r70	60
Zimbabwe: Primary	855	848	838	r796	800
Grand total	r234,380	r242,554	r242,617	r205,948	198,023
Of which:					
Primary	r215,163	r222,639	r223,379	r190,147	r182,473
Secondary	r19,112	r19,789	r17,770	r13,041	r8,990
Undifferentiated	105	126	1,468	2,760	6,560

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Grand total."

[1]Data for 1988-90 is derived in part from 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 July 9, 1993.

[2]May include some secondary metal.

[3]Reported figure.

[4]Formerly part of the U.S.S.R..

[5]All production in the U.S.S.R. from 1988-91 came from Russia.

[6]Dissolved in Dec. 1991.

TITANIUM

By Joseph Gambogi

Mr. Gambogi, a physical scientist with 10 years of Government and industry experience, has been a commodity specialist since 1988. Domestic survey data were prepared by Giovanni C. Jacarepaqua, statistical assistant; and international data tables were prepared by Amy Buck, 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). Titanium dioxide 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.

World production of titanium concentrates was estimated to be 1,637,000 metric tons. Owing to increased demand by the titanium pigment industry, domestic consumption of TiO_2 in concentrates increased 22% from the 1991 level. The pigments industry accounted for about 97% of TiO_2 consumption in concentrates. Apparent domestic consumption of TiO_2 pigments was about 1,000,000 tons. The paint, paper, and plastics industries were the largest consumers of pigment. In 1992, domestic production capacity of pigment increased to 1,197,000 tons.

World production capacity of titanium sponge was estimated to be 111,000 tons. Domestic consumption of titanium metal in 1992 increased slightly, and domestic shipments of mill products increased by about 3%. One of the titanium sponge producers closed its 10,900-metric-ton-per-year production facility. Consequently, domestic capacity of titanium sponge fell to 19,500 tons.

DOMESTIC DATA COVERAGE

Consumption data for titanium raw materials are developed by the U.S. Bureau of Mines (USBM) from one voluntary survey of domestic operations. Of the 30 operations canvassed, 26 responded, representing 99.5% of the data in table 7. Data for nonrespondents were 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 1992 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.

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 micron 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.

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.

Industry Structure

About 40% of the world's titanium feedstocks are supplied by three titanium slag producers: Richards Bay Minerals, the Republic of South Africa; QIT Fer et Titane Inc. (QIT), Canada; and Titania A/S, Norway. The remaining 60% of demand is supplied by producers of ilmenite and rutile concentrates (both natural and synthetic). Most of the production facilities for these concentrates are found in Australia, India, Malaysia, Norway, Sierra Leone, and the Republic of South Africa. Some of the largest producers of these feedstocks are: Cable Sands Ltd., Consolidated Rutile Ltd. (CRL), Indian Rare Earths Ltd. (IREL), Renison Goldfields Consolidated Ltd. (RGC), Sierra Rutile Ltd., the TiWest joint venture, and Westralian Sands Ltd.

World TiO_2 pigment output in 1992 came from about 60 separate facilities ranging in annual capacity from a few thousand tons to nearly 300,000 tons. The world's four largest TiO_2 pigment producers are E.I. du Pont de Nemours & Co. Inc. (Du Pont), SCM Chemicals Inc., Tioxide Group PLC, and Kronos Inc. These four companies own or control about 60% of world capacity. Another 20% of world capacity is divided between Bayer AG, Ishihara Sangyo Kaisha, Kemira Oy, Kerr-McGee Chemical Corp., Sachtleben Chemie GmbH, and Thann et Mullhouse. The remaining 20% of world capacity was divided between about 20 other producers. An estimated 40% of the world's capacity is in North America while about 39% is in Europe (Eastern and Western).

There are 10 major producers of titanium sponge in the world. In Japan there are three producers: Osaka Titanium Co. Ltd., Showa Titanium Co. Ltd., and Toho Titanium Co. Ltd. In the United States there are two producers, Oregon Metallurgical Corp. (Oremet) and Titanium Metals Corp. of America (Timet). In the former U.S.S.R., there are producers at Berezniki, Russian Federation; Ust Kamenogorsk, Republic of Kazakhstan; and Zaporozhye, Ukraine. The United Kingdom's one sponge producer is Deeside Titanium Co. China has one known producer in Shanghi. The United States accounts for about 18% of the world's sponge production capacity.

The titanium industry is moderately integrated from raw materials to semifinished products. Du Pont, the world's largest pigment producer, obtains ilmenite, rutile, and leucoxene from its own mines in Florida and from various suppliers in other countries. In addition to various pigment-related holdings, Tioxide Group owns a 36% share of Westralian Sands Ltd. in Australia. Tioxide is owned by the world's largest paint producer ICI PLC. Kronos, formerly NL Industries Inc., supplies ilmenite to its European pigment plants from its mine at Tellnes, Norway. Titania, a subsidiary of Kronos, operates a smelting plant at Tyssedahl, Norway, that processes part of the Tellnes ilmenite to produce titanium slag for the same market. Hanson Industries PLC, United Kingdom, owner of SCM Chemicals, has a 49% interest in RGC, the major producer of titanium minerals in Australia. Kerr-McGee Chemicals is a joint-venture partner in the Australian minerals sands producer TiWest and holds 25% interest in the new Saudi Arabian pigment producer Cristal Pigment Co. Nearly all of the remaining TiO_2 pigment manufacturers buy their raw materials from independent producers of titanium concentrates.

Outside China and the former U.S.S.R., sponge metal producers do not own their own titanium mine. One U.S. sponge producer purchases rutile and manufactures $TiCl_4$, the intermediate compound used for commercial production of titanium metal. The other U.S. producer purchases $TiCl_4$.

Technology

Exploration.—Hard-rock ilmenite deposits, because of their inherent magnetic properties, are readily amenable to the application of aero- 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 70 or 100 meters. 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 15 meters and preferably 30 meters. The type of drill needed will depend on the nature of the ground, including the presence of clay, hardpan, 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-sluice separators of various designs also have been used. In Australia, the Reichert cone concentrator, which operates on the pinched-sluice principle, has been successful for large-tonnage operations. Flotation also has 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, before 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. Because 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 impurities, the Richards Bay 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. Richards Bay slag also may 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° 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° 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.

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. Cold-hearth melting (electron-beam and plasma-arc) 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

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 upon local market economics.

Tariffs.—The duties shown in table 1 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 1.)*

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.

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 USBM, energy requirements for alluvial mine production are about 5.1 million British thermal units (Btu) per ton of TiO_2 in concentrate. Production of pigment requires about 75 to 112 million Btu per ton of TiO_2, depending on the process and feed material used. Titanium sponge production uses from 408 to 466 million

Btu per ton of metal, of which about 248 to 270 million Btu 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 per ton of titanium ingot.[1]

ANNUAL REVIEW

Strategic Considerations

Security of Supply.—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 1992 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 imported ilmenite.

Dependence on foreign rutile sources for the production of titanium metal 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 1992, 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. In 1992, import reliance was withheld to avoid disclosing company proprietary data. 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.—The Defense Logistics Agency began a modernization program in 1992 to dispose of obsolete and excess materials contained in the National Defense Stockpile (NDS). Although titanium sponge metal remained on the list of strategic and critical materials for stockpiling purposes, the Government's NDS goal was lowered from 176,901 tons to 48,367 tons. The NDS inventory in December contained 23,555 tons of specification metal and 9,857 tons of nonspecification material. Rutile was removed from the list of strategic and critical materials.[2] *(See table 2.)*

Issues

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.

Production

Concentrates.—U.S. producers of ilmenite in 1992 were RGC (USA) Mineral Sands, Inc. [formerly Associated Minerals (USA) Ltd. Inc.] 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. RGC was the only U.S. producer of natural rutile. Kerr-McGee was the sole domestic producer of synthetic rutile, at Mobile, AL.

Du Pont's new dredging operation at its Maxville site was under construction in 1992 and was scheduled to be commissioned in the first half of 1993. The opening of the Maxville site is expected to coincide with the partial closing of Du Pont's nearby Highland operation. Du Pont also purchased land in Georgia as a potential expansion of its titanium mineral operations.

Ferrotitanium.—Ferrotitanium was produced by Galt Alloys Inc., Canton, OH, and Shieldalloy Metallurgical Corp., Newfield, NJ. Two grades were produced—a 40%- and a 70%-titanium grade.

Metal.—In February, RMI Titanium Co. closed its metal reduction facility and supporting sodium production facility at Ashtabula, OH. The closure left Oremet and Timet as the two remaining producers of titanium sponge in the United States. RMI had no plans to reopen the 10,900-ton-per-year sponge operation, but planned to continue to produce mill products, hot-formed parts, superplastically formed parts, and titanium powder. Later in the year, RMI Titanium and Precision Tube Technology Inc. formed a joint venture to manufacture and sell titanium welded coiled tubing. The venture company, called Titanium Tube Technology, targeted its products for offshore petroleum drilling operations. Specific uses were subsea umbilicals that carry injection and control lines for offshore drilling operations.

Timet neared completion of a 10,000-ton-per-year titanium sponge facility.

The facility's vacuum-distillation process was based on technology developed in Japan. The newer technology was expected to produce a much higher quality sponge with fewer impurities and lower production costs. Union Titanium Sponge Corp., a consortium of Japanese companies, contributed to the financing for the facility and had the option of converting the debt to equity interest in Timet.

Timet and Axel Johnson Metals Corp. formed a joint venture called Titanium Hearth Technologies. The joint venture operated an electron-beam hearth furnace at a Morgantown, PA, facility. The cold-hearth furnace was built by Axel Johnson with a melt capacity of 5,400 tons per year of titanium ingot and slab.

Owing to poor market conditions, several companies closed their facilities. International Light Metals (ILM) Corp., a subsidiary of Martin Marietta Corp., permanently shut down its fabricating plant in Torrance, CA. ILM had been a major supplier of titanium extrusions and forgings for the aerospace industry.

Howmet Corp. temporarily shut down its titanium ingot facility at Reno, NV. The Ladish Co. permanently closed its west coast forging facility at Vernon, CA, and consolidated its forging operations into its Cudahy, WI, facility. *(See tables 3 and 4.)*

Titanium Dioxide Pigments.—Du Pont began operating what the company called a market development unit (MDU) at its Johnsonville, TN, TiO_2 facility. The MDU unit simulated plant conditions such that experimental lots of TiO_2 pigments could be produced without interrupting output from the facility's normal production.

Kronos commissioned a new chloride-route titanium dioxide plant at Lake Charles, LA. The facility had two pigment lines with a total capacity of 80,000 tons per year.

Kemira Inc. announced plans to construct a new research and development center at its Savannah, GA, facility. Construction of the center was expected to be completed in 1993.

SCM Chemicals completed the final stage of its environmental improvement program to comply with the Environmental Protection Agency's regulations introduced by the Bevill Amendment to the Resource Conservation and Recovery Act. *(See table 5 and 6.)*

Consumption and Uses

Concentrates.—Total U.S. reported consumption of TiO_2 in concentrates increased 22% from the 1991 level. This increase was partially attributed to increased production of titanium pigments. Although ilmenite consumption decreased by 11%, slag consumption increased 66%, and rutile consumption increased 31%. The pigments end use accounted for 97% of total consumption. *(See table 7.)*

Ferrotitanium.—Reported consumption of titanium in the form of ferrotitanium and scrap in steel and other alloys was nearly unchanged from the revised 1991 level.

Metal.—Net shipments of mill products increased by about 3%, and sponge production was withheld to avoid disclosing company proprietary data. Consumption of scrap for remelting increased by about 30% and supplied a calculated 51% of ingot feedstock. Casting shipments decreased by about 16%. Estimated U.S. mill product usage by application was as follows: commercial aerospace, 49%; military aerospace, 24%; and nonaerospace uses, 27%. Nonaerospace uses include those in the specialty chemical, pulp and paper, oil and gas, marine, and medical industries.

Pigment.—Apparent domestic consumption of TiO_2 pigments was about 1,000,000 tons, about 7% more than that in 1991. The paint, paper, and plastics industries were the largest consumers of pigment. *(See tables 8 and 9.)*

Stocks

The TiO_2 content of inventories of ilmenite and rutile decreased 3% and 29%, respectively. Overall TiO_2 content of concentrate stock decreased by about 2%. Stocks of TiO_2 pigments increased to 108,000 tons, a 50% increase from that of 1991. Pigment stocks held by producers would satisfy about 40 days of supply. *(See table 10.)*

Markets and Prices

Published prices of titanium concentrates, metal, and pigments decreased in 1992. Ilmenite and rutile concentrates fell. The average prices for rutile and ilmenite concentrates fell about 17% and 33%, respectively. The reported price range for titanium sponge was 16% lower than that in the previous year. Although the yearend price for anatase pigment was unchanged, the price for rutile pigment decreased by 6%. *(See table 11.)*

Foreign Trade

The Department of Commerce (DOC) determined not to revoke the antidumping findings on titanium sponge from the Baltic States and Republics of the former U.S.S.R. The DOC also has separated the 83.96% antidumping order from the former U.S.S.R. into 15 separate orders. *(See tables 12, 13, 14, and 15.)*

World Review

Capacity.—The capacity data in this report are for mines and benefication plants, sponge metal facilities, and TiO_2 pigment plants as of December 31, 1992. 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 operation, 3 shifts per day. Capacity figures are based on information obtained from the producing companies, from news items, and from USBM estimates.

Reserves.—U.S. reserves of ilmenite and 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 USBM has compiled a computerized file of worldwide mineral deposit data called the Minerals Availability System (MAS). The MAS Advanced Deposit Information Tracking System contains location and descriptive information on mineral occurrences, mines, and mineral processing operations worldwide. Most of the reserve and resource data found in this report were derived from MAS reports. A public access version containing nonproprietary information contained in the MAS data base is available on request.

Major titanium reserves in the United States are owned by Du Pont and RGC in Florida. Reserves in Australia are held mainly by RGC, Consolidated Rutile; Westralian Sands, and Cable Sands. Reserves at Allard Lake, Quebec, Canada, are held by QIT, 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. Kronos controls Titania, wner of the large hard-rock deposit at Tellnes, Norway. *(See tables 16, 17, and 18.)*

Australia.—RGC Mineral Sands Pty. Ltd. received approval from Australia's Northern Territory Minister of Energy and Mines to conduct exploration for mineral sands on the islands of Melville and Bathhurst, northern Australia. Two exploration licenses were granted for two separate areas measuring approximately 1,600 square kilometers each. Initial exploration was expected to begin within 3 to 6 years. Although RGC was designated as the mine operator, the project was to be a joint venture among the Tiwi Land Council, Tiwi Resources Pty. Ltd., and RGC.[3]

CRA Ltd.'s wholly owned subsidiary Wimmera Industrial Minerals (WIM) curtailed its exploration efforts of the WIM 150 deposit near Horsham, Victoria. Although promising mineral recoveries had been achieved at the pilot plant level, the company concluded the project was not economically viable. The WIM deposit was reported to have a measured resource of 25 million tons of minerals 10 to 15 meters thick covering an area of 40 square kilometers under 4 to 5 meters of overburden. The company planned to continue technical development of processing alternatives.[4]

Woodburn Mineral Sands, formerly Australmin Holdings, closed its operations at Newrybar, Australia. The company had an estimated production capacity of 12,000 tons per year for rutile and 10,000 tons per year for zircon.[5]

RGC reopened its Eneabba North Mine and temporarily closed its Eneabba South and West operations in Western Australia, north of Perth. The Eneabba North Mine was reported to be more cost efficient to operate and contain a higher ilmenite grade.[6]

Cable Sands Pty. Ltd. announced plans to proceed with its Jangardup mineral sands project in Western Australia. The new deposit was expected to produce 200,000 tons per year of ilmenite suitable for use by chloride pigment producers. Construction at the site was expected to begin in early 1993, and production was expected to commence in mid-1994.[7]

Canada.—New Pascalis Mines Ltd. and Tiomin Resources Inc. announced plans to merge the two companies under a new company called Tiomin Resources Inc. Tiomin held mineral exploration rights to a 208-square-kilometer heavy-mineral sands deposit at Natashquan, Quebec, and planned to conduct a feasibility study to determine if the deposit is economically viable.[8]

Czechoslovakia.—As part of a privatization effort by the Czechoslovakian Government, the majority interest in titanium pigment producer Precheza a.s. was scheduled to be sold. Formerly known as Prerovske Chemicke Zavody, Precheza produced pigment using sulfate-base technology and had an estimated capacity of 25,000 tons per year.[9]

India.—IREL proposed a joint venture with the Government of Kerala, India, to mine heavy minerals at Neendakara. The proposed area for development was a 4-by 22-kilometer strip near Kollam on the Arabian Sea and was reported to contain ilmenite, monazite, rutile, zircon, and sillimanite.[10]

In Kerala, Cochin Minerals and Rutile Ltd. were constructing a synthetic rutile facility. The facility was scheduled to be commissioned in mid-1993 and was expected to produce up to 10,000 tons of synthetic rutile annually. When completed, the plant would produce a ferric chloride byproduct and about 1,000 tons of titanium dioxide suitable for pigment applications.[11]

Italy.—Tioxide Specialties Ltd. opened a 360-ton-per-year finishing plant at its Scarlino, Italy, facility. The new facility was designed to produce surface treated ultrafine titanium dioxide. With a particle size of about 60 nanometers, the ultrafine TiO_2 particles were transparent to visible light but blocked ultraviolet radiation. Output from the plant was expected to be used in a variety of

sunscreen applications.[12]

Malaysia.—Tioxide Group Ltd. commissioned a 50,000-ton-per-year sulfate-base TiO_2 pigment plant at Telok Kalong, Malaysia. The new facility was part of Tioxide's global strategy to support both chloride-base and sulfate-base technology.[13]

Mozambique.—Kenmare Resources was in the process of developing a heavy-mineral deposit in Mozambique. The ore body had been estimated by the company to be 167 million tons with a heavy-mineral content of 3.25%.[14]

Sierra Leone.—In the Bonthe District, Sierra Rutile shifted its rutile mining operations from its Pejabu deposit to its Lanti deposit. The Lanti deposit was reported to be a deeper and higher grade deposit than Pejabu. Sierra Rutile also was reported to have signed a loan agreement with the Commonwealth Development Corp. for improvements in equipment and infrastructure. If completed, these improvements would lead to enhanced mine capacity.[15]

South Africa, Republic of.—The Anglo American Corp. announced plans to proceed with the development of its Namakwa mineral sands deposit in the northwestern cape region of the Republic of South Africa. The project included the extraction of an ilmenite concentrate followed by smelting to produce high TiO_2 slag. The design of the smelting furnace was based on a plasma-arc technology. When completed, the furnace was expected to produce up to 195,000 tons per year of high TiO_2 slag and 120,000 tons of pig iron. In addition to ilmenite used for smelting, the deposit was expected to yield up to 140,000 tons of zircon and 38,000 tons of rutile. Production was anticipated to begin in 1994, and total ore reserves were reported to be 500 million tons.[16]

Spain.—Hitox Corp., Corpus Christi, TX, acquired a 96.6% interest in Fluid Minerals Espanola SA. Fluid Minerals operated a 2,500-ton-per-year pigment facility at Bunuel, Spain. The acquisition was expected to allow Hitox better access to European markets.[17]

United Kingdom.—SCM Chemicals completed construction of a hydrochloric acid recovery plant at its chloride-base TiO_2 pigment plant at its Stallingborough facility in the United Kingdom. The recovery process was designed to reduce the amount of metal oxide waste generated by the chloride process. The process used metal oxides to produce hydrochloric acid suitable for use by the steel pickling industry. In a separate project, SCM planned to develop and install equipment to recycle sulfuric acid on its sulfate-base TiO_2 plant at the Stallingborough facility.[18] *(See table 19.)*

Current Research

The USBM is active in several programs to lower the cost of producing titanium alloys. The current research is focused on developing a continuous process to produce titanium powder or granules suitable for powder metallurgy applications. Work also is being conducted to improve the existing technologies for batch-type reduction, arc melting, and fabrication of titanium alloys.

OUTLOOK

Demand for titanium feedstocks is anticipated to grow in line with demand for TiO_2 pigments. However, because of recent increases in global capacity, a surplus of available supply also is expected for the next few years. Increased environmental concerns by the titanium industry are expected to cause tighter specifications for titanium concentrates and a higher reliance on titanium slags and synthetic rutile.

As it has in the past, demand for TiO_2 pigments should follow economic growth. The current overcapacity in the pigment also may continue for the coming 2 to 3 years. A competitive market and increased environmental pressures are likely to force the closure of less profitable producers. Within 5 to 10 years, increased demand is expected to drive the need for new capacity expansions. Growth in global demand over the next 5 years is anticipated to be about 3% per year.

Reduced demand for titanium alloys by the commercial and military aerospace industry is likely to continue, although a turnaround in the world economy could help improve market conditions. No new titanium sponge capacity is expected for several years, and demand will probably remain near current levels for the next 2 years. The tremendous metal capacity of the former U.S.S.R. is becoming an influential factor in world markets. However, the long-term outlook for the titanium metal industry is largely dependent on the industry's ability is expand into nonaerospace markets.

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[2]Public Law 102-484; October 23, 1992. Title XXXIII—National Defense Stockpile Subtitle A—Modernization Program.

[3]Mining Journal. AMC in Tiwi Venture. V. 318 No. 8164, Mar. 13, 1992, p. 180.

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[6]———. RGC Mineral Sands Shuffle. No. 294, Mar. 1992, p. 8.

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[16]Mintek Bulletin. Namakwa Sands Gets Green Light. No. 56. Dec. 1992, pp. 1-2.

[17]Industrial Minerals. Hitox Pigment in Europe. No. 295, Apr. 1992, p. 13.

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TABLE 1
U.S. IMPORT DUTIES

Tariff item	HTS No.	Most favored nation (MFN) Jan. 1, 1992	Non-MFN Jan. 1, 1992
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 2
SALIENT TITANIUM STATISTICS

(Metric tons unless otherwise specified)

	1988	1989	1990	1991	1992
United States:					
Ilmenite concentrate:					
Imports for consumption[1]	394,170	411,751	345,907	213,886	294,585
Consumption	679,008	659,584	688,948	738,089	684,882
Titanium slag:					
Imports for consumption	434,641	386,146	373,623	408,302	537,118
Consumption	300,013	414,830	390,537	341,379	539,323
Rutile concentrate, natural and synthetic:					
Imports for consumption	231,124	264,895	274,605	240,120	317,399
Consumption	352,356	366,143	369,454	368,643	460,960
Sponge metal:					
Production	22,270	25,225	24,679	13,366	W
Imports for consumption	1,364	903	1,093	r612	684
Consumption	21,003	24,927	23,207	r13,594	14,165
Price, Dec. 31, per pound	$4.25-$4.75	$4.80-$5.30	$4.50-$5.00	$4.50-$5.00	$3.50-$4.00
Titanium dioxide pigment:					
Production	926,746	1,006,581	978,659	991,976	1,137,038
Imports for consumption	185,468	166,346	147,592	166,094	169,260
Consumption, apparent[2]	991,536	947,259	925,447	r935,829	999,930
Price, Dec. 31, cents per pound:					
Anatase	95.0	102.0	99.0	99.0	99.0
Rutile	97.0	105.0	100.0	99.0	92- 95
World: Production:					
Ilmenite concentrate[3]	r4,122,853	r4,353,115	r4,071,611	r3,411,295	e3,580,854
Rutile concentrate, natural[3]	r438,450	r459,331	r481,114	r457,685	e442,370
Titaniferous slag	1,725,000	1,765,000	r1,886,000	r1,509,000	e1,637,000

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.

[1]Includes consumption to produce synthetic rutile.

[2]Production plus imports minus exports plus stock decrease or minus stock increase.

[3]Excludes U.S. production data to avoid disclosing company proprietary data.

TABLE 3
U.S. TITANIUM METAL PRODUCTION CAPACITY IN 1992

Company	Ownership	Plant location	Yearend capacity (metric tons)	
			Sponge	Ingot[1]
Howmet Corp., Titanium Ingot Div.	Pechiney, France	Whitehall, MI	—	3,200
A. Johnson Metals Corp.	Axel Johnson Group, Stockholm, Sweden	Lionville, PA	—	[2]2,300
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%	Niles, OH	—	16,300
Teledyne Allvac	Teledyne Inc.	Monroe, NC	—	[3]4,500
Teledyne Wah Chang Albany	do.	Albany, OR	—	900
Titanium Hearth Technologies of America	A. Johnson Metals Corp.; Titanium Metals Corp. of America	Lionville, PA	—	[2]4,500
Titanium Metals Corp. of America	Tremont Corp.	Henderson, NV	12,700	15,900
Viking Metallurgical Corp.	Quanex Corp.	Verdi, NV	—	[2]1,900
Wyman-Gordon Co.	Self	Worcester, MA	—	2,300
Total			19,500	63,200

[1]Based on 7-day-per-week full production. Includes 52,300 tons vacuum-arc double/triple melt, of which triple melt generally ranged from 10% to 30%. The remaining 11,000 tons was single melt (electron-beam and plasma) capacity.
[2]Single melt only.
[3]Includes 2,300 tons of single melt capacity.

TABLE 4

COMPONENTS OF U.S. TITANIUM METAL SUPPLY AND DEMAND

(Metric tons)

Component	1988	1989	1990	1991	1992
Production:					
Sponge	22,270	25,225	24,679	13,366	W
Ingot	38,856	41,306	36,809	24,884	28,100
Mill products	27,837	29,946	25,619	22,263	19,054
Exports:[1]					
Sponge	80	136	331	418	178
Other unwrought	210	1,173	3,102	2,144	1,185
Scrap	5,989	5,474	5,487	4,567	2,770
Ingot, slab, sheet bar, etc.	2,083	2,702	2,371	1,700	1,455
Other wrought	2,679	NA	NA	NA	NA
Other articles of titanium	NA	3,857	4,526	3,301	2,431
Total[2]	11,041	13,342	15,816	12,130	8,019
Imports:[1]					
Sponge	1,364	903	1,093	r612	684
Scrap	4,235	5,308	3,037	2,668	6,257
Ingot and billet	237	190	162	25	241
Other unwrought	NA	119	213	175	128
Other wrought (mill products)	822	1,049	988	757	375
Other articles of titanium	NA	200	279	156	81
Total[2]	6,658	7,770	5,772	4,394	7,766
Stocks, yearend:					
Government: Sponge (total inventory)	33,413	33,413	33,413	33,413	33,413
Industry:					
Sponge	2,439	2,114	3,267	2,852	1,929
Scrap	8,596	8,028	8,535	7,905	8,891
Ingot	3,933	3,548	3,725	2,826	2,352
Other	8	7	3	8	W
Total industry[2]	14,977	13,697	15,530	13,591	13,172
Reported consumption:					
Sponge	21,003	24,927	23,207	r13,594	14,165
Scrap	18,058	17,596	14,973	11,381	14,828
Receipts:					
Home	NA	11,273	11,139	8,486	8,521
Purchased	NA	12,583	9,710	7,313	12,665
Ingot	35,556	31,396	35,320	24,238	23,944
Mill products (net shipments):	22,558	24,997	23,923	15,600	16,074
Forging and extrusion billet	10,694	11,742	10,729	7,454	7,629
Rod and bar	3,528	3,566	3,499	2,141	2,484
Other[3]	8,336	9,689	9,695	6,005	5,961
Castings (shipments)	473	485	482	608	510

rRevised. NA Not available. W Withheld to avoid disclosing company proprietary data.

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export categories for 1989, 1990, 1991, and 1992 are not necessarily comparable with 1988.

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

[3]Data for sheet and strip, plate, extrusions (other than tubing), pipe and tubing, and other have been combined to avoid disclosing company proprietary data.

TABLE 5

CAPACITIES OF U.S. TITANIUM DIOXIDE PIGMENT PLANTS ON DECEMBER 31, 1992[1]

Company	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	—	104,000
Kronos Inc.	Lake Charles, LA	—	80,000
SCM Chemicals Inc.	Ashtabula, OH	—	165,000
	Baltimore, MD	68,000	50,000
Total		122,000	1,197,000

[1]The table does not include Hitox Corp.'s Corpus Christi, TX, production capacity of about 13,600 tons per year of buff TiO_2 pigment that is produced by refining and fine grinding of synthetic rutile.

TABLE 6

COMPONENTS OF U.S. TITANIUM DIOXIDE PIGMENT SUPPLY AND DEMAND

(Metric tons unless otherwise specified)

Component	1989		1990		1991		1992	
	Gross weight	TiO_2 content	Gross weight	TiO_2 content	Gross weight	TiO_2 content	Gross weight	TiO_2 content
Production[1]	1,006,581	935,919	978,659	913,275	991,976	926,506	1,137,038	e1,059,982
Shipments:[2]								
Quantity	1,126,622	1,046,633	1,116,431	1,045,748	1,124,194	1,052,350	1,261,812	1,178,902
Value thousands	$2,352,390	$2,352,390	$2,404,282	$2,404,282	$2,381,906	$2,381,906	$2,574,927	$2,574,927
Exports	212,197	e193,311	202,288	e189,544	r211,854	r e197,872	270,422	e252,304
Imports for consumption	166,346	e154,669	147,592	e138,294	166,094	e155,464	169,260	e160,797
Stocks, yearend	62,205	e58,768	61,721	e57,597	72,108	e67,493	108,173	e102,764
Consumption, apparent[3]	947,259	e884,562	925,447	e863,196	r935,829	r e874,064	999,930	e932,970

eEstimated. rRevised.

[1]Excludes production of buff pigment.

[2]Includes interplant transfers.

[3]Production plus imports minus exports plus stock decrease or minus stock increase.

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

TABLE 7
U.S. CONSUMPTION OF TITANIUM CONCENTRATES

(Metric tons)

Year	Ilmenite[1]		Titanium slag		Rutile (natural and synthetic)[2]	
	Gross weight	TiO_2 content[e]	Gross weight	TiO_2 content[e]	Gross weight	TiO_2 content[e]
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	688,948	446,228	390,537	313,648	369,454	347,057
1991:						
Alloys and carbide	(3)	(3)	(4)	(4)	—	—
Pigments	737,414	476,145	341,379	273,976	315,742	286,741
Welding-rod coatings and fluxes	(3)	(3)	—	—	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
1992:						
Alloys and carbide	(3)	(3)	(4)	(4)	—	—
Pigments	683,972	425,876	539,323	455,768	426,366	405,875
Welding-rod coatings and fluxes	(3)	(3)	—	—	(3)	(3)
Miscellaneous[5]	909	647	(4)	(4)	34,603	32,553
Total	[6]684,882	426,523	539,323	455,768	460,969	438,428

[e]Estimated.
[1]Includes a mixed product containing rutile, leucoxene, and altered ilmenite.
[2]Includes synthetic rutile made in the United States.
[3]Included with "Miscellaneous" to avoid disclosing company proprietary data.
[4]Included with "Pigments" to avoid disclosing company proprietary data.
[5]Includes ceramics, chemicals, glass fibers, and titanium metal.
[6]Data do not add to total shown because of independent rounding.

TABLE 8
U.S. DISTRIBUTION OF DOMESTIC TITANIUM PIGMENT SHIPMENTS, TITANIUM DIOXIDE CONTENT, BY INDUSTRY

(Percentage)

Industry	1988	1989	1990	1991	1992
Ceramics	0.4	0.4	W	W	0.4
Coated fabrics and textiles	W	.4	0.2	W	.3
Floor coverings	1.2	1.1	1.0	W	1.0
Paint, varnish, lacquer	48.1	50.0	48.9	46.6	44.7
Paper	24.2	25.8	26.5	26.4	26.2
Plastics	17.0	16.3	16.6	16.8	17.5
Printing ink	1.7	.8	1.6	1.8	1.7
Roofing granules	.4	.3	.4	W	W
Rubber	1.7	1.4	1.5	1.8	1.8
Other	5.3	3.5	3.3	6.6	6.4
Total	100.0	100.0	100.0	100.0	100.0

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

TABLE 9
U.S. CONSUMPTION OF TITANIUM PRODUCTS[1] IN STEEL AND OTHER ALLOYS

(Metric tons)

	1988	1989	1990	1991	1992
Carbon steel	877	r1,538	1,530	1,479	1,579
Stainless and heat-resisting steel	2,742	2,647	2,469	1,927	1,756
Other alloy steel (includes HSLA)	249	149	r171	r171	270
Tool steel	W	W	W	W	W
Total steel[2]	3,868	r4,334	r4,170	r3,577	3,606
Cast irons	W	W	W	34	W
Superalloys	642	r747	836	688	523
Alloys, other than above	r869	873	973	665	738
Miscellaneous and unspecified	54	r70	r54	15	77
Total consumption[2]	r5,434	r6,023	r6,032	r4,979	4,943

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1]Includes ferrotitanium, titanium scrap, and other titanium additives.
[2]Data may not add to totals shown because of independent rounding.

TABLE 10
U.S. STOCKS OF TITANIUM CONCENTRATES AND PIGMENT, DECEMBER 31

(Metric tons)

	Gross weight	TiO_2 content
Ilmenite:[1]		
1990	341,891	196,645
1991	250,762	146,129
1992	245,766	141,313
Titanium slag:[1]		
1990	85,960	68,605
1991	88,079	72,280
1992	138,509	112,487
Rutile:[1]		
1990	171,085	161,026
1991	208,030	196,526
1992	148,983	140,224
Titanium pigment:[2]		
1990	61,721	e57,597
1991	72,108	e68,503
1992	108,173	e101,478

eEstimated.
[1]Consumer stocks.
[2]Bureau of the Census. Producers stocks only.

TABLE 11

PUBLISHED PRICES OF TITANIUM CONCENTRATES AND PRODUCTS[1]

		1991	1992
Concentrates:			
Ilmenite, f.o.b. Australian ports	per metric ton	$68.00-$76.00	$58.00-$62.00
Rutile, bagged, f.o.b. Australian ports	do.	515.00-545.00	380.00-414.00
Rutile, bulk, f.o.b. Australian ports	do.	537.00-552.00	345.00-387.00
Rutile, large lots, bulk, f.o.b. U.S. east coast	do.	606.00-650.00	510.00-520.00
Titanium slag, 80% TiO_2, Canada[e]	do.	280.00-305.00	264.00
Titanium slag, 85% TiO_2, Republic of South Africa[e]	do.	295.00-325.00	310.00
Metal:			
Sponge	per pound	4.50- 5.00	3.50- 4.00
Mill products:			
Bar	do.	11.50- 13.24	7.50- 9.00
Billet	do.	7.80- 9.59	6.00- 7.50
Plate	do.	12.80- 13.75	8.50- 9.50
Sheet	do.	9.60- 11.60	7.50- 8.00
Strip	do.	10.70- 12.57	NA
Ferrotitanium	do.	NA	1.40- 1.50
Scrap:			
Turnings, unprocessed	do.	.80- .90	.65- .80
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.	.99	.92- .95

[e]Estimated based on U.S. imports for consumption. NA Not available.
[1]Yearend.

Sources: American Metal Market, American Paint and Coatings Journal, Chemical Marketing Reporter, Industrial Minerals (London), Metal Bulletin, Metals Week, and industry contacts.

TABLE 12

U.S. EXPORTS OF TITANIUM PRODUCTS, BY CLASS

Class	1990		1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Metal:						
Sponge	331	$2,073	418	$2,604	178	$1,102
Scrap	5,487	22,443	4,568	10,706	2,770	7,201
Other unwrought						
Billet	969	17,890	513	8,087	509	9,652
Blooms and sheet bars	887	23,417	1,038	21,390	514	10,103
Ingot	514	7,426	149	2,437	432	5,828
Other	3,102	20,502	2,145	15,919	1,185	17,789
Wrought:						
Bars and rods	1,697	54,244	1,147	34,833	1,129	28,681
Other	2,829	94,046	2,153	78,227	1,302	52,346
Total	15,816	[1]242,040	12,131	174,203	8,019	132,702
Ores and concentrates	18,765	7,398	26,912	10,167	34,665	10,566
Pigment and oxides:						
Titanium dioxide pigments	153,361	327,009	r168,362	r276,229	231,734	362,606
Titanium oxides	48,927	107,551	43,492	76,683	38,688	57,766
Total	202,288	434,560	r211,854	r352,912	270,422	420,372

rRevised.

[1]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF TITANIUM CONCENTRATES, BY COUNTRY

Concentrate and country	1990		1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ilmenite:						
Australia	326,186	$22,206	213,886	$24,071	264,459	$17,133
India	19	36	—	—	220	194
Sierra Leone	19,701	720	—	—	21,397	2,415
South Africa, Republic of	—	—	—	—	8,505	578
Other	—	—	—	—	5	93
Total[1]	345,907	22,962	213,886	24,071	294,585	20,414
Titanium slag:						
Canada	99,510	22,434	73,346	19,084	67,642	17,848
Gabon	—	—	—	—	24,844	6,508
Norway	5,581	1,271	5,257	1,200	18,780	4,173
South Africa, Republic of	268,531	65,745	329,691	85,500	421,467	126,025
Other	—	—	8	8	4,386	1,388
Total[1]	373,623	89,450	408,302	105,792	537,118	155,943
Rutile, natural:						
Australia	120,686	68,885	57,388	33,170	76,728	34,676
Canada	379	22	113	60	33	53
Netherlands	1,943	1,493	—	—	—	—
Sierra Leone	52,776	24,467	76,368	33,545	76,155	33,606
South Africa, Republic of	42,234	16,626	40,460	19,773	28,156	12,783
Other	9	133	538	130	58	104
Total[1]	218,026	111,627	174,866	86,678	181,130	81,222
Rutile, synthetic:						
Australia	52,578	13,632	59,091	31,564	125,831	44,028
Brazil	2	5	—	—	—	—
India	4,000	2,400	—	—	—	—
Malaysia	—	—	6,163	3,390	10,438	4,508
Total[1]	56,579	16,037	65,254	34,953	136,269	48,536
Titaniferous iron ore:[2]						
Canada	28,818	2,169	27,012	1,593	32,381	1,564

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

[2]Includes 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 14

U.S. IMPORTS FOR CONSUMPTION OF TITANIUM PIGMENTS, BY COUNTRY

(Metric tons)

Country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
80% or more titanium dioxide:				
Australia	172	$269	120	$190
Belgium	6,776	11,200	4,308	7,015
Canada	37,554	63,115	38,815	65,669
China	1,757	1,793	1,640	1,512
Finland	2,286	4,166	3,365	5,848
France	2,428	4,524	3,411	5,526
Germany	20,706	39,966	17,058	32,694
Japan	4,610	8,642	6,197	11,464
Mexico	13	3	—	—
Netherlands	206	336	54	82
Norway	4,939	8,352	6,061	10,392
Singapore	4,213	6,419	4,771	7,215
United Kingdom	239	596	2,148	3,716
Other	1,203	1,786	4,279	6,576
Total[1]	87,102	151,167	92,229	157,900
Other titanium dioxide:				
Belgium	170	276	352	624
Canada	4,834	10,129	4,536	8,387
France	15,997	25,419	10,314	15,577
Germany	1,724	6,078	1,796	6,717
Italy	2,505	4,187	605	1,149
South Africa, Republic of	226	366	5,013	7,363
Spain	6,064	8,900	10,465	16,514
United Kingdom	19,516	31,688	17,975	28,153
Other	1,480	2,598	2,029	4,204
Total[1]	52,516	89,641	53,085	88,690
Titanium oxide:				
Australia	1,021	1,681	36	55
Belgium	946	1,531	450	697
Canada	5,305	7,980	8,394	12,244
China	483	546	301	361
Finland	271	464	—	—
France	4,687	7,308	7,704	11,321
Germany	5,526	10,182	4,139	7,245
Japan	58	573	187	1,358
Mexico	40	59	40	60
Norway	1,110	1,869	970	1,633
United Kingdom	6,425	11,064	1,266	2,488
Yugoslavia	78	120	120	187
Other	527	1,105	338	608
Total[1]	26,477	44,482	23,946	38,254
Grand total[1]	166,094	285,290	169,260	284,843

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

Source: Bureau of the Census.

TABLE 15

U.S. IMPORTS FOR CONSUMPTION OF TITANIUM METAL, BY CLASS AND COUNTRY

Class and country	1990		1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Unwrought:						
Sponge:						
China	116	$842	94	$600	230	$1,411
Japan	934	9,057	357	3,484	321	2,907
United Kingdom	26	367	55	894	45	650
U.S.S.R.[1]	11	98	91	399	84	387
Other	r6	r35	r15	r74	4	9
Total[2]	1,093	10,398	612	5,451	684	5,363
Waste and scrap:						
Austria	72	402	—	—	—	—
Belgium	18	73	67	169	50	101
Canada	228	791	186	586	269	542
China	268	1,528	66	227	49	132
France	283	1,448	125	500	686	2,174
Georgia[3]	—	—	—	—	66	66
Germany	52	282	205	704	1,208	3,708
Japan	1,004	5,799	475	1,733	1,509	5,611
Russia[3]	—	—	—	—	189	420
Sweden	77	665	100	267	109	356
U.S.S.R.[1]	397	2,680	443	1,195	309	713
United Kingdom	521	3,230	815	2,694	1,451	4,591
Other	117	653	185	428	362	1,022
Total[2]	3,037	17,550	2,666	8,503	6,257	19,436
Ingot and billets:						
Japan	162	47	3	661	2	452
United Kingdom	—	—	20	424	239	1,609
Other	—	—	1	10	—	—
Total[2]	162	47	24	1,095	241	2,062
Powder:						
Israel	18	431	22	522	30	700
Other	2	95	12	175	20	185
Total[2]	20	526	34	697	50	886
Other:[4]						
Japan	24	519	3	121	—	—
Netherlands	1	2	18	203	—	—
Switzerland	—	—	36	407	7	24
United Kingdom	139	1,686	63	751	18	72
Other	29	152	21	79	53	395
Total	193	2,359	141	1,561	78	491
Wrought titanium:[5]						
Canada	755	17,802	391	9,337	148	3,641
France	17	548	41	515	8	655
Germany	20	379	60	1,115	18	841
Japan	352	9,858	317	8,350	201	4,757

See footnotes at end of table.

TABLE 15—Continued

U.S. IMPORTS FOR CONSUMPTION OF TITANIUM METAL, BY CLASS AND COUNTRY

Class and country	1990		1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Wrought titanium—Continued:[5]						
Sweden	6	$429	7	$431	19	$399
United Kingdom	95	5,173	68	2,799	44	1,631
Other	22	1,557	30	1,466	18	905
Total[2]	1,266	35,746	914	24,014	456	12,830

[r]Revised.
[1]Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.
[2]Data may not add to totals shown because of independent rounding.
[3]Formerly part of the U.S.S.R.; data were not reported separately until 1992.
[4]Includes blooms, sheet, bars, slabs, and other unwrought.
[5]Includes bars, castings, foil, pipes, plates, profiles, rods, sheet, strip, tubes, wire, and other.

Source: Bureau of the Census.

TABLE 16

U.S. TITANIUM RESERVES AND RESERVE BASE IN 1992

(Thousand metric tons of TiO_2 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

[1]The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves) and some of those that are currently subeconomic (subeconomic resources).
[2]Ilmenite except for the 9.8 million tons in Colorado perovskite.
[3]Rutile except for the 200,000 tons in Arkansas anatase.

TABLE 17

WORLD TITANIUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1992

[Thousand metric tons of TiO_2 content of concentrates, gross weight of sponge (over 99% Ti), and gross weight of pigment (average about 95% TiO_2)]

	Ilmenite	Rutile	Rutile, synthetic	Sponge metal	TiO_2 pigment		
					Sulfate[1]	Chloride[2]	Total
North America:							
Canada	[3]880	—	—	—	62	38	100
Mexico	—	—	—	—	—	90	90
United States	217	30	100	20	120	1,207	1,327
Total	1,097	30	100	20	182	1,335	1,517
South America: Brazil	83	[4]15	—	—	55	—	55
Europe:							
Belgium	—	—	—	—	40	40	80
Czech Republic	—	—	—	—	22	—	22
Finland	—	—	—	—	80	—	80
France	—	—	—	—	233	—	233
Germany	—	—	—	—	270	80	350
Italy	—	—	—	—	80	—	80
Netherlands	—	—	—	—	—	45	45
Norway	450	—	—	—	27	—	27
Poland	—	—	—	—	36	—	36
Spain	—	—	—	—	65	—	65
U.S.S.R.[5]	250	10	—	52	100	—	100
United Kingdom	—	—	—	5	115	195	310
Yugoslavia	—	—	—	—	28	—	28
Total	700	10	—	57	1,096	360	1,456
Africa:							
Sierra Leone	35	150	—	—	—	—	—
South Africa, Republic of	[6]850	94	—	—	35	—	35
Total	885	244	—	—	35	—	35
Asia:							
China	90	—	—	5	25	—	25
India	200	19	138	—	13	22	35
Japan	—	—	46	29	272	45	317
Korea, Republic of	—	—	—	—	18	—	18
Malaysia	275	—	96	—	50	—	50
Saudi Arabia	—	—	—	—	—	52	52
Singapore	—	—	—	—	—	42	42
Sri Lanka	80	13	—	—	—	—	—
Taiwan	—	—	—	—	10	—	10
Thailand	16	—	—	—	—	—	—
Total	661	32	280	34	388	161	549
Oceania: Australia	1,100	260	250	—	26	124	150
World total (may be rounded)	4,530	590	630	111	1,781	1,980	3,761

[1]Sulfate process.
[2]Chloride process.
[3]Contained in 80% TiO_2 slag made from ilmenite.
[4]Mainly anatase.
[5]As constituted before Dec. 31, 1991.
[6]Contained in 85% TiO_2 slag made from ilmenite.

Sources: Technical publications industry contacts; and U.S. Bureau of Mines estimates.

TABLE 18

WORLD TITANIUM RESERVES AND RESERVE BASE IN 1992

(Thousand metric tons of TiO_2 content)

	Reserves			Reserve base[1]		
	Ilmenite	Rutile and anatase[2]	Total	Ilmenite and perovskite[3]	Rutile and anatase[2]	Total
North America:						
Canada	27,000	—	27,000	73,000	—	73,000
United States	7,800	300	8,100	33,300	1,400	34,700
Total	34,800	300	35,100	106,300	1,400	107,700
South America:						
Brazil	1,600	66,000	67,600	1,600	86,000	87,600
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.[4]	5,900	2,500	8,400	13,000	2,500	15,500
Total	39,300	2,500	41,800	113,400	23,500	136,900
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	39,600	45,000	4,500	49,500
Total	39,300	5,700	45,000	64,700	6,600	71,300
Asia:						
China	30,000	—	30,000	41,000	—	41,000
India	31,000	4,400	35,400	31,000	4,400	35,400
Malaysia	—	—	—	1,000	—	1,000
Sri Lanka	3,600	800	4,400	3,800	800	4,600
Total	64,600	5,200	69,800	76,800	5,200	82,000
Oceania:						
Australia	24,000	5,300	29,300	66,000	42,000	108,000
World total (rounded)	204,000	85,000	289,000	429,000	165,000	594,000

[1]The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

[2]Mainly anatase in Brazil; rutile elsewhere.

[3]Ilmenite except for 9.8 million tons in Colorado perovskite.

[4]As constituted before Dec. 31, 1991.

TABLE 19

TITANIUM: WORLD PRODUCTION OF CONCENTRATES (ILMENITE, LEUCOXENE, RUTILE, AND TITANIFEROUS SLAG), BY COUNTRY[1]

(Metric tons)

Concentrate type and country	1988	1989	1990	1991	1992e
Ilmenite and leucoxene:[2]					
Australia:					
Ilmenite	1,610,175	1,696,000	1,602,000	1,363,000	1,500,000
Leucoxene	11,742	18,000	19,000	18,000	18,000
Brazil[3]	142,167	r144,212	114,117	r69,064	70,000
China e	150,000	150,000	150,000	150,000	150,000
India	r229,693	r240,656	r e280,000	r311,537	300,000
Malaysia	486,305	r533,657	530,237	336,347	4337,744
Norway	898,035	929,830	814,488	r625,000	4718,000
Portugal	59	111	43	e40	30
Sierra Leone	42,118	62,310	54,639	r60,371	60,000
Sri Lanka	74,305	101,354	66,413	60,861	60,000
Thailand	18,254	16,985	10,674	r17,075	17,080
U.S.S.R. e [5]	460,000	460,000	430,000	400,000	350,000
United States	W	W	W	W	W
Total	r4,122,853	r4,353,115	r4,071,611	r3,411,295	3,580,854
Rutile:					
Australia	230,637	243,000	245,000	201,000	200,000
Brazil	1,514	r2,613	1,814	r1,094	1,100
India	r9,584	r9,931	r e11,000	r13,635	10,000
Sierra Leone	r126,332	r128,198	144,284	154,800	145,000
South Africa, Republic of e	55,000	60,000	464,056	75,000	75,000
Sri Lanka	5,255	5,589	5,460	3,080	3,200
Thailand	128	—	—	76	70
U.S.S.R. e [5]	10,000	10,000	9,500	9,000	8,000
United States	W	W	W	W	W
Total	r438,450	r459,331	r481,114	r457,685	442,370
Titaniferous slag:[6]					
Canada e [7]	1,025,000	1,040,000	r1,046,000	r701,000	753,000
South Africa, Republic of e [8]	700,000	725,000	840,000	r808,000	884,000
Total	1,725,000	1,765,000	r1,886,000	r1,509,000	1,637,000

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]Table includes data available through July 22, 1993.

[2]Excludes production of unbeneficiated anatase ore.

[3]Ilmenite 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.

[4]Reported figure.

[5]Dissolved in Dec. 1991. All production in the U.S.S.R. came from Russia and Ukraine; however, information is inadequate to formulate reliable estimates for individual countries.

[6]Slag is also produced in Norway but is not included under "Titaniferous slag" to avoid duplicative reporting. Beginning in 1988, about 25% of Norway's ilmenite production was used to produce slag containing 75% TiO_2.

[7]Contains 80% TiO_2.

[8]Contains 85% TiO_2.

TUNGSTEN

By Gerald R. Smith

Mr. Smith, a physical scientist with 29 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 reported domestic consumption of tungsten in primary end-use categories decreased by about 13% in 1992 compared with that of 1991. Demand generally declined in the cemented carbide end-use sectors that included the combined cutting tool, mining tool, oil drilling equipment, and wear-resistant component industries. Demand for mill products made from metal powder also declined in 1992. Counter to these declines was an increase in the use of ferrotungsten in steels, particularly in the tool steel sector.

The average price for wolframite concentrates (January-March 1992) and the average combined price for wolframite and scheelite concentrates (April-December 1992) remained essentially unchanged compared with the average price for wolframite concentrates in 1991, according to quotations published in Metal Bulletin. However, the average price for these concentrates progressively decreased during the year, declining by nearly 27% in December 1992 compared with that of January 1992. Prices for ammonium paratungstate (APT) on the world market decreased steadily during 1992, consistent with the declining prices for concentrates. The already low tungsten mining activity in the United States further declined in 1992, as the continuing low prices for concentrate and the growing use of intermediate tungsten materials made mining uneconomical and impractical. This condition continued in spite of the imposition of the 151% antidumping tariff on imports of ore concentrates from China that began in July 1991 and continued through all of 1992. Although the tariff provided protection from imports of concentrate, no new constraints were instituted during 1992 on imports of downstream tungsten products from China, following the expiration of the Orderly Marketing Agreement, in late 1991, that had limited imports of APT and tungstic acid.

A summary of the important U.S. and international statistics for 1992 and the previous 4 years are shown in table 1. *(See table 1.)*

DOMESTIC DATA COVERAGE

Domestic production data for tungsten are developed by the U.S. Bureau of Mines by means of two separate, voluntary surveys. These surveys are "Tungsten Ore and Concentrate" and "Tungsten Concentrate and Tungsten Products." Of the 24 mining and 16 processing operations to which survey requests were sent, response was received from 63% and 100%, respectively, of those operations surveyed, 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 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 (WO_3). In the United States, sales are based on the short ton unit of WO_3. This is equivalent to 1% of a short ton, or 20 pounds of WO_3, 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 also are 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

In early March 1992, the U.S. Department of Defense (DOD) submitted an Annual Materials Plan to the U.S. Congress that included recommendations for significant changes in the National Defense Stockpile (NDS) goals for tungsten. Under a newly recommended 3-month war scenario with a 1-year mobilization period, the DOD had proposed that a goal of 6,285 metric tons of contained tungsten be established for the tungsten materials in the stockpile. As an alternative, the DOD also proposed that the tungsten goal be decreased to 14,050 tons from the existing level of 37,336 tons, should the current 3-year war scenario continue to be the preferred approach for determining the stockpile goals. To begin accomplishing the proposed reduction in the tungsten goal,

an initial 5-year disposal plan was recommended, during which 9,979 tons of stockpile-grade tungsten was to be sold. About 93% of the tungsten held in the stockpile is in the form of ore concentrates.

Although the initial fiscal year 1993 Defense Authorization Bill prepared by the U.S. Senate contained language consistent with DOD's recommendation to reduce the tungsten in the stockpile according to the 3-month war scenario, the final bill contained no such language. In the final Senate bill, passed on September 18, 1992, tungsten, along with five other materials, was removed from the Senate's disposal list following results of a Government Accounting Office review placing these materials in a "high-risk" category because of the uncertainty of their supply from other countries. As a result of the Senate's action, no further disposals of tungsten from the NDS were authorized in the final fiscal year 1993 Defense Authorization Bill passed by the U.S. Congress and signed by the President in October 1992. According to a DOD spokesperson, however, although no tungsten was authorized for sale in fiscal year 1992 and none was included for disposal in the fiscal year 1993 authorization bill, the matter of future tungsten disposals would undergo further review as part of DOD's preparation of subsequent Defense Stockpile Annual Materials Plans.

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 DOD 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 DOD 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 DOD in 1992 contained a recommendation that the quantity of tungsten in the NDS be gradually reduced to about 38% of its present level. DOD's efforts to generally reduce the levels of many metals and materials in the stockpile, in part, reflected a revised assessment of the U.S. defense needs in the world's changing political and military structure. The proposed new levels were intended to prepare the United States in the event of a relatively short, small-scale war rather than a longer term global war.

Issues

During 1992, China continued to be the principal supplier of tungsten products to the world market. Declining prices for concentrates and intermediate materials continued to make it increasingly more difficult for the market economy producers to operate economically. Although efforts were introduced by China to place more adequate controls on its production, distribution, and pricing procedures, there was no evidence of any positive effects on the market by yearend 1992, as a result of these efforts. Most tungsten mines in the United States remained closed or were operated at reduced capacity during the year, in spite of the imposition of a 151% tariff on imports of ore concentrates from China that began in July 1991 and continued through all of 1992. Although the 151% tariff provided significant protection from imports of concentrate, no protection existed against imports of downstream tungsten products, as a result of the expiration of the Orderly Marketing Agreement in October 1991, limiting imports of APT and tungstic acid, and the failure to institute any new constraints on imports of downstream tungsten products from China during 1992. Discussions continued between U.S. Government and industry officials throughout 1992 regarding the possibility of instituting trade restrictions on all downstream products through tungsten carbide powder imported from China, but little progress was made toward implementing any such measures.

As a result of the 151% antidumping tariff on ore concentrates, the shift to importing the downstream intermediate materials, including APT, tungsten oxide, and sodium tungstate, from China continued throughout 1992. Declining prices for these intermediate materials relative to the price for ore concentrate effectively decreased the demand for the ore concentrates provided to the world market by other producers. This additional factor further contributed to the increasing inability of these producers to remain in business during 1992.

Production

The already low tungsten mining activity in the United States further declined in 1992 as the continuing low prices for concentrate and the growing use of intermediate tungsten materials made mining uneconomical and impractical. Recent statistical trends in domestic mine shipments and their corresponding values are shown in figures 1 and 2, respectively. Actual mine shipment data have been withheld since 1986 to avoid disclosing the company proprietary data for the one or two mines that were in operation since that time. Producers of tungsten concentrate in 1992 were Curtis Tungsten Inc. at its Andrew Mine, Upland, CA, and U.S. Tungsten Corp., a division of Strategic Minerals Corp., at its Pine Creek Mine, Bishop, CA. Major processors of tungsten materials in 1992 were Buffalo Tungsten

Inc., Depew, NY; General Electric Co., Euclid, OH; GTE Products Corp., Towanda, PA; Kennametal Inc., Latrobe, PA, and Fallon, NV; Teledyne Firth Sterling, LaVergne, TN; and Teledyne Wah Chang Huntsville, Huntsville, AL. Net production statistics for tungsten metal powders, carbides, and chemicals are shown in table 2. *(See table 2 and figures 1 and 2.)*

Curtis Tungsten Inc. operated its Andrew Tungsten Mine near Los Angeles, CA, intermittently during 1992. Adverse weather conditions again affected production at the mine. The mine was closed for nearly a quarter of the year because of heavy rains and flooding, just as it had been closed for nearly 5 months in 1991 because of a severe drought.

U.S. Tungsten Corp., Bishop, CA, continued as the only other company producing tungsten concentrate. As with its mine production, operations at its APT conversion facility were limited because of the low prices existing in the tungsten market.

GTE Corp., Stamford, CT, reported in August 1992 that it had reached an agreement to sell part of its lamp and lighting business to Osram, a Siemans AG company based in Munich, Germany, and part to Sylvania Lighting International B.V., an international consortium. Osram will purchase GTE's North American lighting business while the consortium will acquire GTE's international lighting business. Affected by the sale will be all of GTE's electrical products group, including GTE Products Corp., Towanda, PA, a tungsten processor and producer of a variety of tungsten materials and end-use items. The transaction, which needed the approval from the European Merger Commission, the U.S. Federal Trade Commission, and the U.S. Department of Justice, was expected to be completed in early 1993. According to a GTE spokesperson, it was anticipated that no jobs would be lost as a result of this transaction.

GTE Corp. further announced in late December 1992 that it had reached a definitive agreement on the sale of its GTE Valenite cemented carbide division, Troy, MI, to Cincinnati Milacron Inc., Cincinnati, OH. The Valenite sale also was expected to be completed in early 1993. When completed, Valenite will become a wholly owned subsidiary of Cincinnati Milacron, with current Valenite employees expected to remain as employees of the subsidiary. According to a Milacron spokesperson, Valenite's cemented carbide cutting and wear-resistant components business offered an excellent fit with Milacron's precision grinding wheel and metalworking fluids production business. It also would complement Milacron's machine tool equipment operations and products.

Consumption and Uses

Total reported domestic consumption of tungsten in primary end-use categories (table 3) decreased by about 13% in 1992 compared with that of 1991. Demand generally declined in the cemented carbide end-use sectors that included the combined cutting tool, mining tool, oil drilling equipment, and wear-resistant component industries. Demand for mill products made from metal powder also declined in 1992. Counter to these declines was an increase in the use of ferrotungsten in steels, particularly in the tool steel sector. *(See table 3.)*

Overall weakness in the U.S. economy continued to be the single most important factor influencing the decline in demand for tungsten products during 1992. Weaknesses remained in the major industrial sectors of auto, aerospace, construction, and mining where a significant quantity of tungsten is consumed as cemented carbide components. An increase was observed in the demand for cemented carbide components in the oil drilling industry during the last half of 1992. After the steady decline in the number of oil drilling rigs in the United States, from 1,179 following the war in the Persian Gulf to a low of 596 in mid-June 1992, the number of rigs gradually increased to a high of 935 by yearend 1992, according to figures reported by the International Association of Drilling Contractors and Baker Hughes Inc.

Markets and Prices

Effective April 1, 1992, Metal Bulletin (London) combined the scheelite and wolframite quotations to represent one tungsten ore concentrate price spread. This change was prompted by the significantly decreased trading in scheelite. The higher scheelite quotation was traditionally representative of transactions in artificial, low-molybdenum scheelite produced at the King Island Mine in Australia, and the lower quotation was based upon sales of gravity-separated scheelite. With the closure of the King Island Mine in late 1990, there was an eventual near exhaustion of the artificial-type scheelite on the world market. Coupled with the nominal trading in other forms of scheelite in recent years, the new tungsten ore concentrate price spread, accordingly, was more representative of the wolframite sales transactions than of the scheelite transactions.

The average price for wolframite concentrates (January-March 1992) and the new average combined price for wolframite and scheelite concentrates (April-December 1992) (table 4) remained essentially unchanged compared with the average price for wolframite concentrates in 1991, according to quotations published in Metal Bulletin. However, the average price for these concentrates progressively decreased during the year, declining by nearly 27% in December 1992 compared with that of January 1992. *(See table 4.)*

Prices for APT on the world market decreased steadily during 1992, consistent with the declining prices for concentrates. According to quotations in Metals Week, the average price for APT on the U.S. market, duty-paid and delivered to processing plants, decreased by 20% from an average of $73.30 per metric ton unit (mtu) tungsten oxide in January to an average of $58.42 per mtu by yearend. Similarly, the price of APT on the European market, duty-free and including the cost of insurance and freight delivered to Rotterdam, decreased by 25%, from $62.50 per mtu to $47 per mtu. Quotations for Chinese No. 1 Grade APT

in Hong Kong declined by 40% during the year from an average price of $66 per mtu to an average of $39.50 per mtu.

The price of tungsten metal powder decreased by about 2% in 1992 to $21.87 per kilogram of contained tungsten compared with $22.30 per kilogram in 1991, based upon the average value of imported powder reported by the Bureau of the Census. On this basis, the price of tungsten carbide powder increased by about 5% in 1992 to $24.81 per kilogram of contained tungsten compared with $23.61 per kilogram in 1991.

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 5 through 13. Import tariff rates for the various materials are shown in table 14. *(See tables 5 through 14.)*

Total U.S. imports of tungsten materials decreased by 57% in 1992 compared with those of 1991. China continued to be the dominant supplier, providing about 28% of all imported tungsten materials. China's share of the total quantity of tungsten materials imported by the United States was down about 18 percentage points compared with that of 1991. The total quantity of tungsten materials imported from China decreased from 7,103 metric tons of contained tungsten in 1991 to 1,829 metric tons in 1992. Of the total tungsten imports from China, the percentages imported as the concentrate and as the intermediate products (APT, tungsten oxide, and sodium tungstate) were 1% and 74%, respectively, in 1992, compared with 45% and 44%, respectively, in 1991. The virtual elimination of imports of concentrates from China in 1992 resulted from the continued imposition of the 151% antidumping tariff on Chinese concentrates that began in July 1991. Major suppliers of concentrates to the United States in 1992 included Bolivia (27%), Peru (25%), Portugal (23%), and Burma (9%).

World Review

Capacity.—Rated capacity for mines and mills as of December 31, 1992, was approximately 48,000 tons of contained tungsten. 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 declined by about 9% in 1992 compared with that of 1991. Most of this decline was attributed to lower capacity in China, resulting from the apparent closure of several smaller, inefficient mines following the discontinuation of Government subsidies to tungsten mines during the last quarter of 1992.

Austria.—At yearend 1992, Wolfram Bergbau and Huttengesellschaft, operator of the Mittersill Tungsten Mine, Mittersill, Austria, reported plans to place the mine on care-and-maintenance status in early 1993. The concentrate production portion of the company's integrated operation for making tungsten powder was said to have become uneconomical in light of the existence of low-priced tungsten intermediate materials on the world market. The company did not reveal how it planned to acquire material to continue its metal powder production operation once the mine was closed. Average annual production of concentrate at the Mittersill Mine since 1987 was about 1,300 tons of contained tungsten.

Annual concentrate production and consumption statistics for the world are shown in tables 15 and 16, respectively. *(See tables 15 and 16.)*

Bolivia.—Representatives from the Bolivian mining industry reported in September 1992 that they would be forced to close many of their remaining tungsten mines unless the world market for concentrates improved significantly or additional financing was obtained. A primary reason given for the possible closures was the declining demand for concentrates resulting from the increased use of alternate, low-priced intermediate tungsten materials from China. Affected by the closures would be the medium and small miners and the cooperatives. Corporación Minera de Bolivia, the state mining corporation, ceased production of tungsten concentrates in 1986. Total Bolivian production of concentrates was about 1,100 tons of contained tungsten in 1992, representing about 3.5% of the estimated world production.

Canada.—In November 1992, Canada Tungsten Mining Corp. Ltd., Vancouver, British Columbia, took an almost complete writedown of the company's leasing interest in the APT production facility in Fort Madison, IA. This cost reduction move also included the sale of the remaining nominal interest in the facility to a subsidiary of AMAX, Inc., Greenwich, CT, which owns a 57% share in Canada Tungsten. In the event that tungsten market factors improve, such that the Fort Madison plant can be reopened, Canada Tungsten will have the option of repurchasing the leasing interest for a nominal amount over an extended period of time. Production of APT was suspended at the Fort Madison plant in March 1990 in what was described at that time as an inventory control measure. Subsequently, the company continued to supply its customers with APT and other upgraded products from its inventories until early 1992.

China.—Representatives of China National Nonferrous Metals Import and Export Corp. (CNIEC) revealed in late 1992 that Government subsidies to

tungsten mines officially had been discontinued. This action, part of the market-oriented reforms urged by the State Council, was expected to force the closure of some of the less efficient operations unable to compete as self-dependent, individual enterprises. The move by the State Council appeared to be a continuation of the policy that began in early 1991. In that policy, the Council announced plans to significantly reduce concentrate production as well as to limit the number of ammonium paratungstate and tungsten oxide production facilities. The opinion of some industry observers was that this new Chinese policy and related actions was prompted by the realization that they were not receiving an appropriate economic return for the large quantities of tungsten material being exported. Although the preceding Chinese actions were considered as positive signs toward eventually achieving a more balanced supply-demand condition in the tungsten market, significant additional time obviously was necessary to assess their affect on the market.

In early 1992, CNIEC and China National Minerals and Metals Import and Export Corp. (Minmetals) initiated plans to form a joint venture to control the exports of tungsten materials. The Beijing-based company was positioned to fall under the supervision of the Ministry of Foreign Economics and Trade (MOFERT) and was designed to help control tungsten supplies through elimination of the competition for sales between Minmetals and CNIEC. By yearend, the joint venture reportedly received the additional support of the State Council, in a further step toward implementation. Although the joint venture appeared to be in direct contrast to the decentralization process and market-oriented reforms that were being carried out by the State Council, it, nevertheless, seemed to gain acceptance as a meaningful measure toward exercising control over China's tungsten products. It was anticipated that, when the venture was implemented, it would include export controls over not only concentrates but also downstream materials.

European Community (EC).—Imports of tungsten concentrate, tungstic acid and oxide, and tungsten carbide powder and fused tungsten carbide from China remained subject to significant duties during 1992. Alternative minimum price standards also were continued for the specific exporters, CNIEC and Minmetals. Although there were reports that the present import control measures were ineffective, prompting special discussions with Chinese trade officials, there were no indications, by yearend, that EC officials planned further review of the existing legislation controlling imports of Chinese tungsten materials.

International Tungsten Industry Association (ITIA).—In conjunction with the International Molybdenum Association, the ITIA held a conference entitled "Alloy Steels and Specialty Alloys 1992." The November meeting, held in Dusseldorf, Germany, included papers detailing developments in the use of tungsten in high-performance nickel alloys, specialty steels for the chemical processing industry, ordnance, tool steels, and high-speed steels. Another paper presented information on tungsten supply, demand, application, and outlook. The outlook portion of this discussion emphasized present complexities and uncertainties with respect to producer stock levels, governmental restructuring in consuming countries, and economic recovery rates in market economy countries. These conditions effectively clouded the forecasts for the market. As a result, both pessimistic and optimistic scenarios were presented that had tungsten concentrate prices ranging from a low of $60 per mtu to a high of $100 per mtu by the year 2002.

In early 1992, the ITIA announced plans for its next international symposium. Responding to a proposal by the CNIEC, the site selected for the 6th International Tungsten Symposium was Guangzhou, China, from November 2-4, 1993. The ITIA planned to organize the symposium in conjunction with the Nonferrous Metals Society of China and the China Tungsten Industry Association, acting as cosponsors.

Korea, Republic of.—Korea Tungsten Mining Co. Ltd. (KTMC) discontinued concentrate production at its Sangdong Mine in Kwang-Do Province, Republic of Korea, at the end of May 1992. According to comments from a company spokesperson, the operation reportedly was closed because of significant competition from China, as well as lower demand and depressed prices for concentrates on the world market. KTMC planned to continue to process concentrates supplied from imports and inventories to meet existing demand for its tungsten products. The Sangdong Mine will remain on care-and-maintenance status while the negative market factors exist. KTMC had been progressively reducing its production of concentrates since 1984, eventually halting sales to the open market in 1988. Production in 1991 was only about one-third that of the previous peak production levels of approximately 2,700 tons of contained tungsten.

Russia.—Effective June 17, 1992, the Russian Federation (Russia) officially received most-favored-nation status in its trade relations with the United States. As a result, the U.S. import tariffs on tungsten materials from Russia were decreased by 66% for ore concentrates and an average of 80% for other tungsten materials. Throughout the year, increasing interest in such imports was shown by both traders and consumers. The materials of interest included ore concentrate, metal powder, ferrotungsten, APT, oxide, and unwrought bar and rod.

United Kingdom.—Murex Ltd., Rainham, United Kingdom, closed its Sheffield, United Kingdom, APT plant at the beginning of 1992 after a compulsory purchase of the facility was made by the Sheffield Development Corp. to acquire land needed for road construction purposes. Even before this forced closure, however, Murex had decreased its APT production to well below plant capacity and was relying mostly on the

free market as its source of APT. According to a company representative, there was no commercial benefit for it in purchasing concentrate and converting it in-house to APT. Using the purchased APT as its starting material, Murex continued to produce various sizes of tungsten metal powder and tungsten carbide powder, as well as grade cemented carbide powders and cast tungsten carbide at its Rainham, United Kingdom, facility. By yearend, however, there were reports that Murex would cease production at its Rainham facility as a result of the adverse business climate.

United Nations Conference on Trade and Development (UNCTAD).—Through its standing committee on commodities, UNCTAD officially approved a new tungsten committee at a meeting held in October 1992. The newly formed tungsten committee, entitled the Intergovernmental Group of Experts on Tungsten (IGE), replaced the Committee on Tungsten (COT), which had acted as the intergovernmental tungsten discussion and working group under UNCTAD from December 1964 through February 1992. The IGE planned to continue the efforts of the COT. Under the terms of reference for the COT, opportunities were provided for international consultations regarding trade in tungsten, for promotion of improvements in statistics, for a study of developments in the tungsten industry, and for access to the account for funding developmental activities within the Common Fund under UNCTAD.

The IGE convened its first session in Geneva, Switzerland, on December 7-11, 1992. 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. A pessimistic picture of the current situation and short-term outlook for the tungsten market was presented. Weak demand, caused by a slow growth in the world economy, an abundant oversupply of stocks, and correspondingly lower prices, generally described the present tungsten market. Certain structural changes occurring in the market also were contributing to its present profile. The changes included an increasing use of obsolete scrap to meet existing demand, continuing governmental restructuring in Eastern Europe and the Commonwealth of Independent States (CIS), and a growing reliance on the use of intermediate tungsten products in favor of the traditional ore concentrates.

The need to improve transparency in the UNCTAD statistics was again expressed during this meeting. After a review of and correction of the country statistics provided to UNCTAD by the various delegations, the representatives of these delegations generally stressed the fact that the continuing absence of significant country data was preventing any appreciable advances in achieving data transparency. The delegates again sought data withheld by China, but none of these data were supplied. Verification of the accuracy of the Chinese data now being carried as estimates by UNCTAD also was unattainable, although an extended intragroup debate was conducted on this subject. Delegates also sought additional data from the Russian Federation and further suggested that data from the individual members of the CIS would be extremely useful. As had been stated in the 1991 meeting of the COT, the delegates from the Russian Federation expressed the hope that, in the future, it would be possible to gather such data and present it for inclusion in the UNCTAD statistics.

The issue of the need for greater cooperation toward achieving market stabilization was revived as the Chinese delegation expressed its support for further discussion on this subject. Most other delegations asserted that the idea of market stabilization had been determined to be outmoded. Furthermore, according to most delegates, pursuit of market stabilization was inconsistent with what they deemed should be the principal focus of the group. According to the work program of the Committee on Commodities, emphasis should be placed on means to improve market transparency, including the accumulation, dissemination, and analysis of statistics, and market intervention should not be a goal of the group.

For consideration by the IGE at its first meeting were four project proposals submitted for funding under UNCTAD's Common Fund for Commodities. The fund supports developmental activities within the individual commodities embraced by UNCTAD. Three of the proposals had been submitted by the Chinese delegation and one by the Secretary General of the ITIA, representing ITIA's members. After considering the report of the committee that had reviewed these proposals, the IGE decided to request the Secretary General of UNCTAD to submit for funding, on its behalf, one of the Chinese proposals, as well as the ITIA proposal. The proposals were entitled "Development of the Rare Earth Doped Cemented Carbide and its Mechanism Research" and "Health and Environmental Effects Testing of Tungsten Materials," respectively. The IGE's recommendation for financing of these proposals was approved on a technical and market basis, provided that no written statement to the contrary, with explanation, was received from any member of the IGE by the Secretary General of UNCTAD by February 11, 1993.

A provisional agenda for the second session of the IGE was adopted. Essentially, the IGE agreed in the agenda that its future activities should include enhancing market transparency; improving the collection and dissemination of statistics; reviewing the current market situation, short-term outlook, and medium- to long-term perspectives; and considering project proposals for sponsoring under UNCTAD's Common Fund for Commodities. In addition, the discussion of cooperation toward achieving market stabilization will remain as an agenda item. It further was agreed that the participation of industry advisors in the meetings should be encouraged and that the duration of the next meeting be shortened to 3 days from the current 5 days.

Current Research

Scientists from Rutgers University and Procedyne Corp., New Brunswick, NJ, reported the scale-up of a new process for preparing ultrafine-grained tungsten carbide powders at their Nanodyne Inc. facility in New Brunswick. The process, which utilizes a series of proven scalable technologies, is capable of producing particles that are orders of magnitude smaller than the approximately 1-micrometer size currently achievable using mechanical milling processes. The demand for submicrometer tungsten carbide powder continues to increase in response to the need for cutting and wear-resistant cemented carbide components with superior toughness, as measured by hardness, strength, and impact resistance.[1]

A new catalytic electrode containing tungsten carbide powder was shown to be an effective device for recombining hydrogen and oxygen gas released during operation of a lead-acid battery. According to the Bulgarian Academy of Science researchers who developed and patented the electrode, it provides a more economical means of rendering such batteries suitable for sealing, that is, requiring no maintenance, than existing methods.[2] In another research effort offering promise for expanded use of tungsten, certain tungsten and tungsten-copper alloys have been included among select materials of construction able to meet the stringent thermal, electrochemical, and wear-resistance requirements in the channel portion of a coal-fired magnetohydrodynamics (MHD) electric power generation system. In this MHD process, an extreme environment is created as an electrically conductive plasma is accelerated through the channel at supersonic velocity and under high-temperature and high-pressure conditions. Laboratory tests, at the present time, have yielded sufficient advancements in the MHD technology so that these materials can be evaluated in large-scale components prototypical of coal-fired powerplant hardware. Adoption of the MHD method by the electric utility industry is still contingent upon the long-term durability of these materials in the MHD channel.[3]

Results of additional studies on the recycling of tungsten were reported in 1992. In one of these research efforts, heavy-metal alloy machine turnings containing 90% tungsten were converted to a directly reusable heavy-metal alloy powder.[4] The process utilized physical pulverizing and sieving techniques combined with air oxidation and hydrogen reduction steps. In another recycling study, an electrolytic method was described for recovering cemented tungsten carbide scrap.[5] It was shown that the cobalt binder in the cemented carbide could be selectively dissolved anodically at high efficiency, leaving an uncontaminated tungsten carbide product.

The proceedings of an international conference, held in Arlington, VA, in November 1992, reported up-to-date research and development information on tungsten and tungsten alloys.[6] The conference, sponsored by the Metal Powder Industries Federation, Princeton, NJ, included approximately 70 oral and poster presentations outlining the most recent advances in the processing and application of tungsten, its alloys, and its composites. A number of papers revealed potential new methods and offered clearer understandings for improving the ballistic behavior of tungsten heavy-metal alloys.

Details on the development of a tungsten-free, energy-saving light bulb were revealed in mid-1992 by two California research groups.[7] The bulb, known as the E-Lamp, was reported to consume about one-fourth of the electrical energy of a conventional incandescent bulb and to last up to 25 times longer. A magnetic coil in the bulb emits a high-frequency radio signal that excites mercury vapor, which, in turn, strikes a phosphorescent coating on the inside of the bulb, emitting visible light.

Several advancements in thermal spray tungsten carbide-cobalt coatings technology were presented in the proceedings of an international conference, sponsored by the American Society for Materials-International.[8] Spray techniques discussed in the various papers on carbide coatings included plasma and vacuum plasma, high-velocity-oxy-fuel, and detonation gun. Properties such as microstructure, phase structure, porosity, microstructure, abrasion wear resistance, wear rate, homogeneity, hardness, and bonding strength of the coatings were evaluated. Spraying variables considered included spraying power and distance; coating composition and cooling rate; rate of powder injection in the plasma system; and gas and powder temperature, velocity, and pressure in the high-velocity system. Coatings were formed on substrates such as unalloyed steels, stainless steels, rolling mill rolls, and mandrels for precision forging machines.

OUTLOOK

Based upon apparent consumption data accumulated during the first quarter of 1993, the total annual demand for tungsten materials in the United States in 1993 was estimated to be about 7,000 tons of contained tungsten. This would represent a decline in apparent consumption of approximately 5% compared with that of the revised figure of 7,420 tons for 1992. The economic recovery rate is expected to be slow in 1993, continuing to suppress the demand for cutting and wear-resistant components integrally associated with the metalworking, machining, construction, transportation, mining, and oil and gas drilling industries. According to industry reports, although the short-term outlook for metal cutting tools, wear parts, and drilling components is not particularly bright, a low growth rate is, nonetheless, expected through the remainder of this decade. Demand in the lighting, electrical, and electronic sectors is expected to continue, although there could be some erosion of this demand in view of recent breakthroughs in the development of tungsten-free light bulbs. In addition to the effect of economic factors, any growth in tungsten demand will continue to be dampened 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 a more efficient use of tungsten.

Supplies of tungsten concentrate and intermediate materials for U.S. consumption are expected to be sufficient for the remainder of the decade, in spite of the fact that production of concentrates at most domestic tungsten mines continues to be uneconomical. However, in as much as the present production, pricing, and distribution policies of the major supplier, China, appear to be in a state of flux, future supplies from this source are uncertain. Any future curtailment of the flow of tungsten materials from China would likely be accompanied by the entrance of more producers into the market, many of whom have been forced to close or reduce production as a result of the poor world economic conditions. In addition, there is an ever increasing availability of tungsten materials on the market from the CIS.

[1]Scientific American. Fine Grain Nanophase Materials Move Out of the Lab. V. 267, No. 4, 1992, pp. 114-115.

[2]JEC Battery Newsletter. Tungsten Carbide Electrodes for Lead-Acid Batteries. No. 4, July-Aug. 1992, pp. 23-24.

[3]Farrar, L. C., and J. A. Shields, Jr. Tungsten and Tungsten-Copper for Coal-Fired MHD Power Generation. J. of Metals, v. 44, no. 8, Aug. 1992, pp. 30-35.

[4]Rao, K. Subba, A. Saibabu, B. Sarma, and N. Maitra. Studies of Recycling of Tungsten Alloy Scraps. Trans. of the Powder Metall. Association of India, v. 19, Dec. 1992, pp. 85-89.

[5]Srinivasan, G. N., A. Varadharaj, and S. Visvanthan. Electrolytic Recovery of Tungsten Carbide and Cobalt From Scraps/ Rejects of Cemented Tungsten Carbide. Trans. of the Powder Metall. Association of India, v. 19, Dec. 1992, pp. 90-96.

[6]Bose, A., and R. J. Dowding (eds.). Proceedings of the First International Conference on Tungsten and Tungsten Alloys. (Arlington, VA, Nov. 15-18, 1992.) Met. Powder Ind. Federation, Princeton, NJ, 1992, 562 pp.

[7]Burgess, J. Building a Better Light Bulb. Washington Post, no. 180, Section C, June 2, 1992, p. 1.

[8]American Society for Metals International. Proc. of the Conference on Thermal Spray: International Advances in Coatings Technology. (Orlando, FL, May 28-June 5, 1992.) ASMI Publ., 1992, 1,064 pp.

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Other Sources

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ITIA Newsletters.
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UNCTAD Reports. Meeting of Intergovernmental Group of Experts on Tungsten. December 1992.

TABLE 1
SALIENT TUNGSTEN STATISTICS

(Metric tons of tungsten content unless otherwise specified)

		1988	1989	1990	1991	1992
United States:						
Concentrate:						
Mine production		W	W	W	W	W
Mine shipments		W	W	W	W	W
Value	thousands	W	W	W	W	W
Consumption		7,832	7,725	[1]5,878	[1]5,309	4,313
Shipments from Government stocks		524	466	—	—	—
Exports		172	203	139	21	38
Imports for consumption		8,045	7,896	6,420	7,837	2,477
Stocks, December 31:						
Producer		21	10	16	26	44
Consumer		499	1,261	1,077	1,778	702
Ammonium paratungstate:						
Production		8,357	7,831	[1]6,142	[1]5,448	4,902
Consumption		8,014	8,493	8,787	[2]8,897	7,013
Stocks, December 31: Producer and consumer		1,016	915	896	578	333
Primary products:						
Production		8,068	8,749	[3]4,677	8,980	7,979
Consumption		8,298	7,990	8,496	7,981	6,906
Stocks, December 31:						
Producer		1,890	1,562	[4]1,459	[4]1,667	[4]1,508
Consumer		930	761	793	796	601
World: Concentrate:						
Production		r50,869	r51,442	r51,845	r41,880	e31,555
Consumption		r51,155	r52,912	r43,195	r41,690	e32,904

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.

[1]Excludes 2 months of "Withheld" data.

[2]Excludes 1 month of "Withheld" data.

[3]Includes only hydrogen-reduced metal powder and chemicals.

[4]Excludes tungsten carbide-cast and crystalline.

TABLE 2

NET PRODUCTION[1] AND STOCKS OF TUNGSTEN PRODUCTS IN THE UNITED STATES IN 1992

(Metric tons of tungsten content)

	Tungsten carbide powder			Chemicals	Total
	Hydrogen-reduced metal powder	Made from metal powder	Cast and crystalline		
Net production	4,237	3,737	W	5	7,979
Producer stocks, December 31, 1992	753	611	W	144	1,508
Producer stocks, December 31, 1991	918	550	W	199	1,667

W Withheld to avoid disclosing company proprietary data.
[1]Gross production less quantity used to make other products in table.

TABLE 3

CONSUMPTION AND STOCKS OF TUNGSTEN PRODUCTS IN THE UNITED STATES IN 1992, BY END USE

(Metric tons of tungsten content)

End use	Ferro-tungsten[1]	Tungsten metal powder	Tungsten carbide powder	Tungsten scrap[2]	Other tungsten materials[3]	Total[4]
Steel:						
Stainless and heat-resisting	52	—	—	W	—	52
Alloy	66	—	—	W	—	66
Tool	407	—	—	W	—	407
Superalloys	W	W	25	W	W	25
Alloys (excludes steels and superalloys):						
Cutting and wear-resistant materials	—	W	4,211	W	—	4,211
Other alloys[5]	W	7	W	W	—	7
Mill products made from metal powder	—	1,309	W	—	W	1,309
Chemical and ceramic uses	—	—	—	—	W	W
Miscellaneous and unspecified	46	131	8	442	201	828
Total[4]	572	1,446	[6]4,244	442	201	6,906
Consumer stocks, December 31, 1992	18	58	[6]450	59	16	601

W Withheld to avoid disclosing company proprietary data; included in "Miscellaneous and unspecified."
[1]Includes scheelite, natural and synthetic.
[2]Does not include that used in making primary tungsten products.
[3]Includes tungsten chemicals and others.
[4]Data may not add to totals shown because of independent rounding.
[5]Includes welding and hard-facing rods and materials and nonferrous alloys.
[6]Based on reported consumption plus information from secondary sources on companies not canvassed; includes estimates.

TABLE 4

MONTHLY PRICE QUOTATIONS OF TUNGSTEN CONCENTRATE IN 1992

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	Average	Low	High	Average	Average	Low	High	Average	Average
January	55.00	71.00	63.00	57.15	56.00	67.00	61.50	55.79	55.00	59.00	57.00	62.83
February	55.00	71.00	63.00	57.15	56.00	66.00	61.00	55.34	55.00	59.00	57.00	62.83
March	55.00	71.00	63.00	57.15	56.00	66.00	61.00	55.34	54.00	59.00	56.25	62.00
April	—	—	—	—	56.00	66.00	61.00	55.34	52.00	58.00	54.40	59.97
May	—	—	—	—	55.00	66.00	60.57	54.95	50.00	56.00	52.50	57.87
June	—	—	—	—	53.00	64.00	59.21	53.71	50.00	52.00	50.88	56.09
July	—	—	—	—	53.00	62.00	57.50	52.16	48.00	51.00	49.50	54.56
August	—	—	—	—	53.00	62.00	57.50	52.16	48.00	50.00	49.00	54.01
September	—	—	—	—	48.00	62.00	55.75	50.58	48.00	50.00	49.00	54.01
October	—	—	—	—	45.00	57.00	51.67	46.87	42.00	50.00	48.10	53.02
November	—	—	—	—	45.00	55.00	50.00	45.36	42.00	47.00	43.75	48.23
December	—	—	—	—	40.00	50.00	45.00	40.82	42.00	45.00	43.50	47.95

[1]Low 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 WO_3, which is an average of all semiweekly low and high prices, was $63.00 for 1992. The average equivalent price per short ton unit of WO_3 was $57.15 for 1992; combined with wolframite quotation beginning Apr. 1992, because of significant decline in trading of scheelite ore concentrates.

[2]Low 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 WO_3, which is an average of all semiweekly low and high prices, was $56.81 for 1992. The average equivalent price per short ton unit of WO_3 was $51.54 for 1992.

[3]Low 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 WO_3, which is an average of all weekly low and high prices, excluding duty, was $50.91 for 1992. The average equivalent price per metric ton unit of WO_3 was $56.11 for 1992.

TABLE 5
U.S. EXPORTS OF TUNGSTEN ORE AND CONCENTRATE, BY COUNTRY

Country	1991		1992	
	Tungsten content[1] (metric tons)	Value (thousands)	Tungsten content[2] (metric tons)	Value (thousands)
Australia	4	$34	—	—
Austria	1	10	3	$25
India	—	—	10	75
Israel	—	—	2	13
Mexico	2	17	1	9
Netherlands	—	—	21	157
Singapore	—	—	1	5
United Kingdom	13	103	—	—
Total[3]	21	165	38	284

[1]Calculated based upon an estimated value of $61 per metric ton unit WO_3.
[2]Calculated based upon an estimated value of $58 per metric ton unit WO_3.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 6
U.S. EXPORTS OF AMMONIUM PARATUNGSTATE, BY COUNTRY

Country	1991		1992	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Belgium	—	—	30	$410
Canada	(1)	(1)	—	—
Germany	—	—	34	183
Hungary	10	$73	—	—
Japan	535	2,856	406	2,760
Netherlands	2	12	—	—
Sweden	170	879	—	—
United Kingdom	54	294	—	—
Total[2]	770	4,114	470	3,354

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 7

U.S. EXPORTS OF TUNGSTEN CARBIDE POWDER, BY COUNTRY

Country	1991		1992	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Argentina	(1)	$15	1	$52
Australia	3	104	3	120
Austria	48	808	23	384
Belgium	57	1,007	27	516
Brazil	2	74	7	188
Canada	249	5,473	316	7,148
Chile	(1)	3	(1)	3
Colombia	(1)	5	—	—
Czechoslovakia	(1)	8	—	—
Denmark	19	234	40	413
Finland	3	77	1	74
France	21	389	11	282
Germany	123	3,328	98	3,059
India	—	—	(1)	21
Ireland	1	35	(1)	19
Israel	3	268	5	365
Italy	48	1,612	35	1,109
Japan	55	1,064	34	795
Korea, Republic of	1	44	(1)	9
Luxembourg	13	320	4	104
Malaysia	—	—	(1)	4
Mexico	5	268	3	159
Netherlands	8	323	6	177
Singapore	2	100	2	144
South Africa, Republic of	32	385	14	149
Spain	—	—	1	12
Sweden	16	206	20	215
Switzerland	15	741	9	405
Taiwan	5	144	7	227
Turkey	(1)	11	—	—
United Kingdom	107	1,820	43	1,816
Venezuela	1	17	3	107
Other	—	—	1	22
Total[2]	839	18,880	715	18,098

[1]Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 8

U.S. EXPORTS OF TUNGSTEN AND TUNGSTEN ALLOY POWDER, BY COUNTRY

Country	1991			1992		
	Gross weight (metric tons)	Tungsten content[1] (metric tons)	Value (thousands)	Gross weight (metric tons)	Tungsten content[1] (metric tons)	Value (thousands)
Australia	2	1	$25	12	10	$112
Austria	1	1	45	23	19	336
Belgium	4	3	140	11	9	171
Brazil	8	6	225	3	3	175
Canada	37	30	1,037	40	31	945
Finland	2	1	81	1	1	64
France	10	8	440	4	3	180
Germany	135	108	3,542	123	99	2,962
Hong Kong	(2)	(2)	27	1	1	44
Israel	234	188	2,819	78	62	1,045
Italy	19	15	1,051	4	3	145
Japan	12	10	428	10	8	164
Korea, Republic of	31	25	134	(2)	(2)	3
Mexico	8	7	166	3	3	89
Netherlands	193	155	1,445	18	14	181
Pakistan	44	35	581	—	—	—
Singapore	16	13	243	(2)	(2)	3
South Africa, Republic of	1	1	20	(2)	(2)	6
Spain	—	—	—	1	1	11
Sweden	2	1	72	(2)	(2)	17
Switzerland	1	1	55	2	1	106
Taiwan	32	26	381	26	21	623
Turkey	3	2	77	2	1	38
United Kingdom	62	49	825	33	26	905
Other	3	3	90	1	1	56
Total[3]	861	689	13,947	395	316	8,380

[1]Tungsten content estimated by multiplying gross weight by 0.80.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9

U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1991		1992	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Tungsten and tungsten alloy wire:				
Argentina	(1)	$5	(1)	$24
Belgium	1	102	1	47
Brazil	7	490	5	532
Canada	24	2,143	12	1,134
China	—	—	4	290
Colombia	1	261	—	—
France	3	383	2	265
Germany	1	308	1	206
Hong Kong	1	152	6	603
India	21	1,369	22	1,285
Italy	4	469	3	306
Japan	7	1,010	9	1,296
Korea, Republic of	5	352	5	279
Mexico	3	297	4	332
Netherlands	1	143	(1)	72
Poland	1	60	(1)	14
Switzerland	(1)	101	(1)	4
Taiwan	4	293	7	475
United Kingdom	2	423	1	241
Venezuela	—	—	(1)	6
Other	5	486	7	466
Total[2]	93	8,848	89	7,877
Unwrought tungsten and alloy in crude form, waste and scrap:				
Australia	5	96	8	130
Belgium	(1)	11	—	—
Canada	8	198	6	164
Chile	7	212	11	258
France	1	15	(1)	5
Germany	202	3,227	146	1,435
Israel	39	910	—	—
Japan	20	229	1	25
Korea, Republic of	(1)	13	—	—
Mexico	40	955	1	29
Spain	35	834	1	15
Sweden	6	123	2	22
Taiwan	7	198	—	—
United Kingdom	12	281	9	169
Other	8	202	2	48
Total[2]	391	7,503	186	2,302
Other tungsten metal:				
Australia	1	216	1	130
Austria	(1)	24	—	—

See footnotes at end of table.

TABLE 9—Continued

U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1991		1992	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Other tungsten metal—Continued:				
Belgium	—	—	(1)	$6
Brazil	2	$142	1	101
Canada	4	229	4	271
Colombia	1	164	(1)	69
France	1	188	(1)	66
Germany	4	331	4	250
Hong Kong	1	107	2	301
India	1	28	1	90
Ireland	55	9,004	66	3,635
Italy	1	149	10	949
Japan	13	3,063	8	2,937
Korea, Republic of	5	952	2	380
Mexico	8	725	9	814
Netherlands	1	274	1	199
Singapore	1	115	1	228
South Africa, Republic of	1	55	1	76
Spain	1	42	—	—
Sweden	2	181	1	80
Switzerland	1	67	(1)	67
Taiwan	11	895	6	498
Thailand	1	69	1	59
United Kingdom	13	888	21	1,797
Venezuela	(1)	22	(1)	11
Other	2	208	4	804
Total[2]	130	18,135	144	13,817
Ferrotungsten and ferrosilicon tungsten:				
Belgium	—	—	33	79
Canada	13	115	1	9
Mexico	19	45	19	45
Total[2]	32	161	53	132
Wrought tungsten:				
Australia	(1)	32	(1)	3
Canada	45	2,127	40	1,180
France	5	249	11	329
Germany	5	227	3	183
India	2	82	4	169
Israel	17	49	29	96
Italy	—	—	1	76
Japan	29	1,299	25	904
Mexico	10	119	30	185
Netherlands	—	—	10	77
Philippines	—	—	3	67
Singapore	1	46	2	58
Spain	3	136	8	193

See footnotes at end of table.

TABLE 9—Continued

U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1991		1992	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Wrought tungsten—Continued:				
United Kingdom	4	$210	14	$242
Venezuela	2	77	—	—
Other	4	273	6	289
Total[2]	127	4,926	185	4,052
Other tungsten compounds:[3]				
Argentina	2	23	(1)	3
Brazil	—	—	3	46
Canada	5	28	—	—
France	(1)	118	—	—
Israel	(1)	7	(1)	3
Japan	18	107	18	64
United Kingdom	23	182	5	36
Total[2]	49	464	27	152

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes only other tungstates.

Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF TUNGSTEN ORE AND CONCENTRATE, BY COUNTRY

Country	1991		1992	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Australia	216	$1,390	—	—
Belgium	4	27	—	—
Bolivia	1,170	6,735	658	$4,380
Brazil	79	485	36	200
Burma	305	2,067	232	1,390
Canada	—	—	33	130
China	3,185	16,031	15	130
France	14	87	(1)	3
Hong Kong	124	663	—	—
Japan	28	178	—	—
Kenya	12	50	—	—
Korea, Republic of	6	40	—	—
Malaysia	11	70	—	—
Mexico	148	953	65	369
Netherlands	22	131	24	79
Peru	1,052	5,417	613	3,897
Portugal	828	5,193	574	4,424
Rwanda	148	840	31	222
Singapore	13	73	—	—
South Africa, Republic of	52	218	—	—
Spain	33	301	—	—
Thailand	378	2,272	61	275
Uganda	8	48	46	168
United Kingdom	—	—	91	599
Total[2]	7,837	43,269	2,477	16,265

[1]Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM PARATUNGSTATE, BY COUNTRY

Country	1991		1992	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
China	667	$5,474	287	$1,858
Germany	24	165	64	547
Hong Kong	28	213	—	—
Korea, Republic of	48	435	16	107
Netherlands	26	154	12	135
Sweden	18	122	—	—
United Kingdom	30	193	—	—
Total[1]	842	6,756	378	2,647

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

Source: Bureau of the Census.

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF FERROTUNGSTEN, BY COUNTRY

Country	1991		1992	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Canada	12	$74	—	—
China	506	3,014	356	$1,826
Germany	—	—	1	9
Hong Kong	—	—	37	253
Mexico	8	40	19	100
United Kingdom	—	—	1	5
Total[1]	525	3,128	414	2,194

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

Source: Bureau of the Census.

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1991		1992	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Waste and scrap:				
Australia	7	$35	—	—
Austria	12	100	—	—
Belgium	39	278	13	$75
Brazil	40	184	41	201
Canada	19	139	16	99
China	205	1,687	39	263
France	50	349	16	80
Germany	714	4,427	323	1,683
Israel	55	260	147	755
Italy	—	—	3	16
Japan	454	2,401	310	1,763
Korea, Republic of	228	813	146	502
Mexico	14	96	13	56
Netherlands	178	865	58	449
Singapore	40	391	42	161
South Africa, Republic of	96	577	56	318
Sweden	19	98	—	—
Switzerland	—	—	7	58
United Kingdom	232	1,253	271	1,247
Other	35	187	4	11
Total[1]	2,435	14,141	1,503	7,737
Unwrought tungsten, except alloys, in lump, grains, and powders:				
Belgium	5	205	4	185
Canada	11	443	12	562
China	37	597	—	—
Germany	14	372	16	829
Japan	18	774	14	727
Korea, Republic of	—	—	3	83
South Africa, Rupublic of	—	—	15	60
Sweden	—	—	(2)	6
Uganda	—	—	27	61
United Kingdom	46	542	56	684
Other	1	9	1	40
Total[1]	132	2,943	148	3,237
Unwrought tungsten—ingots, shot, alloys and other:				
Austria	4	100	3	120
Belgium	30	160	61	321
China	4	91	9	219
Germany	1	12	—	—
Other	1	16	(2)	16
Total[1]	40	380	73	675

See footnotes at end of table.

TABLE 13—Continued

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1991		1992	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Wrought tungsten—wire, plate, sheet, strip, foil, and other:[3]				
Austria	15	$1,932	14	$1,759
Belgium	(2)	125	1	178
China	(2)	13	4	158
France	(2)	10	(2)	12
Germany	9	1,428	5	1,179
Israel	30	1,853	23	1,324
Japan	82	11,921	95	11,973
Korea, Republic of	1	3	—	—
Mexico	12	2,586	11	2,301
Netherlands	3	345	2	245
Russia[4]	—	—	(2)	10
U.S.S.R.[5]	26	281	—	—
United Kingdom	4	154	2	382
Other	4	592	8	803
Total[1]	184	21,244	163	20,325
Calcium tungstate:				
Australia	2	11	—	—
Germany	3	173	5	247
Spain	14	74	—	—
Total	19	258	5	247
Tungsten oxides:				
China	1,360	10,669	742	5,928
Germany	36	234	1	22
Hong Kong	182	1,139	13	90
Italy	(2)	11	—	—
Korea, Republic of	45	321	—	—
Netherlands	54	302	—	—
United Kingdom	(2)	2	—	—
Total[1]	1,678	12,678	757	6,040
Other metal-bearing materials in chief value of tungsten:				
China	15	227	1	50
Germany	—	—	(2)	7
Hong Kong	—	—	1	35
Sweden	29	55	—	—
Total[1]	44	283	3	92
Chlorides of tungsten:				
Germany	(2)	5	—	—
Sodium tungstate:				
China	1,074	7,780	324	1,917
France	(2)	34	—	—

See footnotes at end of table.

TABLE 13—Continued

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1991		1992	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Sodium tungstate—Continued:				
Germany	(2)	22	(2)	32
Hong Kong	192	1,130	10	67
Japan	(2)	19	1	130
Korea, Republic of	24	209	—	—
Total[1]	1,291	9,194	334	2,146
Tungsten carbide:				
Austria	1	11	39	538
Canada	19	335	12	448
China	50	826	52	866
France	—	—	10	791
Germany	154	2,652	105	2,127
Hong Kong	—	—	8	72
Japan	2	96	(2)	14
Korea, Republic of	41	723	37	621
Luxembourg	33	1,340	(2)	12
Mexico	—	—	24	1,039
Sweden	110	3,578	84	2,572
United Kingdom	9	232	12	485
Other	5	195	5	69
Total[1]	423	9,988	389	9,653

[1]Data may not add to totals shown because of independent rounding.
[2]Less than 1/2 unit.
[3]Quantity estimated from reported gross weight.
[4]Formerly part of U.S.S.R.; data were not reported separately until 1992.
[5]Dissolved in Dec. 1991.

Source: Bureau of the Census.

TABLE 14
U.S. IMPORT DUTIES ON TUNGSTEN

Item	HTS No.	Rate of duty effective Jan. 1, 1992	
		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 15

TUNGSTEN: WORLD CONCENTRATE PRODUCTION, BY COUNTRY[1]

(Metric tons of tungsten content)

Country	1988	1989	1990	1991	1992e
Argentina	13	20	r6	r10	10
Australia	r1,261	r1,371	1,086	237	200
Austria	1,235	1,517	1,378	r1,314	1,600
Bolivia	900	1,118	1,014	r1,065	1,100
Brazil	738	679	r316	r223	250
Burma	307	r233	r351	r275	375
China e	30,000	30,200	32,000	25,000	17,000
Czechoslovakia e	50	74	83	80	70
India	19	12	e13	e10	10
Japan	266	296	254	279	340
Kazakhstan[2]	—	—	—	—	500
Korea, North e	500	500	1,000	1,000	1,000
Korea, Republic of	2,029	1,701	1,361	r780	400
Mexico	206	170	183	r194	190
Mongolia e	1,000	1,000	500	300	260
New Zealand e	5	5	—	—	—
Peru	432	970	1,536	r1,229	600
Portugal	1,382	1,381	1,405	e1,400	1,200
Russia[2]	—	—	—	—	5,500
Rwanda	22	105	156	e175	175
Spain	80	58	49	e50	45
Sweden	420	e80	—	—	—
Tajikistan[2]	—	—	—	—	200
Thailand	651	603	290	r230	200
Turkey	125	r—	—	—	—
Uzbekistan[2]	—	—	—	—	300
Uganda e	4	4	4	4	4
U.S.S.R. e [3]	9,200	9,300	8,800	8,000	—
United Kingdom	3	28	42	9	10
United States	W	W	W	W	W
Zaire	20	16	r17	r e15	15
Zimbabwe e	1	1	1	1	1
Total	r50,869	r51,442	r51,845	r41,880	31,555

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]Table includes data available through May 20, 1993.

[2]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[3]Dissolved in Dec. 1991.

TABLE 16

TUNGSTEN: WORLD CONCENTRATE CONSUMPTION, BY COUNTRY[1]

(Metric tons of tungsten content)

Country	1988	1989	1990	1991	1992e
Argentina	e30	r50	r29	30	30
Australia e	50	50	50	r50	50
Austria e	2,100	1,800	1,800	1,600	1,500
Belgium-Luxembourg	e50	2	—	—	—
Brazil	753	r701	r363	r137	150
Bulgaria e	100	50	50	(2)	—
Canada	386	300	290	r255	3250
China 3 4	r15,000	r17,000	r17,000	r18,000	14,000
Czechoslovakia e	1,200	1,700	600	r400	300
France	34	—	—	—	—
Germany, Federal Republic of:					
Eastern states e	300	300	300	3300	3300
Western states 5	2,144	2,576	749	r e350	250
Hungary e	500	500	200	200	200
India	187	r212	r217	e200	200
Italy 5	e20	r e10	r e10	—	—
Japan	1,980	1,538	1,440	r1,276	900
Kazakhstan 6	—	—	—	—	3500
Korea, North 3	1,000	1,000	1,500	1,500	1,000
Korea, Republic of	1,580	2,000	1,950	r1,700	2,000
Mexico	9	e5	e5	—	—
Netherlands e	330	350	200	(2)	—
Poland 5	424	—	—	—	—
Russia 6	—	—	—	—	36,000
South Africa, Republic of	242	153	114	r161	150
Spain 5	e30	20	20	(2)	—
Sweden	324	320	380	r202	261
Tajikistan 6	—	—	—	—	3200
U.S.S.R. 3 7	14,500	14,500	10,000	10,000	—
United Kingdom e	50	50	50	20	50
United States	7,832	7,725	85,878	85,309	4,313
Uzbekistan 6	—	—	—	—	3300
Total	r51,155	r52,912	r43,195	r41,690	32,904

eEstimated. rRevised.

[1]Source, unless otherwise specified, is Tungsten Statistics, UNCTAD Committee on Tungsten.

[2]Revised to zero.

[3]Estimated by the U.S. Bureau of Mines.

[4]Combined internal consumption plus that which was processed to intermediate products and subsequently exported.

[5]Apparent consumption, production plus imports minus exports.

[6]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[7]Dissolved in Dec. 1991.

[8]Reported figure; excludes 2 months of "withheld" data.

FIGURE 1
QUANTITY OF TUNGSTEN CONCENTRATE SHIPPED
FROM MINES IN THE UNITED STATES

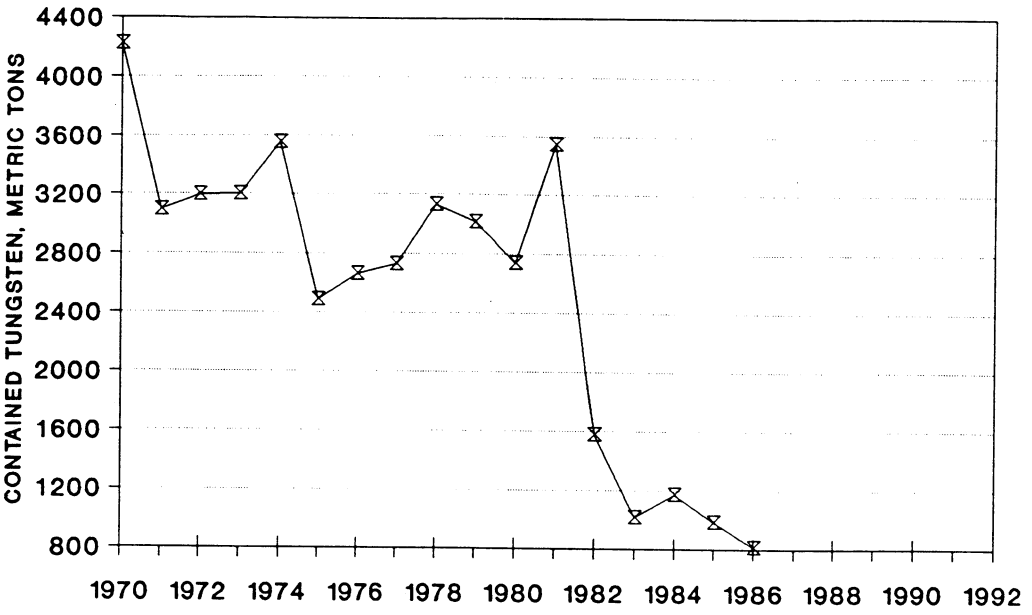
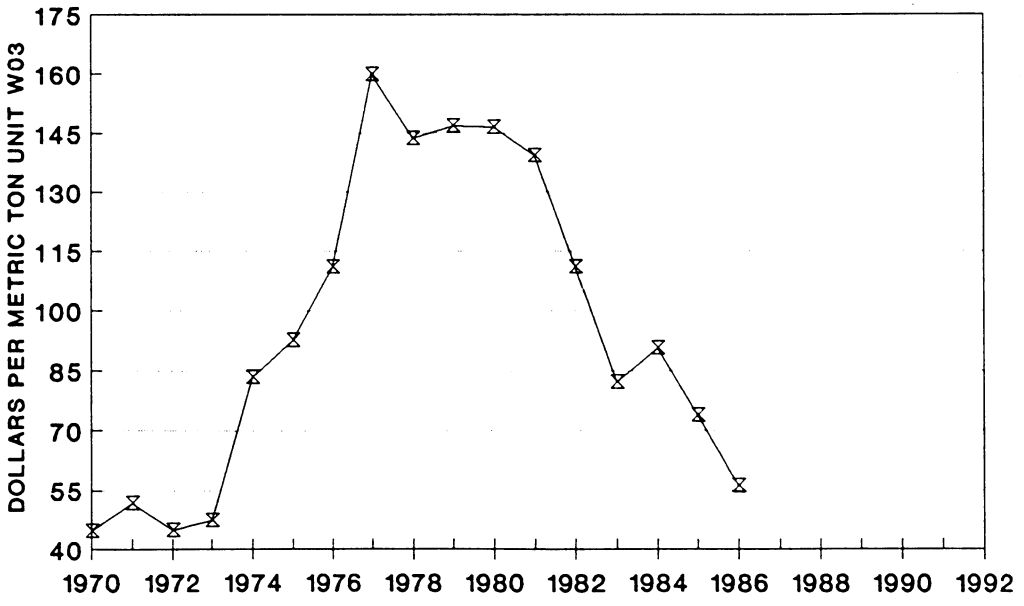


FIGURE 2
VALUE OF TUNGSTEN CONCENTRATE SHIPPED
FROM MINES IN THE UNITED STATES



VANADIUM

By Henry E. Hilliard

Mr. Hilliard, a physical scientist with more than 20 years of U.S. Bureau of Mines experience, has been the commodity specialist for vanadium since 1986. Domestic survey data were prepared by Alex Charleston, 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.

In 1992, steelmaking continued to account for more than 80% of domestic vanadium demand. Consumption showed a modest increase, from 3,300 tons in 1991 to 4,032 tons in 1992. Although overall imports of vanadium raw materials decreased when compared with 1991, imports of ash, residues, and spent catalysts increased. Total U.S. exports of vanadium materials increased from 1,560 tons in 1991 to about 1,700 tons in 1992.

The oversupply of vanadium that began in late 1989 persisted throughout 1992 despite reduced production by the world's largest producer, Highveld Steel & Vanadium Corp. of the Republic of South Africa. A result of the oversupply was continuously lower prices in 1992. Highveld's prices [lbs/vanadium pentoxide (V_2O_5)] were as follows: first quarter, $2.60; second quarter, $2.45; third quarter, $2.20; fourth quarter, $2.10; and 1st quarter 1993, $1.95. Spot or free market prices averaged 30 cents less than Highveld's price. The price of ferrovanadium (FeV) in Europe and Japan declined nearly 12% during 1992 to about $11 per kilogram. Low demand and depressed prices caused German FeV producer Gesellschaft für Electrometallurge GmbH (GfE) to halt production of V_2O_5 for conversion to FeV at its Nuremberg plant. Austrian producer Treibacher reduced FeV capacity by 30% in 1991, with the intention of returning to full production in January 1992 when market conditions were expected to improve. When market conditions did not improve, Treibacher decided to delay indefinitely the return to full production. Like some other metals, the international FeV market was under pressure from low-cost producers from former Eastern bloc countries, especially Czechoslovakia. Czech producer Mnišek Ferozliatinárske Zavody, Š. P., owns a V_2O_5 plant that supplies feed for its FeV operations. Mnišek, a state-run enterprise, was able to produce FeV at competitive prices by using in-house secondary aluminum in its aluminothermic reduction process. Its conversion costs were about 10% less than its Western competitors. U.S. FeV producers fared a little better than their European and Japanese counterparts. Prices were reasonably stable, and the U.S. Bureau of Mines reported a modest increase in demand.

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 1992, 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 3,800 tons. The estimated consumption of nonrespondents, derived using their past consumption relationships, trends, and data from nonsurvey sources, was about 200 tons. The consumption quantity of 4,073 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 former U.S.S.R. World vanadium production for 1988-92 is shown in table 14. The other 17% of the vanadium was recovered from other pertroliferous 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.

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 vanadium, usually as a vanadium-bearing slag. Its annual production of about 15,000 tons is approached only by production in Russia, formerly a part of the U.S.S.R. The bulk of Russian production was 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 the 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 of 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 hydroprocessing catalyst used in petroleum refining. Vanadium is recovered by first roasting the material in

a controlled atmosphere to solubilize the vanadium and other trace metals, for example, 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 before the precipitation of vanadium as ammonium metavanadate, which is then decomposed and fused to form V_2O_5 or used directly to make other vanadium chemicals. AMAX Metals Recovery Inc., Braithwaite, LA, uses a somewhat different process to recover cobalt, molybdenum, nickel, and vanadium from alumina-base spent catalysts. The process developed by AMAX in the early 1980's uses a two-stage caustic-leach process, one to solubilize vanadium and molybdenum, and the other to solubilize alumina. The AMAX process separates the spent catalysts into four products: molybdenum trisulfide, vanadium pentoxide, alumina trihydrate, and a nickel-cobalt concentrate.

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 with a milder reducing agent. 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 flue gases (Stretford Process). In only a few chemical applications could platinum and nickel replace vanadium catalyst.

Economic Factors

Prices.—The price of FeV declined by more than 12% over the previous 12 months and at the end of April FeV sold for about $11.70 per kilogram of vanadium content. The $11.70 price level equated to about $1.80 per pound for V_2O_5, but, with V_2O_5 selling for $2.10 or more, the $11.70 price represented a loss for most Western converters. Vanadium remained in oversupply, and demand has been in decline for almost 2 years. Sharply lower orders for vanadium alloy steels by the construction and automotive sectors was the driving force behind decreased demand. The depressed market caused some European converters, e.g., Treibacher of Austria and GfE of Germany, to shut down some FeV capacity. Treibacher reduced FeV capacity by 30% in October 1991 with the intention of returning to production in January 1992 when market conditions were expected to improve. The expected improvement in prices did not occur, and the shutdown was extended into the second quarter. GfE halted production of V_2O_5 for FeV at its plant in Nuremberg because the company could not make a satisfactory profit under current market conditions. The company planned to continue FeV production at a reduced rate contingent upon the purchase of V_2O_5 at a favorable price from an outside source. Meanwhile, modest increases in demand were reported in January through April. However, reported consumption in two of the largest steel end-use categories

(HSLA and tool steel) remained flat during that period. The outlook for domestic steel production in the third and fourth quarters includes a modest improvement over that of 1991, and a modest increase in demand for vanadium can be anticipated.

Tariffs.—U.S. import duties on selected vanadium items as of January 1, 1992, are listed in table 3. The tariff listing includes rates for both most-favored-nation (MFN) and non-MFN status.

Operating Factors

Environmental Issues.—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.

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; for example, 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 kg 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 kg of body weight 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 on other components in the alloy.

The adopted threshold limit value for time-weighted averages for airborne vanadium, including oxide and metal dusts of vanadium, is 0.5 milligram per cubic meter; the value for fumes of vanadium compounds is 0.05 milligram 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

The Russian Federation was awarded MFN status on June 17, 1992. Vanadium products affected are as follows: V_2O_5, 16% ad valorem MFN vs. 40% ad valorem non-MFN; vanadates, 11.2% MFN vs. 40% non-MFN; FeV, 4.2% MFN vs. 25% non-MFN; and aluminum-vanadium master alloys, free MFN vs. 10.4% non-MFN.

The depressed uranium-vanadium milling industry received more bad news in August when it was announced that the United States had agreed to buy bomb-grade uranium from Russia's dismantled nuclear warheads and convert it into fuel for commercial nuclear powerplants. Under a contract to be negotiated over the next year, Russia would sell U.S. companies 500 tons of highly enriched bomb-grade uranium from its nuclear weapons stockpile. The companies would dilute the enriched uranium to commercial-grade, then deliver it to customers who now buy from the U.S. Energy Department, which runs its own enrichment plants.

There was already a glut of uranium fuel in the commercial market, much of it attributed to the Russians, who have been exporting commercial-grade uranium for several years. At least in part because of Russian inroads, U.S. U_3O_8 production declined from about 17,000 tons in 1980 to less than 4,000 tons in 1990. At the same time, coproduction of V_2O_5 from uranium-vanadium ores declined from 5,000 tons to 1,200 tons. Meanwhile, imports from Russia and other Republics of the former U.S.S.R. rose from near zero to more than 2,700 tons per year. The Commerce Department made a preliminary finding that Russia was "dumping" uranium in the United States at unfairly low prices. That ruling did not apply to highly

enriched bomb-grade uranium because no such material had been sold commercially. A final ruling, due this autumn, could be amended to apply duties to bomb-grade material if it is intended for commercial use.

Russia and five other former Soviet Republics accepted strict quotas imposed by the U.S. Commerce Department that essentially excluded them from the U.S. market unless the price of uranium rises $3 or more above $10 per pound. At the end of 1991, when U.S. producers decided to take action, uranium imports from the former U.S.S.R. were about three million pounds per year. Under the new agreement, Russia, Kazakhstan, Ukraine, and Uzbekistan will be excluded from the U.S. market until the price of uranium rises to $13. At $13, they can ship 2.9 million pounds per year. The quota rises with price. At $21, the quotas are lifted. The quota does not apply to the 10 tons of weapons-grade uranium that Russia has agreed to sell to the Department of Energy.

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 Russia as the 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 National Defense Stockpile remained unchanged at the end of 1992.

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 U_3O_8 to decline from $40.75 per pound in early 1980 to less than $10 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. U.S. vanadium producers recovered 1,400 tons of vanadium oxides from petroleum residues in 1992.

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 ceramics and electronics (batteries).

Based on published U.S. Bureau of Mines statistics, consumption in 1992 increased by more than 20% over consumption in 1991. However, the actual increase was probably closer to 3% for this period. The apparent large increase was due to temporary data processing problems in compiling 1991 data, resulting in unusually low reporting of consumption in 1991.

Reported consumers' and producers' stocks of vanadium oxides, metal, alloys, and chemicals at yearend totaled 1,084 tons of contained vanadium; at yearend 1991, the number was 935 tons.

Foreign Trade

Overall U.S. export of vanadium products was up by about 16% in 1992. Canada 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 only 46 tons gross weight, less than one-third of 1991 exports. Exports of FeV totaled 326 tons gross weight, up from 178 tons in 1991.

Imports for consumption of downstream vanadium compounds increased slightly in 1992; imports of raw materials, slag, ash, etc., were up by about 5%. FeV imports totaled 767 tons gross weight, up from 524 tons in 1991. The imported FeV averaged 81% vanadium, with a mean customs value of $11.88/kg of contained vanadium, down from $12.79 in 1991. Canada was the leading source of FeV, with shipments of 365 tons, followed by Austria, 135 tons, and Belgium, 47 tons. Vanadium pentoxide imports totaled 207 tons of contained vanadium, up from 133 tons in 1991; the average declared value was $3.07 per pound of contained vanadium, down from $3.22 in 1991. Imports for consumption of vanadium-bearing slag totaled only about 143 tons of contained vanadium, all from the Republic of South Africa. An assortment of petroleum residues, spent catalyst, and fly ash totaling about 1,200 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, for example, 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 Russia were not available, but it is believed to be second only to the Republic of South Africa in vanadium production. Most Soviet trade was thought to be with other East European countries. However, significant quantities of Russian and Czech material began to find their way into the world market.

Capacity.—The data in table 12 are rated capacity for mills producing vanadium oxides as of December 31, 1992. 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 judgment 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 titano-magnetite 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 1991 and even lower prices in 1992. 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.

Czechoslovakia.—U.S. imports of ferrovanadium from Czechoslovakia were first reported by the Bureau of the Census in February 1992. Imports for that year totaled only 35 tons vanadium content with a customs value of $409,000. The material was produced by Mnišek Ferozliatinárske Zavody, Š. P., near Prague. Mnišek owns a V_2O_5 plant that supplied feed for its FeV operations. Vanadium-bearing iron slag feed for the V_2O_5 plant was imported from Russia. Vanadium pentoxide capacity was estimated at about 3.6 million pounds per year with the possibility of expansion if market conditions improve. Ferrovanadium capacity has been estimated at 1,500 tons per year and could be easily increased to 2,000 tons per year if market conditions should warrant higher production. Mnišek, a state-run enterprise, was able to produce FeV at competitive prices by using in-house secondary aluminum in its aluminothermic reduction process. Its conversion rate was 10% less than its Western competitors. Approximately 80% of its output was exported, with the remainder consumed by the domestic steel industry. In July the company appointed the Japanese trading house Nissho Iwai as the sole sales for its vanadium exports. During the second half of 1992 Nissho Iwai was expected to sell about 80% of Mnišek's ferrovanadium production to Western Europe, Japan, Southeast Asian countries, and the United States. The company also produced silicon metal at the Mnišek plant.

Netherlands.—Metrex was operating a plant in Heerlen, the Netherlands, that breaks down catalysts into their component parts, recovers the metals and alumina, and sells them to companies that can use them. Company officials stated that it was the only facility of its kind anywhere. However, the plant appeared to be very similar to the one operated by the Metals Recovery Corp. (AMAX-Cri-Met) in Braithwaite, LA, which has been in operation for more than 10 years.

The $15 million Metrex facility is located in the southeast corner of the Netherlands close to Belgium and German borders. It can process up to 7,000 tons per year of spent hydrodesulfurization catalysts, and capacity can be doubled without much difficulty if demand requires. Cobalt, molybdenum, and nickel contained in the original catalyst formulation, along with vanadium adsorbed during processing of the oil fractions, were recovered. Other products stemming from the operation were aluminum oxide, which goes to make ceramic and refractory bricks, and gypsum, from the flue gas.

The metal content of hydrodesulfurization catalysts in their original formulation typically is 2% to 3% by weight cobalt, about 4% nickel, and up to 8% molybdenum. About half the weight of the spent catalysts consists of alumina. The combined carbon, hydrocarbons, and sulfur account for about 35%. The remaining 15% represents cobalt, molybdenum, nickel, and vanadium sulfides. According to plant officials, the Metrex process results in a metals recovery efficiency that exceeds 90%.[13]

Venezuela.—Flexicoke is a byproduct petroleum residue from the noncatalytic thermal conversion process called flexicoking. The huge Lagoven refinery in Venezuela is perhaps the world's largest producer of flexicoke, producing about 300 tons per day. The material from Venezuela may contain as much as 16% V_2O_5 and has been imported by U.S. Vanadium Co. and others as a vanadium raw material. Researchers in Venezuela (INTEVEP S.A., Simon Bolivar University) recently reported new metallurgical applications of flexicoke. In one application, mixtures of iron ore and flexicoke were agglomerated in pellet form to study the reducibility of iron oxide by using flexicoke as a solid reducing agent and to evaluate the manufacture of self-reducing iron ore pellets as raw material for producing steels in induction furnaces of 5-kg capacity. It was determined that the self-reduced pellets could be used as raw material for manufacturing HSLA steels and steels of medium to high carbon content.[14] Another report evaluated flexicoke as a pyroconsolidating agent. For the evaluations, 3 tons of flexicoke per heat of liquid steel was cycled in electric arc furnaces of 150- to 200-ton capacity. The results indicated that the flexicoke can be used as a foaming slag promoter, but its high sulfur content (approx. 2.6%) restricted its use to those steels where maximum sulfur content is 0.015%.[15] For both applications flexicoke is a substitute for metallurgical coke.

OUTLOOK

Like many of its counterparts throughout the metals industry, the vanadium industry was struggling to recover from a recession that caused sales to fall and profits to plummet. And like so many of its counterparts, the industry was finding recovery a painfully slow process. Some traders were optimistic about 1993. They believed that the fundamentals for an economic recovery in the United States were in place. As a result, volume and prices for vanadium products should slowly strengthen in late 1993. There were, indeed, signs that the country was inching toward recovery. Employment was up in the manufacturing sector, productivity was improving, GDP was gaining, and interest rates moved noticeably lower.

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 1991. The constraints on demand have had a number of deleterious effects on the vanadium industry, including lower capacity utilization and prices. Some new vanadium capacity, the PMA 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 1992 was estimated to have been more than 21,000 tons, including about 1,400 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 85% 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. An excellent analysis of the chemical industry is published each year in the June issue of Chemical & Engineering News.

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TABLE 1
SALIENT VANADIUM STATISTICS

(Metric tons of contained vanadium unless otherwise specified)

		1988	1989	1990	1991	1992
United States:						
Production:						
Ore and concentrate:						
Recoverable vanadium[1]		W	W	W	W	W
Value	thousands	W	W	W	W	W
Vanadium oxide recovered from ore[2]		W	W	W	W	W
Vanadium recovered from petroleum residue[3]		2,950	2,389	2,308	2,250	e1,352
Consumption		4,834	4,646	4,081	r3,293	4,073
Exports:						
Ferrovanadium (gross weight)		571	493	334	178	326
Oxides and hydroxides[4]		—	1,080	976	r1,110	1,113
Vanadium pentoxide (anhydride)		620	1,171	819	r700	26
Other compounds (gross weight)		887	688	1,472	816	2,015
Imports (general):						
Ferrovanadium (gross weight)		134	650	323	r534	798
Oxides and hydroxides, other		—	106	271	r110	103
Ore, slag, ash, and residues		3,616	4,210	3,826	882	838
Vanadium pentoxide, anhydride		382	133	83	145	253
World: Production from ore, concentrate, slag[5]		31,731	32,667	30,606	r28,477	e19,700

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.

[1]Recoverable vanadium contained in uranium and vanadium ores and concentrates received at mills, plus vanadium recovered from ferrophosphorus derived from domestic phosphate rock.

[2]Produced directly from all domestic ores and ferrophosphorus slag; includes metavanadates.

[3]Includes vanadium recovered from fly ash, residues, and spent catalysts.

[4]May include ores and concentrates.

[5]Excludes U.S. production.

TABLE 2
CHEMICAL SPECIFICATIONS FOR COMMERCIAL FORMS OF FERROVANADIUM

Alloy	Composition, weight-percent (maxium unless otherwise specified)							
	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	0.50
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, 1992

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.
Ferrovanadium	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.

[1]Specific import classes only.

TABLE 4
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 5
U.S. CONSUMPTION AND CONSUMER STOCKS OF VANADIUM MATERIALS, BY TYPE

(Kilograms of contained vanadium)

Type	1991		1992	
	Consumption	Ending stocks	Consumption	Ending stocks
Ferrovanadium[1]	r2,895,946	r302,483	3,577,681	327,476
Oxide	16,459	12,723	14,716	7,584
Ammonium metavanadate	W	W	W	W
Other[2]	380,805	48,992	480,742	57,348
Total	r3,293,210	r364,198	4,073,139	392,408

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Includes other vanadium-iron-carbon alloys as well as vanadium oxides added directly to steel.
[2]Consists principally of vanadium-aluminum alloy and small quantities of other vanadium alloys and vanadium metal.

TABLE 6
U.S. CONSUMPTION OF VANADIUM IN 1992, BY END USE

(Kilograms of contained vanadium)

End use	Quantity
Steel:	
Carbon	1,261,638
Stainless and heat resisting	28,100
Full alloy	827,835
High-strength low-alloy	989,262
Tool	453,076
Unspecified	20,867
Total	3,580,778
Cast irons	16,680
Superalloys	12,610
Alloys (excluding steels and superalloys):	
Cutting and wear-resistant materials	219
Welding and alloy hard-facing rods and materials	5,960
Nonferrous alloys	W
Other alloys[1]	438,009
Chemical and ceramic uses:	
Catalysts	W
Other[2]	W
Miscellaneous and unspecified	18,883
Grand total	4,073,139

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1]Includes magnetic alloys.
[2]Includes pigments.

TABLE 7
PRODUCERS OF VANADIUM ALLOYS OR METAL IN THE UNITED STATES IN 1992

Producer	Plant location	Products[1]
Bear Metallurgical, Inc.	Butler, PA	FeV.
KB Alloys Inc.	Henderson, KY	VAl, ZrVAl.
Do.	Wenatchee, WA	Do.
Reading Alloys Inc.	Robesonia, PA	NiV, VAl, V.
Shieldalloy Metallurgical Corp.	Cambridge, OH	FeV, Ferovan.[2]
Do.	Newfield, NJ	FeV.
U.S. Vanadium Corp.	Niagara Falls, NY	FeV, VAl, Nitrovan.[2]
Teledyne Wah Chang Albany	Albany, OR	V, VAl.

[1]FeV, ferrovanadium; V, vanadium metal; VAl, vanadium-aluminum alloy; ZrVAl, zirconium-vanadium-aluminum-alloy; NiV, nickel-vanadium alloy.
[2]Registered trademarks for proprietary products.

TABLE 8

U.S. EXPORTS OF VANADIUM IN 1992, BY COUNTRY

Country	Ferrovanadium (gross weight)		Aluminum-vanadium master alloy[1] (gross weight)		Vanadium compounds (contained weight)			
					Pentoxide (anhydride)[2]		Other[3]	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Argentina	—	—	—	—	203	$3	—	—
Belgium	—	—	—	—	1,333	21	549,957	$2,619
Brazil	—	—	—	—	1,247	7	1,935	11
Canada	288,344	$3,237	207,593	$3,855	—	—	[4]92,184	764
Colombia	1,050	9	—	—	—	—	5,170	7
Chile	—	—	—	—	345	3	—	—
France	908	17	—	—	—	—	9,334	124
Germany	—	—	1,198	57	6,075	28	—	—
Grenada	—	—	89	3	—	—	—	—
Iceland	—	—	—	—	—	—	18,722	35
Israel	—	—	118	3	—	—	—	—
Italy	—	—	115	59	—	—	—	—
Japan	—	—	43,913	[4]709	—	—	137,849	236
Korea, Republic of	—	—	1,007	13	—	—	162,674	251
Malaysia	—	—	106	3	—	—	—	—
Mexico	23,919	330	282,183	4,646	1,525	12	85,101	269
Netherlands	—	—	—	—	696	7	—	—
Nigeria	—	—	—	—	2,327	22	—	—
Pakistan	—	—	—	—	1,843	37	—	—
Saudi Arabia	—	—	437	6	2,794	53	—	—
Republic of South Africa:	—	—	—	—	—	—	21,196	204
Spain	—	—	161	5	—	—	—	—
Switzerland	—	—	26	7	—	—	—	—
Taiwan	1,435	20	515	44	—	—	—	—
Thailand	—	—	—	—	—	—	7,477	85
United Kingdom	—	—	26	29	—	—	[4]440	7
Venezuela	10,000	114	7,711	125	795	10	20,681	34
Yugoslavia	—	—	—	—	6,750	72	—	—
Total[5]	325,656	3,727	545,198	9,564	25,933	276	1,112,720	4,645

[1]May include vanadium metal.
[2]May include catalysts containing vanadium pentoxide.
[3]Excludes vanadates.
[4]All or part of these data have been referred to the Bureau of the Census for verification.
[5]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9
U.S. IMPORTS OF FERROVANADIUM, BY COUNTRY

Country	1991			1992		
	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)
General imports:						
Austria	120,000	94,415	$1,236	191,275	135,707	$1,594
Belgium	101,000	78,803	932	[1]79,333	[1]42,887	[1]444
Canada	160,552	130,543	1,796	446,884	364,895	4,418
Czechoslovakia	86,014	70,257	847	60,619	49,091	563
France	20,000	16,301	197	—	—	—
Germany	7,000	5,698	66	—	—	—
Russia[2]	—	—	—	20,046	10,588	83
United Kingdom	39,000	31,747	389	—	—	—
Total	533,566	427,764	[3]5,464	798,157	603,168	7,102
Imports for consumption:						
Austria	138,000	109,049	1,409	188,992	135,307	1,594
Belgium	91,000	70,612	837	[1]68,000	[1]46,701	[1]534
Canada	160,552	130,543	1,796	446,884	364,895	4,418
Czechoslovakia	86,014	70,257	847	43,309	34,999	409
France	20,000	16,301	197	—	—	—
Germany	7,000	5,698	66	—	—	—
Russia[2]	—	—	—	20,046	10,588	83
United Kingdom	21,000	17,113	214	—	—	—
Total	523,566	419,573	[3]5,367	767,231	592,490	7,038

[1]All or part of these data have been referred to the Bureau of the Census for verification.
[2]Formerly part of the U.S.S.R.; data were not reported separately until 1992.
[3]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS OF VANADIUM PENTOXIDE (ANHYDRIDE), BY COUNTRY

Country	1991			1992		
	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)
General imports:						
Canada	56,855	30,706	$102	4	3	$2
China	—	—	—	131,800	114,419	591
France	27	20	3	—	—	—
Germany	999	559	27	862	410	31
South Africa, Republic of	148,520	113,669	905	179,403	137,908	891
United Kingdom	10	3	4	—	—	—
Total	206,411	144,957	[1]1,042	312,069	252,740	[1]1,515
Imports for consumption:						
Canada	56,855	30,706	102	4	3	2
China	—	—	—	71,800	57,910	330
France	27	20	3	—	—	—
Germany	999	559	27	862	410	31
South Africa, Republic of	133,480	101,616	807	196,423	147,633	1,001
United Kingdom	10	3	4	—	—	—
Total	191,371	132,904	943	269,089	205,956	1,364

[1]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11

U.S. IMPORTS OF VANADIUM-BEARING ASH, RESIDUES, SLAG, AND OTHER MATERIALS, BY COUNTRY[1]

Material and country	1991			1992		
	Gross weight (kilograms)	Vanadium pentoxide content (kilograms)	Value (thousands)	Gross weight (kilograms)	Vanadium pentoxide content (kilograms)	Value (thousands)
Slag:[2]						
South Africa, Republic of	1,326,297	318,311	$3,066	1,063,648	255,276	$1,797
Ash and residues:						
Canada	679,974	314,314	537	1,467,898	693,136	955
Chile	—	—	—	16,827	5,385	4
Dominican Republic	52,760	15,828	24	20,735	11,819	16
Germany	536,150	107,230	40	1,016,561	222,275	182
Israel	—	—	—	388,931	105,012	208
Italy	286,729	47,027	182	163,180	39,165	84
Jamaica	68,181	20,454	120	—	—	—
Mexico	246,191	97,210	312	122,101	56,830	111
Netherlands	—	—	—	15,240	4,572	13
Netherlands Antilles	350,219	133,949	183	142,552	32,931	34
Spain	31,090	4,663	12	27,480	5,491	8
United Kingdom	—	—	—	16,750	3,350	4
Venezuela	68,020	25,508	45	90,000	27,000	48
Total	2,319,314	766,183	r1,455	3,488,255	1,206,966	[3]1,669
Other (includes spent catalyst):						
Argentina	—	—	—	18,091	9,046	5
Canada	1,982,781	396,556	219	48,231	22,927	25
France	44,723	7,902	17	—	—	—
Italy	44,435	6,264	25	—	—	—
Netherlands	181,611	28,113	27	—	—	—
United Kingdom	218,300	50,678	45	5,465	984	6
Total	r2,471,850	489,513	[3]332	71,787	32,957	36

rRevised.

[1]General imports.

[2]As adjusted by the U.S. Bureau of Mines.

[3]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 12
WORLD VANADIUM PENTOXIDE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1992[1]

(Metric tons of contained vanadium)

Country	Rated capacity[2]
Austria	1,500
Canada	770
Chile	2,300
China	8,200
South Africa, Republic of	27,200
Russia	9,500
United States	11,000
Venezuela	2,500
Other	550
Total	63,520

[1]Includes V_2O_5 in vanadiferous iron slags and petroleum refinery residues.
[2]Includes capacity of operating plants as well as plants on standby basis.

TABLE 13
VANADIUM: WORLD PROCESSING FACILITIES

Country and plant	Location	Vanadium processing				
		Vanadium pentoxide	Ferro-vanadium	Ammonium metavanadate	Aluminum-vanadium alloy	Other[1]
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:						
Gesellschaft fur Electrometallurgie mbH	Nuremburg		x		x	
Belgium:						
Sadacem (Langerbruggekaai Plant)	Ghent		x			

See footnote at end of table.

TABLE 13—Continued

VANADIUM: WORLD PROCESSING FACILITIES

Country and plant	Location	Vanadium processing				
		Vanadium pentoxide	Ferro-vanadium	Ammonium metavanadate	Aluminum-vanadium alloy	Other[1]
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			
Nanjing Ferroalloy Plant	Jiangsu	x	x			
Shanghai Plant	Shanghai		x			
Russia:						
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			

[1]A, Nitrovan, proprietary product; B, Ferovan, proprietary product; C, Vanadium metal producer; D, Vanadium-zirconium alloy producer; and E, Unsupported vanadium catalyst.

TABLE 14

VANADIUM: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons of contained vanadium)

Country	1988	1989	1990	1991	1992e
Production from ores, concentrates, slag:[2]					
China (in vanadiferous slag product)e	4,500	4,500	4,500	4,500	4,700
Russia[3 4]	—	—	—	—	7,000
South Africa, Republic of:[5]					
Content of pentoxide and vanadate productse	r6,330	r7,270	r7,100	r7,000	7,000
Content of vanadiferous slag producte[6]	11,300	11,300	10,000	r8,480	8,000
Total[7]	17,631	18,567	17,106	r15,477	15,000
U.S.S.R.e[4 8]	9,600	9,600	9,000	8,500	—
United States (recoverable vanadium)	W	W	W	W	W
Total[9]	31,731	32,667	30,606	28,477	19,700
Production from petroleum residues, ash, spent catalysts:[10]					
Japan (in vanadium pentoxide product)e	728	r868	r700	889	870
United States (in vanadium pentoxide and ferrovanadium products)	2,950	2,389	2,308	2,250	11r1,347
Total	3,678	3,257	3,008	3,139	2,217
Grand total	35,409	35,924	33,614	31,616	21,917

eEstimated. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]In addition to the countries listed, vanadium is also recovered from petroleum residues in Germany, and several other European countries, but available information is insufficient to make reliable estimates. Table includes data available through May 21, 1993.

[2]Production in this section is credited to the country that was the origin of the vanadiferous raw material.

[3]Formerly part of the U.S.S.R.

[4]All production in the U.S.S.R. from 1988-91 came from Russia.

[5]Includes production for Bophuthatswana.

[6]Data 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.

[7]Data may not add to reported totals shown because of independent rounding of estimated detail.

[8]Dissolved in Dec. 1991.

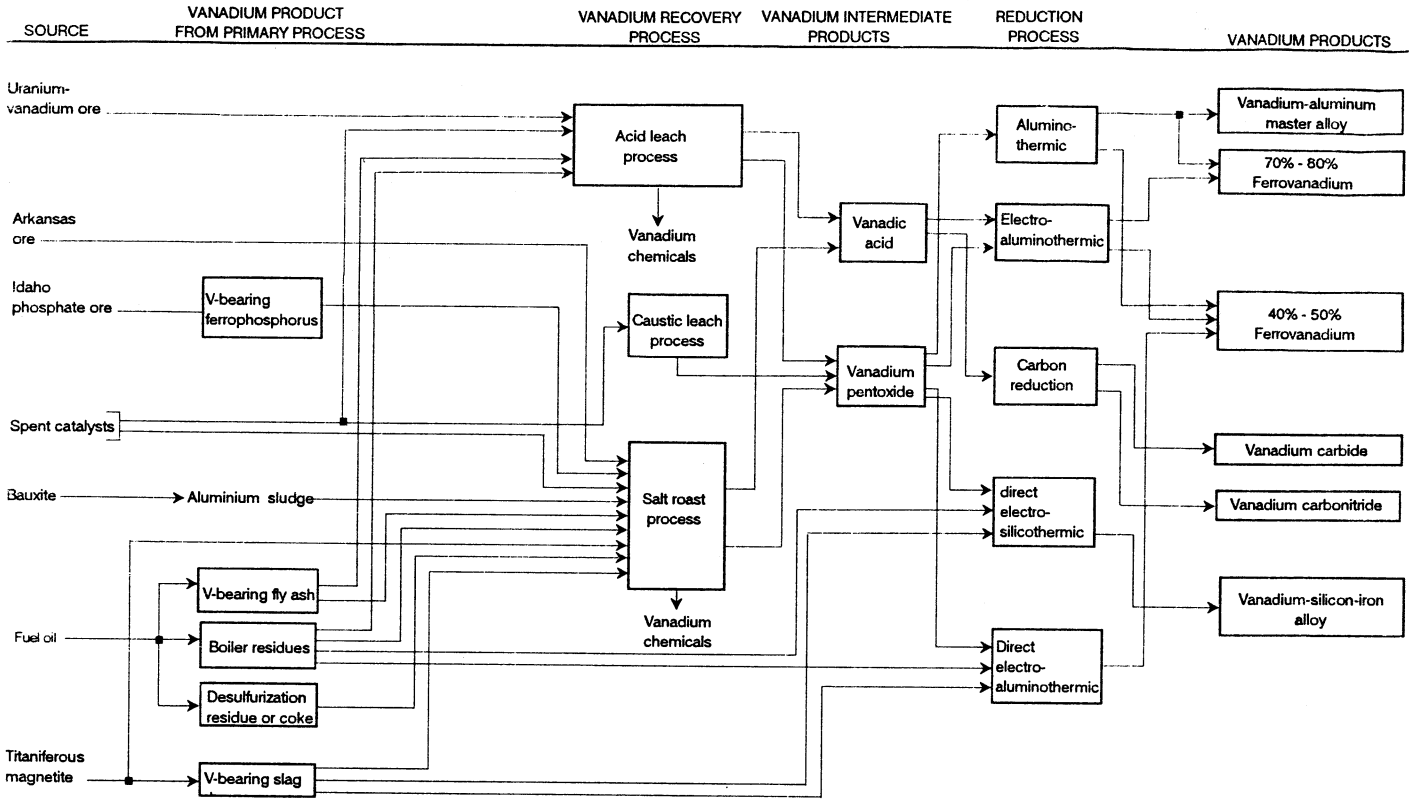
[9]Excludes U.S. production.

[10]Production 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.

[11]Reported figure.

FIGURE 1

GENERALIZED FLOWSHEET FOR THE PROCESSING OF VANDIFEROUS RAW MATERIALS



ZINC

By James H. Jolly

Mr. Jolly is a physical scientist (geologist) with more than 35 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 20 years and the zinc specialist for the past 11 years. Domestic survey data were prepared by Gloria A. Peebles, 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 humankind in compounds, alloys, and metal for more than 2,000 years and is 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 domestic zinc industry continued to show improvement as the Nation slowly climbed out of recession. Mine and smelter output increased slightly whereas metal consumption was up 11% and was the highest since 1989. Mine production rose despite fewer operating mines in 1992. Smelter output was similarly up as smelters operated at relatively high-capacity utilization rates, owing largely to higher zinc prices during the year and increased domestic consumption. The value of unmanufactured zinc exports and scrap was about $283 million, down from $370 million in 1991. Imports of unmanufactured zinc and scrap totaled about $918 million, up about $130 million from that of 1991. The rise in value was attributed largely to increased imports of slab zinc, which accounted for 85% of the import value.

World zinc mine and smelter production declined in 1992. World stocks of both zinc concentrate and zinc metal increased sharply as the year progressed, and by yearend greatly exceeded the levels typical of most other years. Despite an increasingly large oversupply in 1992, zinc prices rose in the early months of the year counter to market conditions and remained at higher than expected levels through early October. Thereafter, the price fell sharply, reflecting a more realistic measure of market conditions. Higher zinc prices in 1992 were attributed in the press mainly to a rolling options-related squeeze at the London Metal Exchange (LME) believed to have been carried out by a small number of metal traders and zinc producers.

World zinc mine production was about 7 million metric tons for the third straight year while smelter output was below 7 million tons for the first time since 1986. The United States accounted for 7.7% of world mine production in 1992 and 5.8% of world smelter production. The United States was the world's largest zinc consumer and was one of the few countries to show a substantial increase in zinc consumption in 1992. U.S. consumption accounted for about 14.8% of world zinc metal consumption, up from the 13.5% of 1991.

DOMESTIC DATA COVERAGE

Domestic data for zinc were developed by the U.S. Bureau of Mines (USBM) 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, 282 responded, representing an estimated 98% of the total reported slab zinc consumption shown for 1992 in tables 1 and 8. Consumption by nonrespondents was estimated using prior-year consumption adjusted for industry trends.

Reported consumption of slab zinc, however, accounted for only 79% of apparent metal consumption. The difference between reported and apparent consumption is mainly a reflection of the current response rate for the USBM's voluntary industry surveys.

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 situation. Domestic smelter capacity is inadequate and would limit refined zinc output. It would also severely limit 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 the Alaskan 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 1992,

resulted in the net export of about 300,000 tons of zinc in concentrate. An additional strategic factor related to Alaskan output is 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 part 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. In 1992, the President signed Public Law 102-484, which authorized the disposal of the entire inventory of zinc in the National Defense Stockpile (NDS). An annual disposal rate of 68,000 tons was proposed to sell off the 343,000 tons of zinc in the NDS; however, the disposal rate was subject to adjustments based on recommendations of a broad-based market impact committee. Because large stockpile disposals of zinc have occurred in the past, the following historical review of stockpile actions may provide a perspective on future disposals and their impact on defense planning.

The need for a stockpile of critical raw materials for national defense purposes became apparent during World War I (WWI) when shortages of materials upset production schedules, delayed development programs, and slowed exports of vital materials to U.S. allies. When the war broke out in Europe in 1914, the United States was the world's single largest zinc producer, accounting for about 35% of world output, and was self-sufficient in zinc. European countries produced most of the remaining world output, but with the outbreak of war, their zinc production was severely curtailed. Battlefields were near major smelting districts, and naval action disrupted concentrate imports. As a result, the British and French sought zinc supplies from the United States. Demand and prices soared, leading to rapid expansion of the U.S. zinc industry. When the United States entered the war in 1917, the industry's capacity to produce zinc exceeded U.S. and export requirements to such an extent that the zinc industry began to worry about industry retrenchment after the war ended. At the end of the war, various Government programs had accumulated in excess of 10,000 short tons[1] of zinc metal and concentrate at domestic smelters; this material was disposed of in 1919 and 1920.

Although zinc was not in short supply in the United States during WWI, it was nonetheless a critical material, in use as brass in artillery and cartridge shell casings, metal liners in ammunition and explosive boxes and magazines, coatings on barbed wire entanglements and sheet metal, a component of naval and battlefield smoke, medical tape and rubber tires, and a substitute for other critical metals, including aluminum, copper, lead, and tin. In the latter part of the war, for example, lead became very scarce, resulting in its substitution by rolled zinc in coffins.

Based on the WWI experience, the U.S. Army developed a list of 42 essential materials required for military operations in 1921, but there was little interest in creating a strategic materials reserve at that time. Materials stockpiling regained impetus in the 1930's owing to deteriorating conditions in Asia and Europe. The Naval Appropriations Act of 1937 authorized the purchase of $3.5 million of critical materials, and in 1939, the Critical Materials Stockpiling Act of 1939 (Public Law 76-117) authorized $100 million for the stockpiling of designated items, including basic industrial raw materials. The outbreak of World War II (WWII) in 1939, however, prevented establishment of the stockpile because the materials to be stockpiled were needed for immediate industrial expansion and military production. The Government, through various agencies, mainly the Reconstruction Finance Corp. and its subsidiary, Metals Reserve Co., controlled the production, price, and distribution of zinc during WWII. Again, at the start of the war, the United States was self-sufficient in zinc production. As the war expanded, the demand on the domestic industry increased. The smelting sector expanded rapidly; the mining sector did not. Mine production rose in 1941 and 1942, but declined thereafter, despite efforts to stimulate output with bonuses and the release of almost 1,100 men from the Army, specifically assigned to work in domestic zinc mines. As a result of deficient domestic zinc mine output, dependence on imported foreign ores and concentrates increased as the war progressed and reached 537,000 short tons (zinc content) in 1943. That year imported ores and concentrates accounted for almost one-half of U.S. smelter feed requirements as compared with only 5% in 1939. Thereafter through the 1960's decade, imported ores and concentrates continued to account for a substantial portion of U.S. zinc needs.

In 1940, the shortage of zinc became acute, and by the end of the year a voluntary system of supply allocation was initiated by the industry. In March 1941, zinc was declared critical, and in June, came under full allocation control of the War Production Board. Stockpiling during WWII was initially based on a 3-year war scenario, but in August 1943 the war outlook had improved to the point where objectives were reduced to a 1-year supply and in June 1945, to a 3-month's supply.

As WWII was winding down, sentiment for a national stockpile after the end of hostilities increased. The military wanted a stockpile to avoid critical materials shortages in the future, whereas materials producers anticipated adverse affects from the dumping of the Government's materials stocks, including an estimated 400,000 short tons of zinc metal and zinc concentrate, in the postwar market. Legislative pressure to assist domestic basic industries in adjusting to a peacetime economy aided passage of the Strategic and Critical Stock Piling Act of 1946 (Public Law 79-520) in July 1946. Wartime zinc stocks that had not been sold to domestic industries to assist conversion and reconstruction efforts

were transferred or eventually smelted to metal for addition to the National Strategic Stockpile. The zinc industry in the 1946-48 period was able to maintain relatively high production rates owing to purchases for the stockpile and to the smelting of Government concentrates.

The advent of the Korean War (1950-53) resulted in continued zinc purchases for the stockpile. Zinc prices and imports increased, but even though Government allocation limits were in place, there were no serious shortages of zinc during the war. In the period 1954-60, the Government continued to accumulate zinc for the stockpile via direct purchases under the Defense Production Act (DPA) of 1950 (Public Law 81-744) and through barter agreements. Zinc additions from the DPA programs were small, but zinc metal obtained through barter of perishable surplus agricultural products totaled 324,000 short tons from 1954 through 1960. Zinc was removed from the barter list in 1960. Stockpile materials obtained under the barter programs were not placed in the national stockpile but were placed in a "supplemental" stockpile and could be released only by the Congress.

The year 1960 marked the end of significant acquisitions for the Government's zinc stockpiles. Thereafter, almost all zinc stockpile transactions involved sales in excess of goals. Stockpile goals or objectives often were reviewed and modified on the basis of assumptions governing military and industrial preparedness and length of a potential U.S. war emergency. Stockpile goals were generally based on 5-year and 3-year wars, but in the late 1950's, the war period was reduced to 1 year, based on the assumption that nuclear war would be short and decisive and would eliminate protracted conventional conflict. In 1958, the stockpile goal for zinc was reduced from 1,250,000 short tons to 178,000 short tons and in 1963, to zero. The assessment that no stockpile of zinc was required was in part based on the assumption that North American sources could supply the necessary zinc requirements in the event of a nuclear or conventional war. The reduction in goals essentially made 1.5 million short tons of zinc in the Nation's stockpiles available for reentry into the U.S. and world economies. In July 1964, Public Law 88-374 authorized the release of 67,500 short tons of zinc to domestic primary producers and 7,500 short tons to independent zinc-base alloyers. In April 1965, Public Law 89-9 authorized the release of 150,000 short tons of zinc to industry and 50,000 short tons for use by the Government, including the Agency for International Development, the U.S. Mint, and the Department of Defense; another 200,000 short tons of zinc was authorized for release in November 1965 (Public Law 89-322). Sales from the aforementioned public laws continued through 1971.

A new zinc stockpile goal, 560,000 short tons, was established in 1969; but despite earlier disposals, large stocks of excess zinc remained. In April 1972, Public Law 92-283 authorized the disposal of 515,000 short tons of zinc from the national stockpile for domestic consumption only. A total of 440,000 short tons was to be released through domestic primary producers and 75,000 short tons was for off-the-shelf sale. In April 1973, the zinc stockpile goal was reduced to 202,700 short tons, making available more excess zinc. In December 1973, Public Law 93-212 authorized the release of an additional 357,300 short tons of zinc, with 150,000 short tons to be sold directly to consumers and the remaining 207,300 short tons to go through participating primary zinc producers.

All zinc sales ceased in June 1976 when a new stockpile goal, incorporating the stocks of the previous goal and unsold excess stocks, was established. In October 1976 the new stockpile goal, 1,313,000 short tons of zinc, was approved. In 1979, the Strategic and Critical Stockpile Revision Act of 1979 (Public Law 96-41) created the National Defense Stockpile (NDS) by combining the national and supplemental stockpiles. It limited the use of Stockpile materials to the national defense and prohibited Stockpile sales for economic purposes. The last mentioned provision was added to ensure that the Stockpile could not be used as a means of controlling commodity prices as an anti-inflation mechanism or producing revenue for budgetary purposes, as both were perceived to have been important underlying factors in previous stockpile disposal legislation. In May 1980, the Stockpile contained 383,000 short tons of zinc and a new Stockpile goal of 1,425,000 short tons was established for zinc. Other than a small drop in the zinc inventory, the zinc stockpile situation of 1980 was unchanged until passage of the 1992 legislation.

During the period of Stockpile sales, the Government attempted to aid zinc producers by price stabilization payments, import quotas, tariffs, and marketing of stockpiled metal through primary producers. The Lead-Zinc Small Producers Stabilization Act of 1961 (Public Law 87-347) encouraged zinc production by authorizing prorated payments for small mine producers for the difference between 14.5 cents per pound and the monthly average price of zinc metal, if less than 14.5 cents. This program expired in 1969. Import quotas were imposed on imported concentrates and metal from 1958 through 1965. Imports were restricted to 80% of the average 1953-57 import level. Tariffs on zinc concentrates and metal operated throughout the sales period; however, when the President's economic stabilization program, effective August 1971, froze the price of zinc, additional tariffs in the form of surtaxes on imported zinc products were temporarily imposed. The surcharge was dropped in December.

Conversely, Government stockpile sales and price controls were, to some extent, viewed as detrimental to the health of the domestic zinc-producing sector. Domestic zinc smelting companies maintained their market shares during the stockpile disposal period; however, the sales and prospects of future sales discouraged domestic investments in new technology and facilities. The sales also tended to hold down zinc prices, thereby limiting industry profit that might have encouraged additional investment in

the industry. Price controls held U.S. zinc prices well below world prices from August 1971 through the end of 1973; as a result, domestic smelters were adversely affected because they could not effectively compete for foreign concentrates on world markets. U.S. zinc metal production declined after 1969, even though U.S. zinc metal consumption was the highest ever in the early 1970's. In the 1971-75 period, seven smelters permanently closed for a number of reasons, including high costs, obsolescence, and environmental restrictions; however, price controls and stockpile sales undoubtedly contributed to their demise. The Government also was adversely affected by price controls and the price-depressing effect of sales in that it received less value for its metal. This was especially true during the second half of 1973 when the average LME zinc price was more than twice the U.S. controlled price and the world price about 50% higher.

In summary, during WWI the United States was self-sufficient in zinc production and capable of supplying its allies with needed refined zinc products. At the start of WWII, the United States was again self-sufficient in zinc production, but beginning in 1940 through the end of the war, the U.S. mining sector was not capable of supplying the greatly expanded refining sector with sufficient zinc feed material. As a consequence, the United States became 30% dependent on imported zinc concentrates during WWII, but remained essentially self-sufficient in refined zinc production.

During the Korean and Vietnam Wars, a somewhat similar situation prevailed as that in WWII in regard to zinc production but in these later wars, U.S. stockpiles contained large quantities of zinc that were available if needed. In the 1940-74 period, the U.S. zinc smelting sector, though dependent on imports for almost 40% of its concentrate supply, provided about 90% of U.S. requirements for refined zinc products.

The peak year for domestic slab zinc production was 1969; thereafter, production declined owing to the permanent closure of 11 of 14 smelters that had operated in the United States in 1968. Two of the remaining three closed for a period of time but reopened after extensive modification. One new "greenfields" smelter opened in 1978, resulting in the four operating primary smelters at the present time. U.S. primary zinc smelter capacity dropped from 1,318,000 short tons in 1968 to 330,000 short tons in 1986, but via expansions, was up to 420,000 short tons in 1992.

Mine production followed a similar but less dramatic decline, although in the past few years the development of a large zinc mine in Alaska reversed the trend and restored U.S. mine output to 1960's levels (about 600,000 short tons per year). Unfortunately, the Alaskan mine, which accounts for about one-half of U.S. zinc mine output, presents problems from a strategic point of view. The mine is isolated, depends on sea transport for supplies and shipments, and has port facilities that are ice-bound for 9 months per year. Presently all concentrate shipments are exported, but even if they were redirected to the United States, there is no excess domestic smelter capacity to process Alaskan material. In addition, the largest domestic primary smelters processes large amounts of secondary materials, which effectively lowers the primary processing capacity of the United States to about 330,000 short tons, about the same as the mine production of the "lower 48 States."

As a result of the decline in U.S. zinc smelter capacity, a major shift in the zinc import pattern occurred in the early 1970's. Concentrate imports fell sharply, whereas slab zinc imports rose dramatically. U.S. net import reliance on refined zinc products currently averages about 60%, the same as that of the past two decades.

The U.S. zinc industry has been in decline over the past two decades, and the Nation is more than ever dependent on foreign sources for its refined zinc supplies. It is doubtful that any new zinc smelters will be built in the United States in the next decade, owing to the difficulty of obtaining construction permits and the long-term threat of Superfund liability. Until the early 1970's, the capacities of domestic smelters were adequate to supply most of the Nation's needs, and because there were numerous smelters, rapid expansion was possible. Present capacity is one-third the former level and is less capable of rapid expansion. Since as early as 1940, domestic mine production, though it could be expanded to a considerable extent, has been inadequate. Although domestic output has improved in the past few years, much of this new production is essentially seasonal and unavailable to domestic markets for reasons stated earlier.

Production

Mine Production.—U.S. zinc mine output was up slightly in 1992. Two closed mines reopened in 1992, whereas another that produced zinc in 1991, the Silver Butte copper-zinc-silver mine in Oregon, operated all year but produced no zinc.

The 20 leading U.S. zinc-producing mines accounted for more than 98% of production, with the 5 leading mines accounting for 66%. Alaska, for the second straight year, was the principal zinc-producing State, followed by, in order of output, Tennessee, New York, Missouri, Colorado, and Montana. The leading domestic zinc mine producers were ASARCO Incorporated, Cominco Alaska Inc., Union Zinc Co., and Zinc Corp. 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 1992. 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.

Despite significant improvement in zinc recovery from ore, zinc output was marginally less at the Red Dog Mine

owing to the milling of slightly fewer tons of ore containing, on average, less zinc. According to the Cominco annual report, zinc recovery in 1992 was 76%, up 8% from last year, but milled ore was only 1,435,000 tons, 15,000 tons less than that in 1991. The ore grade averaged only 19.9% zinc, versus 22.5% in 1991. A total of 218,400 tons of zinc in zinc concentrate and bulk lead-zinc concentrate was produced in 1992, compared with 222,900 tons produced in the previous year. Ore reserves at yearend were 58.2 million tons averaging 18.4% zinc, 5.5% lead, and 103 grams 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., Exalas Resources Corp., and CSX Alaska Mining Inc., milled about 400,000 tons, or 3% more ore in 1992. Although the milled ore averaged 10.8% zinc, about 9% higher in grade than that of 1991, zinc production was only 36,900 tons, or 4% less than the previous year, owing mainly to poorer zinc recovery. Three types of concentrates—zinc, lead, and bulk zinc-lead—were produced; all were exported to foreign smelters. At yearend, ore reserves were about 11.1 million tons averaging 13.2% zinc, 4.0% lead, 480 grams of silver per ton, and 4.8 grams of gold per ton.

In Tennessee, zinc was produced at seven underground mines, four by Asarco in east Tennessee and three by Union Zinc. Asarco's production at four mines was 67,900 tons of zinc in concentrate, up 900 tons from that of 1991. At yearend, ore reserves at the four mines were 5.0 million tons averaging about 3.2% zinc, down slightly from the tonnage and grade reported at the end of 1991.

Union Zinc brought its Idol Mine in east Tennessee on-stream in April at an annual production rate of about 12,000 tons of zinc in concentrate. All of the zinc concentrate was expected to be processed at the Jersey Miniere Zinc Co. (JMZ) plant in Clarksville, TN. 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 company's West Fork and Sweetwater Mines was 13,900 tons, down 300 tons from that of 1991. At yearend, ore reserves at the two mines totaled 25.6 million tons averaging 0.83% zinc. Zinc output at the Magmont Mine, a joint venture of Cominco American and Dresser Industries Inc., fell sharply in December when the company instituted planned reductions in labor and production owing to ore depletion. Surface drilling yielded no new ore extensions, and as a result, the company continued to plan for eventual ore exhaustion and shutdown in 2 or 3 years. According to the Cominco annual report, the Magmont mill processed about 0.87 million tons of ore grading 1.0% zinc, yielding 7,400 tons of zinc in 12,800 tons of concentrate in 1992. In 1991, zinc production was 1,000 tons higher. At yearend, ore reserves totaled 2.6 million tons and averaged 8.5% lead, 1.3% zinc, and 0.4% copper.

The Doe Run Co., a subsidiary of Fluor Corp., produced about 25,000 tons of zinc in about 45,000 tons of concentrate at its six lead mines and four mills in Missouri in 1992. In November, Fluor announced its decision to exit the lead business and classified Doe Run as a discontinued operation. Fluor planned to divest itself of Doe Run by the end of 1993.

In Idaho, zinc was produced at only one mine, the Lucky Friday silver-lead-zinc mine owned by Hecla Mining Co. Hecla milled 159,000 tons of ore grading 2.7% zinc during the year and produced 3,820 tons of zinc in concentrates, one-third more than that in 1991. Toward the end of the year, declining metal prices resulted in below break-even operations; however, Hecla kept the mine in production because it was less expensive to keep it operating than to shut it down. Ore reserves fell slightly and at yearend were 405,000 tons, grading 12.8% lead, 2.8% zinc, and 514 grams of silver per ton.

In Colorado, zinc was only produced as a coproduct of gold-silver operations at the Leadville Unit, managed by Asarco but jointly owned with the Resurrection Mining Co. Asarco increased zinc output in concentrate to 14,800 tons, up 1,400 up tons from that of 1991. Lead and silver output declined but gold production was up. For 1992 they totaled about 5,530 tons, 9,487 kilograms (kg) (305,000 troy ounces), and 426 kg (13,700 ounces), respectively, compared with 5,800 tons, 9,953 kg (320,000 ounces), and 414 kg (13,300 ounces) produced in 1991. At yearend, ore reserves were 640,000 tons (down 40,000 tons from yearend 1991) grading 8.10% zinc, 3.78% lead, 58 grams of silver per ton, and 2.7 grams of gold per ton.

In Montana, the Montana Tunnels Mining Co., a subsidiary of Pegasus Gold Inc., mined and milled a record 4.15 million tons of ore at its Montana Tunnels Mine in 1992; concentrates containing 17,600 tons of zinc, 6,500 tons of lead, 41,368 kg (1.33 million ounces) of silver, and 2,323 kg (74,700 ounces) of gold were produced. Zinc recovery was 90% in 1992. At yearend, proven and probable reserves were up 7.2 million tons to 34.7 tons grading 0.62% zinc, 0.22% lead, 10.6 grams of silver, and 0.7 gram of gold per ton. The new reserves delineated in 1992 extended the expected mining life of Montana Tunnels to 8.4 years, up from 7 years projected 1 year earlier.

In September, Equinox Resources Ltd. reopened its Van Stone zinc-lead mine in Washington. The mine had been placed on care and maintenance in November 1991 after having only opened in April of that same year. 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.

Minnova Inc. completed an underground exploration program at the Pend Oreille lead-zinc mine near Metaline Falls, WA, that resulted in identifying 3.4 million tons of geologic ore reserves grading 10.7% zinc and 1.8% lead. Minnova exercised an option to purchase a substantial interest in the mine's owner, Resource Finance Co., before the end of the year and planned a final feasibility study that could lead to a mine startup date before the end of 1994. The Pend Oreille Mine last operated in 1977.

Permitting difficulties caused Noranda Ltd. to abandon all activities at the Lynne zinc-copper deposit in Wisconsin. Wetlands and bogs over parts of the deposit were classified by the State as lakes, under which State law forbids mining. The Lynne deposit reportedly contained 6 million tons of ore averaging 8.5% zinc, 1.3% lead, and 0.6% copper and had been expected to yield 50,000 tons of zinc annually.

Exxon Minerals Co. and Phelps Dodge Mining Co. reached an agreement to conduct a joint evaluation of the Crandon zinc-copper-lead deposit in Wisconsin. Exxon had previously identified 66 million tons of ore averaging 5.6% zinc, 0.5% lead, and 1.1% copper in the deposit before suspending both permitting and development activities in 1986 based mainly on unfavorable economic forecasts for zinc and copper. A decision by the two companies as to whether or not to proceed with joint-venture development of the property was expected in early 1993.

Smelter and Refinery Production.—Refined metal production was up slightly from that of 1991 and was the highest since 1981. Three companies, ZCA, JMZ, and Big River Zinc Co., operated four primary zinc refineries in 1992. 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 mainly 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 45,000 tons had been added, raising plant capacity to about 146,000 tons in 1992. Most of the added capacity, however, was dedicated to the processing of EAF zinc calcine. The capacities of the other primaries were unchanged, as were the capacities of the secondaries with metalmaking facilities.

ZCA and Mitsui Mining and Smelting Co. formed a joint company, Mitsui/ZCA Zinc Powders Co., to produce high-quality zinc powder for use in mercury-free, alkaline batteries. The joint company was building a $3 million, 2,700-ton-per-year plant at ZCA's Monaca smelter. Production was scheduled to start in mid-1993.

Zinc Oxide.—Domestic American- and French-process zinc oxide was produced entirely from zinc metal and scrap by eight companies in 1992. 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 agricultural purposes. The principal zinc oxide producers in 1991 were Asarco, Eagle Zinc, North American Oxide Inc., and ZCA.

ZCA closed its 40,000-ton-per-year, zinc-oxide-producing facilities at Palmerton, PA, in late 1992, but, as the year progressed, increased zinc oxide production capacity by 27,000 tons at its Monaca plant to maintain company production levels.

In June, Midwest Zinc Corp., Chicago, IL, purchased the closed Memphis, TN, zinc oxide plant of PASCO Zinc products for $1.2 million. PASCO, a subsidiary of Pigment and Chemical Inc., had permanently closed the 18,000-ton-per-year, French-process zinc oxide plant in July 1991 owing to weak markets and financial difficulties. Midwest rehabilitated the facilities, and, in September, restarted the plant at a reduced rate.

Byproduct Sulfur.—Production of sulfur in byproduct sulfuric acid at primary zinc plants was 148,400 tons, about 12,000 tons higher than production in 1991. Acid production at zinc plants in 1992 was valued at $15.1 million.

Consumption and Uses

Zinc is found in a great many manufactured products, but its role is not obvious to the public because it tends to lose its identity in the products. Zinc-containing products were used extensively in 1992 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 1992, about 22,000 tons of Special High Grade (SHG) zinc was used by the U.S. Mint to

produce 9.1 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 rose about 100,000 tons to slightly more than 1.03 million tons in 1992. 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 1992.

According to the American Iron and Steel Institute, reported shipments of domestically produced galvanized sheet and strip totaled 9.6 million tons, up 1.4 million tons from shipments in 1991. 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 22% of the tonnage compared with 23% in 1991. The distribution of total shipments by industry sector in 1992 was as follows: automotive, 40%; service centers, 26%; contractors and construction, 20%; and other, including exports, 14%. 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 173,000 tons, up from 172,000 tons reported in 1991. Zinc die-cast shipments by weight were estimated to have been distributed equally between automotive, hardware, and other uses.

Zinc consumption in the production of copper-base alloy of brass mills, ingotmakers, and foundries was up about 30,000 tons from that of 1991, according to the Copper Development Association Inc. (CDA). The brass and bronze industries were estimated to have consumed about 306,000 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 17.2 kg in 1992, down about 0.9 kg from that in 1991. Diecastings accounted for about 7.7 kg corrosion protection via galvanizing and coatings, 8.2 kg and other, including rubber, brass, and zinc solder, 1.4 kg.

The apparent domestic consumption of zinc oxide was about 165,000 tons, up from 150,000 tons in 1991, but about the same as that of 1990. Domestic production was up, whereas exports were down. Nonetheless, U.S. producers have increased their share of the U.S. zinc oxide market over the past 4 years, mainly at the expense of imports. Because the USBM information on zinc oxide consumption by industry sector reflects only shipments as reported by the domestic producers, the consumption data listed in table 11 account for only about 80% of the apparent market. Of the reported amounts, the rubber and chemical industries continued to be the principal consumers.

A historical study of zinc production and consumption in the United States for the period 1850-1990 was published in April.[2] The study showed that the United States was the world's leading producer and consumer of zinc during the 1850-1990 period. During that period an estimated 41 million tons of recoverable zinc came from U.S. ores, 59 million tons of refined zinc was produced at U.S. zinc plants, and about 73 million tons of zinc entered the U.S. economy in the form of end products. Potential losses of zinc into the environment from U.S. mining, processing, consumption, use, and disposal were estimated to total 63 million tons. About 23 million tons or about 8.5% of total zinc placed in use in the world since 1800 was still in use in the United States at the end of 1990.

Stocks

Metal stocks held by domestic producers, consumers, and merchants continued to decline in 1992 and were at their lowest levels since the early years of WW II. In recent years, these domestic stock levels have tended to be in the 4- to 6-week consumption range but fell into the 3-week range in 1992, reflecting the continuing general trend by consumers and merchants toward lower inventories and just-in-time delivery. Metal stocks in Western countries (exclusive of Eastern countries defined as all countries in the former Communist bloc or still Communist countries) rose sharply as the year progressed. According to the International Lead and Zinc Study Group (ILZSG), stocks in Western countries were 1,129,000 tons at the end of 1992, up 350,000 tons from those at the end of 1991. Virtually all of the additional stocks were placed in LME warehouses, as industrial stocks tended to remain at 1991 levels. ILZSG data indicated that 80% of metal stock rise was attributable to increased imports from Eastern countries. Inventories of zinc in concentrate at domestic primary smelters totaled 41,500 tons at yearend compared with only 29,000 tons at the end of 1991, according to the American Bureau of Metal Statistics Inc.

Markets and Prices

In 1991, all U.S. zinc producers switched to an LME price basis. For domestic metal, sellers generally charged a premium of 2 to 5 cents per pound over

the LME spot price, or some average of LME prices, to take into account delivery and/or importing costs such as tariff, shipping, and insurance. In this report, the domestic zinc price in 1992 is that published by Metals Week (MW), which based its price on the daily LME spot price for SHG plus a premium that reflected market conditions.

In 1992, the LME established six new warehouse locations in the United States where various LME registered metals, including zinc, could be delivered or picked up. Together, with the Baltimore facility that was established in 1991, the new warehouses at Chicago, IL; Detroit, MI; Long Beach, CA; Louisville, KY; New Haven, CT; and Toledo, OH, were the seven originally planned for establishment in the United States.

The domestic zinc metal price began the year in a declining trend, which reached a daily low of about 49 cents per pound in mid-January. February was lackluster with prices not responding to some industry cutbacks. The daily price per pound at the end of February fell below 48 cents. Prices rose in March despite increases in world and LME zinc metal stocks. In April, prices continued to rise amid stock increases and complaints that the LME zinc cash to 3-month contract was being manipulated by a small number of traders and producers who had secured large options positions. In effect, this created supply tightness by withholding metal from the market. By rolling over the options when they expired, prices were kept at artificially high levels (62 to 65 cents per pound) until early October when, in the face of weak world demand and a continuous and relentless rise in world stocks, options support collapsed. Prices fell rapidly from about 65 cents to the 50 cent level in November and December.

An updated version of the USBM historical price series for metals, including zinc, was published.[3] Interestingly, the estimated average price of zinc for 1992 in 1987 constant dollars, about 52 cents per pound, was virtually the same as the historic average constant dollar price, 52.16 cents, for the 1920-89 period. A similar comparison showed the yearend constant dollar price for zinc to be well below the historic average.

Foreign Trade

The value of U.S. exports of basic zinc materials, including waste and scrap, was about $292 million, down from $316 million in 1991 despite significantly higher zinc prices in 1992. Export tonnages and value of zinc concentrate and zinc scrap were down in 1992. They accounted for 73% and 16%, respectively, of the total export value for the year.

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 were up about 100,000 tons to meet the increased domestic industrial requirements of 1992. The value of basic zinc imports was about $922 million, up from $741 million in 1991. Slab zinc accounted for 85% of the total value of imports.

Three categories of zinc metal were included in the draft proposal for tariff elimination in the North American Free Trade Agreement between Canada, Mexico, and the United States. Tariffs on slab zinc and zinc alloys containing greater than 99.99% zinc would be completely eliminated in Canada and the United States in 1994 and in Mexico in 1999. Tariffs on metal containing less than 99.99% zinc would be phased out by the year 2004 in the United States and by 1999 in Mexico; Canada had no tariff in this category.

In August, the U.S. Senate ratified the Basel Convention, which places restrictions on the movements of hazardous waste between countries and forbids the movements of hazardous waste between countries that have and countries that have not ratified the convention. However, before the United States can officially initiate treaty requirements, the U.S. Congress must pass implementing legislation, which as of yearend, was not in place.

Although the Basel Convention became a reality for signatory countries in May, the United States and most other members of the Organization of Economic Cooperation and Development (OECD) did not become signatories in 1992. However, the OECD members agreed to abide by a set of controls governing the transboundary movement of recyclable wastes until Basel approval was finalized by its members. The OECD wastes were classified into three tiers—green for no restrictions other than acceptable practice, amber for predesignation of responsibility and proper legal documentation, and red for no relief from Basel restrictions. Most zinc wastes and scrap were classified in the green tier; these include galvanizer's top and bottom dross, zinc skimmings, die-cast dross, and zinc waste and scrap metal and alloys. The amber tier included zinc ash and residues and zinc slags containing up to 18% zinc. No specific zinc wastes or scrap were included in the red tier. Recyclable waste "contaminated" by material from a more hazardous tier may have to be documented and handled as though it were classed in the tier of the contaminant.

World Review

Despite a general slowing in the world economy, both mine and smelter production in the Western countries rose to record levels. Consumption in Western countries, on the other hand, was only 5.35 million tons, 50,000 tons less than in 1991, according to ILZSG. In Eastern countries, mine output, smelter output, and consumption all declined; however, consumption fell at a faster rate, resulting in huge surpluses in metal output. Net exports of zinc metal to the West from Eastern countries totaled about 280,000 tons, resulting in a huge buildup in Western countries' stocks. Western stocks totaled about 1 million tons at yearend, up about 360,000 tons from the end of 1991; virtually all of the increase was added to LME stocks. Despite poor market fundamentals, zinc prices were considerably higher than expected for most of the year, owing to options-related

manipulation of the LME zinc contract. Only in the last quarter of the year did prices fall in reaction to market realities.

Higher mine output, principally in Brazil, Canada, India, and Mexico, offset substantially lower output in Germany, Peru, Spain, Yugoslavia, and several Eastern countries. Germany, Saudi Arabia, and the United Kingdom were nonproducers in 1992.

World metal production was less than that in 1991 but production in Western countries rose slightly to a record 5.62 million tons. Countries with significant production increases, all related to new smelter capacity, were Brazil, Germany, India, Mexico, and Spain. Significant declines in output occurred in Austria because the Gailitz zinc plant closed, Belgium because of the Overpelt smelter closure, Mexico because of technical problems, and Yugoslavia because of the country's civil turomil. Metal production in countries of the former U.S.S.R. declined below 1991 levels despite the importation of concentrate from Western countries. According to ILZSG, these countries imported about 110,000 tons of zinc in concentrate in 1992; some was imported under tolling arrangements.

According to ILZSG, zinc metal consumption in the Western countries was down from the record high of 1991, but nonetheless was the second highest ever. Consumption in Eastern countries was estimated to have fallen for the fourth straight year. The United States recorded the only significant increase in consumption worldwide, but this was not enough to offset declines in France, Japan, and minor decreases in many other countries. The world's leading metal-consuming nations, in order of estimated consumption, were the United Sates, Japan, Russia, and Germany. Based on ILZSG data, the principal uses of zinc metal in 1992 in the major Western economies were estimated to be as follows: galvanizing, 49%; brass and bronze, 19%; zinc-based alloys, 14%; chemicals, 7%; zinc semimanufactures, 7%; and other, 4%.

On a geographic basis, the Americas accounted for about 44% of world mine output. Europe, including several countries of the former U.S.S.R., accounted for 16%; Asia and Australia accounted for 23% and 14%, respectively. Canada remained the world's largest producer. Australia, Canada, China, Peru, and the United States together accounted for 58% of the world's zinc mine production; 47 other countries accounted for the remaining 42%.

World exports of zinc concentrates totaled about 3.3 million tons, of which an estimated 90% was from the Western countries. Australia, Canada, Peru, and the United States accounted for 75% of the Western concentrate exports. Canada, Japan, the Republic of Korea, and the Western European countries were the largest importers.

World zinc mine capacity, based on the capacities of operating mines and temporarily closed mines expected to reopen, was about 8.5 million tons at the end of 1992, up about 150,000 tons from 1 year earlier. Seven mines closed, eight mines opened, and seven mines increased capacity in 1992.

The Bismark Mine in Mexico and the Hajar Mine in Morocco, each with zinc production capacities exceeding 50,000 tons, were the largest new mines to open. Two German mines, Hilfe Gottes and Meggan, with a combined capacity of 64,000 tons, were the largest in capacity terms to close permanently.

World smelter capacity totaled about 8.4 million tons at yearend, about the same as last year. Four smelters completed expansions in 1992, adding about 120,000 tons of new zinc capacity. This gain was negated by the closure of the 120,000-ton-per-year Overpelt smelter in Belgium.

OUTLOOK

U.S. demand for zinc is forecast to rise slowly, increasing from slightly more than 1.03 million tons in 1992 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. Near the end of the decade, zinc-air and other zinc battery systems may become important for electric vehicle propulsion or for load-leveling and power backup systems.

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 remain at 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 environmental regulations and the long-term liability threat posed by Superfund legislation. The United States is expected to continue 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 35% to 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. Extensive use of zinc in electric vehicle batteries could increase the percentage of secondary zinc used annually to more than 50% after the year 2000.

[1]Short tons are used in this historical summary to conform with NDS and defense preparedness standard usage.

[2]Jolly, J. H. Materials Flow of Zinc in the United States 1850-1990. BuMines OFR 72-92, Apr. 1992, 53 pp.

[3]———. Zinc. Ch. in Metal Prices in the United States Through 1991. BuMines Spec. Pub., 1992, pp. 191-195.

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TABLE 1
SALIENT ZINC STATISTICS

(Metric tons unless otherwise specified)

		1988	1989	1990	1991	1992
United States:						
Production:						
Domestic ores, recoverable content		244,314	275,883	515,355	517,804	523,804
Value	thousands	$324,249	$499,103	$847,485	$602,426	$673,686
Slab zinc:						
From domestic ores		196,476	229,870	230,470	217,691	227,127
From foreign ores		44,818	30,435	32,234	35,585	44,762
From scrap		88,492	97,904	95,708	r122,457	127,623
Total		329,786	358,209	358,412	r375,733	399,512
Secondary zinc[1]		248,461	249,122	245,692	W	W
Exports:						
Ores and concentrates (zinc content)		33,590	78,877	220,446	r381,818	387,918
Slab zinc		482	5,532	1,238	1,253	5,886
Imports for consumption:						
Ores and concentrates (zinc content)		62,966	40,974	46,684	45,419	44,523
Slab zinc		749,133	711,554	631,742	549,137	644,482
Stocks of slab zinc, Dec. 31:						
Industry (rounded)		r64,900	r60,100	r60,400	r57,300	57,900
Government stockpile		340,577	340,577	340,577	340,577	340,577
Consumption:						
Slab zinc:						
Reported		833,473	884,655	801,969	r790,378	814,228
Apparent (rounded)[2]		1,089,000	1,060,000	992,000	933,000	1,035,000
All classes (rounded)[3]		1,340,000	1,311,000	1,240,000	r1,165,000	1,276,000
Price: High-Grade, cents per pound (delivered)		60.20	82.02	74.59	52.77	58.38
World:						
Production:						
Mine	thousand metric tons	r6,774	r6,808	r7,184	r7,170	e7,137
Smelter	do.	7,163	r7,190	r7,060	r7,175	e6,354
Price: London, cents per pound		51.11	77.64	66.46	50.67	56.24

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.
[1]Excludes secondary slab and remelt zinc.
[2]Domestic production plus net imports plus or minus stock changes.
[3]Based 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 STATE

(Metric tons)

State	1988	1989	1990	1991	1992
Alaska	—	W	W	W	W
Colorado	W	W	W	W	W
Idaho	W	W	W	W	W
Illinois	W	W	W	W	W
Kentucky	W	—	W	—	W
Missouri	41,322	50,790	48,864	42,506	44,031
Montana	18,935	W	W	W	20,588
Nevada	—	—	7,889	W	—
New Mexico	—	W	W	W	W
New York	W	W	W	W	W
Oregon	—	—	—	751	—
Tennessee	119,954	W	W	W	W
Washington	—	—	—	W	W
Total	244,314	275,883	515,355	517,804	523,804

W Withheld to avoid disclosing company proprietary data; included in "Total."

TABLE 3
LEADING ZINC-PRODUCING MINES IN THE UNTED STATES IN 1992, 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.
4	Balmat	St. Lawrence, NY	Zinc Corp. of America	Do.
5	Pierrepont	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	Leadville Unit	Lake, CO	do.	Do.
11	Jefferson City	Jefferson, TN	Union Zinc Co.	Do.
12	West Fork	Reynolds, MO	ASARCO Incorporated	Lead-zinc ore.
13	Fletcher	do.	The Doe Run Co.	Lead ore.
14	Coy	Jefferson, TN	ASARCO Incorporated	Zinc ore.
15	Cumberland	Smith TN	Jersey Miniere Zinc Co.	Do.
16	Buick	Iron, MO	The Doe Run Co.	Lead-zinc ore.
17	Magmont	do.	Cominco American Inc.	Lead ore.
18	Rosiclare	Hardin and Pope, IL	Ozark-Mahoning Co.	Fluorspar.
19	Idol	Grainger, TN	Jersey Miniere Zinc Co.	Zinc ore.
20	Casteel[1]	Iron, MO	The Doe Run Co.	Lead ore.
21	Van Stone	Stevens, WA	Equinox Resources	Zinc ore.
22	Viburnum No. 29	Washington, MO	The Doe Run Co.	Lead ore.
23	Sweetwater	Reynolds, MO	ASARCO Incorporated	Do.
24	Lucky Friday	Shoshone, ID	Hecla Mining Co.	Lead-zinc ore.
25	Franklin 73	Clear Creek, CO	Franklin Consolidated Mining Co.	Gold ore.

[1]Includes Brushy Creek Mill.

TABLE 4
PRIMARY AND SECONDARY SLAB ZINC PRODUCED IN THE UNITED STATES

(Metric tons)

	1988	1989	1990	1991	1992
Primary:					
From domestic ores	196,476	229,870	230,470	217,691	227,127
From foreign ores	44,818	30,435	32,234	35,585	44,762
Total	241,294	260,305	262,704	253,276	271,889
Secondary:					
At primary smelters	W	W	W	W	W
At secondary smelters	W	W	W	W	W
Total	88,492	97,904	95,708	r122,457	127,623
Grand total (excludes zinc recovered by remelting)	329,786	358,209	358,412	r375,733	399,512

rRevised. W Withheld to avoid disclosing company proprietary data.

TABLE 5
DISTILLED AND ELECTROLYTIC ZINC, PRIMARY AND SECONDARY, PRODUCED IN THE UNITED STATES, BY GRADE

(Metric tons)

Grade	1988	1989	1990	1991	1992
Special High	90,034	113,819	116,647	W	W
High	74,870	79,145	86,006	96,469	100,250
Continuous Galvanizing	44,890	48,252	50,577	r41,358	50,503
Controlled Lead	W	W	W	W	W
Prime Western	119,992	116,993	105,182	r237,906	248,759
Total	329,786	358,209	358,412	r375,733	399,512

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Prime Western."

TABLE 6
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)	
	1991	1992
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	54,000	54,000
Electrothermic:		
Zinc Corp. of America, Monaca, PA[1]	136,000	146,000
Total available capacity	370,000	380,000
Total operating capacity	370,000	380,000

[1]Includes secondary capacity.

TABLE 7
U.S. CONSUMPTION OF ZINC

(Metric tons)

	1988	1989	1990	1991	1992
Slab zinc, apparent (rounded)	1,089,000	1,060,000	992,000	933,000	1,035,000
Ores and concentrates (zinc content)	2,412	2,107	2,178	(1)	W
Secondary (zinc content)[2]	248,461	249,122	245,692	(1)	W
Total (rounded)	1,340,000	1,311,000	1,240,000	1,165,000	1,276,000

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Data revised and withheld to avoid disclosing company proprietary data; included in "Total."
[2]Excludes secondary slab and remelt zinc.

TABLE 8
U.S. REPORTED CONSUMPTION OF SLAB ZINC IN 1992, BY INDUSTRY USE AND GRADE

(Metric tons)

Industry use	Special High Grade	High-Grade	Prime Western	Remelt and other grades	Total
Galvanizing	78,827	77,536	184,120	55,997	396,480
Zinc-base alloys	164,255	W	W	W	165,598
Brass and bronze	45,665	W	37,758	W	112,990
Zinc oxide	W	W	—	—	71,224
Other	W	W	W	—	67,936
Total	414,661	119,660	223,723	56,185	[1]814,228

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Data do not add to total shown because of independent rounding.

TABLE 9
ROLLED ZINC PRODUCED AND QUANTITY AVAILABLE FOR CONSUMPTION IN THE UNITED STATES

(Metric tons)

	1991	1992
Production[1]	41,756	48,160
Exports	10,385	5,423
Imports for consumption	537	171
Available for consumption	30,503	44,391

[1]Includes other plate more than 0.375 inch thick and rod and wire.

TABLE 10
ZINC CONTENT OF PRODUCTION AND SHIPMENTS OF ZINC PIGMENTS AND COMPOUNDS[1] IN THE UNITED STATES

(Metric tons)

	1991		1992	
	Production	Shipments	Production	Shipments
Zinc chloride[2]	5,311	5,554	6,332	6,309
Zinc oxide	94,564	96,064	104,901	103,037
Zinc sulfate	25,483	24,873	28,236	27,763

[1]Excludes leaded zinc oxide and lithopone.
[2]Includes zinc content of zinc ammonium chloride.

TABLE 11

REPORTED DISTRIBUTION OF ZINC CONTAINED IN ZINC OXIDE SHIPMENTS, BY INDUSTRY[1]

(Metric tons)

Industry	1988	1989	1990	1991	1992
Agriculture	1,988	1,520	1,764	1,822	W
Ceramics	3,302	2,780	2,618	2,973	W
Chemicals	21,898	22,462	20,723	20,177	W
Paints	3,441	4,695	4,579	3,848	3,669
Photocopying	W	W	W	W	W
Rubber	55,213	57,781	56,622	55,254	W
Other	12,189	13,277	12,681	11,990	99,368
Total	98,031	102,515	98,987	96,064	103,037

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

[1]In addition, zinc oxide was imported as follows, in metric tons: 1988—73,042; 1989—59,557; 1990—49,454; 1991—38,215; and 1992—38,997; distribution cannot be distinguished by industry.

TABLE 12

U.S. EXPORTS OF ZINC ORES AND CONCENTRATES, BY COUNTRY

(Zinc content)

	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	3,618	$2,065	114	$1,030
Belgium	108,147	54,188	62,190	31,934
Bulgaria	2,000	1,668	—	—
Canada	184,398	r118,367	182,623	106,086
Germany	(1)	(1)	30,485	20,453
Haiti	15	195	4	51
Italy	14,982	6,975	8,397	3,981
Jamaica	7	19	—	—
Japan	r43,556	23,942	66,628	46,403
Korea, Republic of	7,090	4,996	6,378	4,252
Mexico	r1,013	r1,093	2,930	2,373
Netherlands	81	48	27	96
Switzerland	(2)	4	—	—
Taiwan	4	10	—	—
United Kingdom	r16,908	r7,356	28,143	22,682
Total[3]	r381,818	r220,927	387,918	239,343

rRevised.

[1]Revised to zero.

[2]Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 13
U.S. EXPORTS OF ZINC COMPOUNDS

	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Lithopone	1,176	$1,984	40	$226
Zinc chloride	1,306	905	2,532	1,395
Zinc compounds, n.s.p.f.	3,944	30,474	4,554	40,382
Zinc oxide	6,653	8,756	5,594	7,263
Zinc sulfate	3,087	8,475	3,259	9,664
Zinc sulfide	146	508	102	663

Source: Bureau of the Census.

TABLE 14
U.S. IMPORTS FOR CONSUMPTION OF ZINC PIGMENTS AND COMPOUNDS

	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Lithopone	1,312	$1,125	1,267	$804
Zinc chloride	2,175	2,142	3,096	2,611
Zinc compounds, n.s.p.f.	221	467	260	574
Zinc oxide	38,215	43,712	38,997	49,702
Zinc sulfate	4,617	2,384	3,828	2,313
Zinc sulfide	1,566	3,435	1,624	3,590

Source: Bureau of the Census.

TABLE 15

ZINC: WORLD MINE PRODUCTION (CONTENT OF CONCENTRATE AND DIRECT SHIPPING ORE UNLESS NOTED), BY COUNTRY[1]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992e
Algeria	6.3	6.3	4.2	r2.6	24.0
Argentina	36.8	43.2	38.7	39.3	241.0
Australia	759.0	803.0	r937.0	1,048.0	21,028.0
Austria	17.1	14.8	r16.7	14.8	215.8
Bolivia	57.0	74.8	103.8	r129.8	2143.9
Bosnia and Herzegovina[3]	—	—	—	—	8.0
Brazil	155.5	178.4	r158.0	r130.0	140.0
Bulgaria	r44.1	r39.7	r34.7	r29.1	29.0
Burma	1.6	1.4	r1.6	r1.8	1.3
Canada	1,370.0	1,216.1	1,203.2	r1,156.6	21,311.9
Chile	19.2	18.4	25.1	31.0	30.0
China e	528.0	538.0	619.0	650.0	670.0
Colombia	.1	.4	.4	r.3	.3
Congo (Brazzaville) e	r—	r—	r—	r—	—
Czechoslovakia e	7.0	27.1	7.5	7.0	7.0
Ecuador e	.1	.1	.1	.1	.1
Finland	63.9	58.4	51.7	55.5	230.8
France	31.1	r26.7	23.9	27.1	16.5
Georgia[4]	—	—	—	—	5.0
Germany: Western states	75.6	63.9	58.1	54.0	214.3
Greece	21.2	25.0	26.7	r39.0	227.0
Greenland	77.5	71.5	47.9	—	—
Honduras	23.5	37.2	29.6	r38.3	32.0
India	61.4	65.4	r74.0	r102.0	148.0
Iran e	15.0	29.0	r29.0	r70.0	75.0
Ireland	173.2	168.8	166.5	187.5	2194.1
Italy	37.2	43.3	r43.0	r36.3	229.5
Japan	147.2	131.8	127.3	133.0	2134.5
Kazakhstan[4]	—	—	—	—	200.0
Korea, North e	225.0	230.0	230.0	200.0	200.0
Korea, Republic of	21.8	23.2	22.8	r22.0	23.0
Macedonia[3]	—	—	—	—	20.0
Mexico	262.2	284.1	322.5	r300.7	2279.0
Morocco	10.9	18.7	18.8	r24.3	221.0
Namibia	36.7	41.7	37.7	r33.2	236.1
Norway	17.8	15.0	17.5	18.9	221.1
Peru	485.4	597.4	r583.9	r627.8	2600.6
Philippines	1.4	1.2	.1	r—	—
Poland	e184.0	179.0	178.0	e144.0	2151.0
Romania e	41.0	254.5	r35.0	r26.0	29.0
Russia[4]	—	—	—	—	150.0
Saudi Arabia	.7	2.6	2.5	2.5	2.5
Serbia and Montenegro[3]	—	—	—	—	35.0
South Africa, Republic of	89.6	77.3	74.8	r64.4	269.8

See footnotes at end of table.

TABLE 15—Continued

ZINC: WORLD MINE PRODUCTION (CONTENT OF CONCENTRATE AND DIRECT SHIPPING ORE UNLESS NOTED), BY COUNTRY[1]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992[e]
Slovenia[3]	—	—	—	—	5.0
Spain	r281.7	r266.7	e258.0	r261.3	2201.8
Sweden	r200.4	173.5	r164.1	r161.2	2169.8
Thailand	81.0	91.0	81.0	87.0	69.0
Tunisia	r8.5	10.0	7.0	r5.0	23.0
Turkey[5]	37.5	39.4	re40.0	re33.5	35.0
U.S.S.R.e[6]	r600.0	r550.0	r550.0	r475.0	—
United Kingdom	5.5	5.8	6.7	r1.1	—
United States	256.4	288.3	543.2	546.6	2551.6
Uzebekistan[4]	—	—	—	—	70.0
Vietnam[e]	5.5	5.5	5.5	r15.0	15.0
Yugoslavia[7]	91.2	94.7	83.8	e75.0	—
Zaire	75.7	72.8	61.8	r42.4	222.3
Zambia[8]	25.2	22.9	32.1	r19.8	19.0
Total[9]	r6,773.7	r6,807.8	r7,184.3	r7,169.7	7,136.5

[e]Estimated. [r]Revised.
[1]Table includes data available through July 13, 1993.
[2]Reported figure.
[3]Formerly part of Yugoslavia; data were not reported separately until 1992.
[4]Formerly part of the U.S.S.R.; data were not reported separately until 1992.
[5]Content in ore hoisted.
[6]Dissolved in Dec. 1991.
[7]Dissolved in Apr. 1992.
[8]Data are for years beginning Apr. 1 of that stated. Content of ore milled.
[9]Data may not add to totals shown because of independent rounding.

TABLE 16

ZINC: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992[e]
Algeria, primary	r37.0	r28.0	r23.6	r24.9	24.0
Argentina:					
Primary	32.7	31.6	31.5	35.8	35.0
Secondary	2.7	2.7	2.7	2.8	2.7
Total	35.4	34.3	34.2	38.6	37.7
Australia:					
Primary[2]	302.5	294.0	304.0	r322.0	330.0
Secondary	r e3.7	5.5	r4.5	r4.5	34.5
Total	r e306.2	299.5	r308.5	r326.5	334.5
Austria, primary and secondary	23.9	26.1	r26.0	r16.6	36
Belgium, primary and secondary	298.1	286.9	289.7	297.6	215.0
Brazil:					
Primary	139.7	155.8	149.5	r157.5	160.0
Secondary	4.3	6.4	4.6	r5.5	6.0
Total	144.0	162.3	154.1	r163.0	166.0
Bulgaria, primary and secondary	r82.0	r89.6	r73.0	r46.1	46.0
Canada, primary	703.2	669.7	591.8	660.6	670.0
China, primary and secondary[e]	420.0	451.0	550.0	r612.0	630.0
Czechoslovakia, secondary	1.4	1.3	1.7	r1.0	38
Finland, primary	156.1	162.5	174.9	170.4	3170.5
France, primary and secondary	274.1	265.8	264.1	299.6	304.7
Germany:					
Eastern states, primary and secondary	20.0	18.5	r12.7	—	—
Western states:					
Primary	r317.3	r301.0	r289.0	—	—
Secondary	r39.0	r52.5	r48.6	—	—
Total	r376.3	r372.0	r350.3	r345.7	3383.1
Hungary, secondary[e]	1.6	1.4	1.3	1.3	1.0
India:					
Primary	68.9	71.6	r79.1	85.8	136.8
Secondary[e]	.2	.2	.2	.2	.2
Total[e]	69.1	71.8	r79.3	86.0	137.0
Italy, primary and secondary	242.1	259.5	r264.4	r263.8	253.0
Japan:					
Primary	601.1	591.2	605.7	640.6	3645.0
Secondary	77.1	73.3	81.8	90.2	384.5
Total	678.2	664.5	687.5	730.8	3729.5
Kazakhstan, primary[4]	—	—	—	—	190.0
Korea, North, primary[e]	210.0	210.0	200.0	175.0	175.0
Korea, Republic of, primary	223.0	240.2	248.2	r254.1	3253.0
Macedonia[5]	—	—	—	—	32.0
Mexico, primary	192.5	193.3	199.3	r189.1	3151.6
Netherlands, primary and secondary[6]	211.0	203.0	208.5	r211.1	205.0
Norway, primary	121.2	120.4	125.1	r124.9	3127.6
Peru, primary	123.1	126.7	120.6	154.6	3126.4

See footnotes at end of table.

TABLE 16—Continued

ZINC: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1988	1989	1990	1991	1992[e]
Poland, primary and secondary	174.0	164.0	132.0	[r]126.0	135.0
Portugal, primary	5.5	5.0	[e]5.5	[r e]2.0	3.0
Romania, primary and secondary[e]	42.0	42.0	11.0	10.0	10.0
Russia:[4]					
Primary	—	—	—	—	140.0
Secondary	—	—	—	—	60.0
Total	—	—	—	—	200.0
Serbia and Montengero[5]	—	—	—	—	[3]14.2
South Africa, Republic of, primary	85.2	85.0	[r]91.8	91.5	92.0
Spain, primary and secondary	256.0	257.0	252.7	273.4	356.4
Thailand, primary	68.6	68.4	63.3	62.2	62.0
Turkey, primary	22.5	24.2	20.1	17.4	22.5
Ukraine, secondary[4]	—	—	—	—	20.0
U.S.S.R.:[e 7]					
Primary	848.0	862.0	780.0	700.0	—
Secondary	115.0	115.0	110.0	100.0	—
Total	963.0	977.0	890.0	800.0	—
United Kingdom, primary and secondary	76.0	79.8	93.3	100.7	[3]96.8
United States:					
Primary	241.3	263.1	262.7	253.3	271.9
Secondary	88.5	95.1	95.7	[r]122.5	127.6
Total	329.8	358.2	358.4	[r]375.8	[3]399.5
Uzbekistan, primary[4]	—	—	—	—	65.0
Vietnam, undifferentiated[e]	4.2	4.2	4.2	[r]10.0	10.0
Yugoslavia, primary and secondary[8]	127.5	119.4	113.7	[3]78.0	—
Zaire, primary	61.1	54.0	38.2	[r]28.3	[3]18.8
Zambia, primary	[r]18.3	[r]12.4	[r]9.7	[r]6.3	6.0
Grand total	[r]7,163.2	[r]7,190.4	[r]7,060.0	[r]7,174.9	6,875.2
Of which:					
Primary	[r]4,578.8	[r]4,570.1	[r]4,413.6	[r]4,156.3	3,876.1
Secondary	[r]333.5	[r]353.4	[r]351.1	[r]328.0	307.3
Undifferentiated	[r]2,250.9	[r]2,266.8	[r]2,295.3	[r]2,690.6	2,691.8

[e]Estimated. [r]Revised.

[1]Wherever 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, 1993.

[2]Excludes zinc dust.

[3]Reported figure.

[4]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[5]Formerly part of Yugoslavia; data were not reported separately until 1992.

[6]Sales for 1989-92.

[7]Dissolved in Dec. 1991.

[8]Dissolved in Apr. 1992.

ZIRCONIUM AND HAFNIUM

By Joseph M. Gambogi

Mr. Gambogi, a physical scientist with 10 years of Government and industry experience, has been a commodity specialist since 1988. Domestic survey data were prepared by the Section of Nonferrous Metals Data. World production data are provided by country specialists in the Division of International Minerals.

Zirconium and hafnium are relatively abundant in the Earth's crust; however, zircon (zirconium silicate) is the only naturally occurring mineral of commercial significance. Zircon is a byproduct of the mining and processing of heavy mineral sands for the titanium minerals rutile and ilmenite. The major end uses of zircon are refractories, foundry sands (including investment casting), and ceramic opacification. Zirconium and hafnium metal are both contained in zircon at a ratio of about 50:1. Zirconium-clad fuel rods and hafnium control rods make up the core of nuclear reactors. Commercial-grade zirconium, unlike nuclear grade, contains hafnium and is used in the chemical process industries because of its excellent corrosion resistance.

DOMESTIC DATA COVERAGE

Data in this report are collected from various sources. U.S. mine production of zircon sand is obtained by directly surveying the three producing operations, 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, and frits. However, owing to a lack of participation from larger industries (e.g., refractories), it is difficult to publish reliable consumption figures, thus 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 these reasons that only estimated consumption numbers can be used for industry groupings. *(See table 2.)*

BACKGROUND

Definition, Grades, and Specifications

Zirconium and hafnium are chemically similar elements with atomic numbers 40 and 72, respectively. Both elements are classified in the periodic table as members of Group 4b and have only one oxidation state, +4, and have similar ionic radii. Owing to these similar properties, zirconium and hafnium are usually found together in nature.

Zircon purity is commonly measured by the combined zirconium dioxide (zirconia)-hafnium dioxide (hafnia) content. Hafnium occurs in zircon in a typical ratio of 1 part hafnium to 50 parts zirconium. Commercially available zircon typically grades 64.5% to 66% combined zirconia-hafnia. Zircon grades are similar on a worldwide basis, but no standard requirement exists. Standard-grade zircon has a typical analysis of 65% minimum zirconium dioxide-hafnium dioxide, 0.25% maximum titanium dioxide, and 0.12% maximum iron oxide. Intermediate-grade zircon has a typical analysis of 65.5% zirconium dioxide-hafnium dioxide, 0.03% maximum titanium dioxide, and 0.1% maximum iron oxide. Premium-grade zircon has a typical analysis of 66% minimum zirconium dioxide-hafnium dioxide, 0.1% maximum titanium dioxide, and 0.05% maximum iron oxide.

Zirconium metal for the chemical process industry is available in three American Society for Testing and Materials (ASTM)-approved grades: R60702 for unalloyed zirconium, R60704 for the tin-iron alloy, and R60705 for the niobium alloy. Zirconium alloys for the nuclear industry, the compositions of which are specified, are designated as Zircaloy-2, Zircaloy-4, or Zr-2.5 Cb.

Hafnium metal as produced by the Kroll process is called hafnium sponge or "Kroll-process" sponge or metal. After refining by the iodide process, the metal is called crystal bar.

Industry Structure

Zirconium ore minerals are sold by mine producers directly to processors, consumers, and commodity brokers. Primary ore concentrate of zircon and baddeleyite may be used in certain industrial uses with little or no processing, but most applications require additional processing. Processors grind the concentrates to specification for certain applications or convert zircon and baddeleyite to refined products such as zirconium metal, hafnium metal, alloys, high-purity zirconia, and other compounds. Extensive processing is required to produce ultrapurity powders and nuclear-grade metals. Processors producing oxide and metal are often partially integrated. Fabricated and semifabricated products are marketed directly to manufacturers.

Geology-Resources

Zircon is a common accessory mineral in igneous rocks. It is frequently found associated with silicic rocks, including granite, granodiorite, syenite, monzonite, and nepheline syenite. Zircon is also found in pegmatites, crystalline

limestone, and the metamorphic rocks gneiss and schist. From an economic viewpoint, sedimentary placer deposits are the most significant.

Placer deposits originate when chemical and mechanical weathering liberates minerals from the source rock. This is followed by transport of the minerals to the sea by water, wind, and gravity. Upon reaching the sea, deposits of economic value form primarily by hydraulic sorting. Heavy minerals, including zircon, are concentrated by marine currents and wave action. Mechanical sorting by the sea and wind further sorts the grains to produce well-sorted beach deposits.

Technology

Economic concentrations of zircon are found in association with other heavy minerals such as ilmenite, rutile, and monazite. Heavy mineral sand deposits are usually mined by floating cutterhead or bucketwheel dredges that handle up to 2,800 mt/h of sand. Sand recovered by these techniques is sent to a wet mill and treated by wet-gravity methods, using spirals, cones, sluices, or jigs to produce a mixed heavy mineral concentrate containing zircon. The mixed concentrate typically contains other economic minerals such as the titanium minerals, ilmenite, rutile, and leucoxene, and often smaller amounts of the rare-earth mineral monazite.

The mixed heavy mineral concentrate is scrubbed, dried, and screened, and the individual heavy minerals are separated by electrostatic, electromagnetic, magnetic, and gravity processes. Zircon, in contrast to ilmenite, rutile, and many other heavy minerals, is nonconductive and can be separated along with monazite by electrostatic methods. Monazite, which is slightly magnetic and may be slightly higher in specific gravity, can be separated from zircon by electromagnets or by additional gravity methods.

To obtain premium-grade zircon, the zircon concentrate from the electrostatic-electromagnetic circuit is again subjected to gravity concentration to reduce the content of aluminum- and titanium-bearing minerals. Certain zircon products are leached in an acidic solution to remove iron oxide and other grain coatings.

Zircon used in foundry and certain refractory applications is graded and sized and, in many cases, ground or milled to produce zircon flour. Foundry applications generally use zircon sand and flour mixtures, which may be treated with resin coatings and binders.

Zirconia is produced directly from zircon by either plasma fusion or electric arc techniques. The plasma method for zirconia production employs heating a finely divided zircon above its dissociation temperature to form small zirconia crystallites and glassy amorphous silica. The hot zirconia and silica particles are rapidly quenched, and the silica is removed by leaching with sodium hydroxide, leaving insoluble zirconia crystallites.

In electric arc production, zircon is heated to temperatures of approximately 2,500° C, producing dissociation. The silicon component is vaporized and recovered as fumed silica, leaving a residual melt that is air quenched to form zirconia. A more complex electric arc method melts a mixture of limestone and zircon to form calcium zirconate and tricalcium silicate clinker. Cooling of the mixture disintegrates it into a very fine powder composed of tricalcium silicate and lime and a coarser fraction of calcium zirconate crystals. The calcium zirconate is separated from the other constituents by either air classification or flotation. The acid-soluble calcium zirconate crystals are treated with acids or other reagents, forming zirconia or zirconium salts.

Other compounds of zirconium, such as the hydrous or carbonated oxide, acetate, sulfate, fluoride, chloride, and organic complexes, are usually prepared from zirconia or its salts by chemical reactions.

The deBoer-van Arkel iodide process, first described in 1925, is essentially a refining process and was commercially adopted in 1945 as the first practical method for producing ductile zirconium metal. Zirconium metal is reacted with iodine vapor at 200° C to form zirconium tetraiodide, leaving most impurities except hafnium in a solid state. The gaseous halide diffuses to a heated filament where, at 1,300° C, the reaction is reversed, depositing very high-purity elemental zirconium on the filament and regenerating iodine vapor for reuse. The process yields high-purity metal but is expensive to operate. Industrial-scale plants for producing zirconium metal are based on the Kroll process in which zirconium tetrachloride is reduced with molten magnesium in an inert atmosphere. The resulting mixture of zirconium metal sponge and magnesium chloride is vacuum-distilled to remove the magnesium chloride. The zirconium is crushed, sized, and compacted to form a consumable electrode. The electrode is arc melted in an inert atmosphere to give a first-melt ingot. The first-melt ingot is then used as a consumable electrode to produce a metallurgically homogeneous second-melt ingot, which is machined to give a clean surface and readied for fabrication.

Zirconium tetrachloride is produced by chlorinating zircon sand in a fluidized bed containing carbon at a temperature of about 1,150° C.

Byproducts and Coproducts

Zircon is mined from deposits with a heavy mineral grade between 2% and 20%. The associated economic heavy minerals are ilmenite, leucoxene, rutile, monazite, and the tin minerals cassiterite and stannite. Its classification as a byproduct or a coproduct depends on the fraction of zircon in relation to the other minerals. If zircon and the titanium minerals are expected to account for the majority of the revenue, it is considered a coproduct. If minerals other than zircon provide the carrying costs of the operation, then zircon is considered a byproduct. Small quantities of baddeleyite are recovered as a byproduct of copper, phosphate, and vermiculite mining in the Republic of South Africa.

ANNUAL REVIEW

Issues

Processing of some mineral sands 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 usually the minerals of consequence because 100% separation of a heavy minerals deposit is impossible to obtain within economic considerations. 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 result in some radioactive contamination. Monazite processing to obtain rare-earth elements results in relatively large production of a byproduct, thorium nitrate. Because demand for thorium is greater than that for rare earths, excess thorium has been placed in low-level storage sites such as those in 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. However, some concentration does occur in the zirconium chemical and metal industries. These industries have 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%, the 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 the Okayama Prefecture. Basically the policy 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 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.

Production

Domestic production and consumption of zircon concentrates increased moderately in 1992 but were significantly lower than levels achieved in the late 1980's. Milled zircon production increased 2% over that of 1992 while zirconium oxide production decreased 11%.

U.S. mine producers of zircon in 1992 were RGC (USA) Mineral Sands, Inc. and E.I. du Pont de Nemours & Co. Both producers mined heavy mineral sands deposits in Florida. Nord Ilmenite produced zircon concentrate from a previously mined mineral sands deposit in New Jersey.

Countless other end products also were 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. Zirconium chemicals and zirconia are further processed 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

In 1992, demand for zircon products increased moderately and reductions in stock levels over the previous 2 years assisted in improving market conditions for zircon producers. Apparent consumption of zircon concentrates increased 8% compared with that of 1991. Published prices for zircon and zircon oxide-related products varied considerably by product type.

Published prices for zirconium and hafnium products were unchanged while the domestic list price for standard and premium-grade zircon decreased 20% compared with that of 1991. Prices for domestic zircon and aluminum silicates increased 32%, and imported grades of zircon sand increased in the range of 42% to 72%. The published price for imported baddeleyite concentrate increased in the range of 13% to 19% over that of 1992. The changes in prices for zircon oxides were mixed. Prices for commercial-grade powder increased 7% while electronic-grade prices were unchanged. Meanwhile, insulating grades of zirconium oxides decreased 10% to 20%.

World Review

Australia.—Production of zircon by Australian producers was estimated to have increased 20% compared with that of 1991. However, production was significantly less than the record level achieved during 1989. Inventory levels also were also reported to have declined.

Cable Sands (WA) Pty. Ltd. announced plans to proceed with its Jangardup mineral sands project in Western Australia. When completed, the project was expected to produce 200,000 tons per year of ilmenite, 8,000 tons per year of leucoxene, and 8,000 tons per year of zircon. Construction was set to begin in the first quarter of 1993, and initial production was scheduled for April 1994.

ISK Mineral Pty. Ltd. exhausted its Waroona deposit and closed its mining operations south of Perth, Western Australia. After postponing plans to develop its Dardanup mineral sands deposit, ISK scheduled to close its Picton separation plant in 1993. Before the closure, Waroona's capacity was estimated to be 105,000 tons per year of ilmenite, 6,500 tons per year of zircon,

and 2,000 tons per year of leucoxene.[1]

Owing to poor market conditions, ICI Australia Ltd. closed its zirconia ceramic facility at Rockingham, Western Australia. Although the facility was opened in 1987 to produce electronic-grade zirconia powders, it was reported to be operating at only 25% of its 400-ton-per-year capacity. ICI continued to operate production facilities in North America.[2]

CRA Ltd.'s plans for the development of the Wimmera (WIM) mineral sands project near Horsham, Victoria, were significantly curtailed. Although promising mineral recoveries had been achieved during a pilot plant investigation, CRA concluded the project was not economically viable. The WIM deposit was reported to have a measured resource of 25 million tons, and the project was expected to annually produce 290,000 tons of heavy mineral concentrates, including 130,00 tons of zircon. The company planned to continue technical development of processing alternatives.

Newcrest Mining Ltd. closed its Woodburn mineral sands mining and processing operations in New South Wales. Although the operation was capable of processing about 24,000 tons per year of concentrate, actual production rates were reported to be significantly less.[3]

Canada.—In 1992, Tiomin Resources Inc. was in the process of evaluating the development of a deposit reported to have resources exceeding 96 million tons of heavy minerals. Tiomin Resources Inc. held mineral exploration rights to the 208-square-meter property at Natashquan, Quebec.

South Africa, Republic of.—The Anglo American Corp. announced plans to proceed with the development of its Namakwa heavy mineral sands project located in the northwestern cape region of South Africa. When completed, the project is expected to initially produce 195,000 tons annually of high TiO_2 slag. In addition to the recovery of ilmenite used for smelting to high TiO_2 slag, the project is expected to recover an estimated 140,000 tons of zircon and 38,000 tons of rutile. Reserves are reported to be 500 million tons, and production is scheduled to begin in 1994.[4]

Richards Bay Minerals sought approval of its St. Lucia mineral sands project in South Africa. Reserves at St. Lucia are estimated at 9.74 million tons of ilmenite, 0.94 million tons of rutile, and 1.66 million tons of zircon.[5]

Vietnam.—Westralian Sand Ltd. was reported to be investing in the modernization and possible expansion of a heavy mineral operation in Ha Tinh, Vietnam. Westralian Sand's investment represented a 60% interest in the operation. The remaining interest was held by the Provincial government and the Vietnamese Ministry of Heavy Industry.

Current Research

Sierra Rutile Ltd. (SRL) developed a froth flotation process to separate fine size zircon, rutile, and ilmenite from heavy mineral dry mill tailings. The froth flotation process was developed to reprocess dry mill tailings that have been stockpiled for many years at SRL's rutile operations. Previously at SRL, ilmenite was recovered as a byproduct but no attempt was made to separate zircon. The new process produces a zircon-rich concentrate and a rutile/ilmenite tailing that can be processed by conventional means to produce salable rutile and ilmenite concentrates. Sierra Rutile was granted a U.S. patent for the zircon-rutile-ilmenite process.[6]

OUTLOOK

Zircon is a byproduct of heavy mineral operations whose primary products are titanium-bearing ores and concentrates. Almost all titanium ores are consumed for producing titanium dioxide, the predominant white pigment used in most industries. Therefore, zircon supply is largely driven by demand for titanium dioxide pigments. Because global demand in the titanium pigment industry is expected to increase moderately over the next few years, the available supply of zircon is also expected to increase moderately.

The outlook for demand of zircon materials is determined by the major consuming industries, including the steel, glass, refactories, and ceramics markets. During the late 1980's, a temporary shortage of material caused prices for zircon products to soar. In reaction to soaring prices and the material shortage, consuming industries developed substitutions and process changes that have eroded zircon demand over the past few years. However, zircon producers have lower price levels and ensure a stable supply of material. If the global economic conditions permit, zircon demand is expected to increase moderately over the next few years.

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[1]Industrial Minerals. ISK Minsands Development Shelved. No. 305, Feb. 1993. p. 9.

[2]———. ICI to Close Zirconia Powder Plant. No. 302, Nov. 1992, p. 10.

[3]———. Sands Run Out for Woodburn. No. 299, Aug. 1992, p. 9.

[4]Mintek Bulletin. Namakwa Sands Gets Green Light. No. 56, Dec. 1992, p. 1.

[5]Mining Journal. Favorable Conclusion for St. Lucia. V. 320, No. 8218, Apr. 2, 1993, p. 239.

[6]Proceedings from 10th International Minerals Congress. Development and Operation of Zircon Flotation at Sierra Rutile Ltd., pp. 160-172.

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.

TABLE 1
SALIENT U.S. ZIRCONIUM STATISTICS

(Metric tons)

	1988	1989	1990	1991	1992
Zircon:					
Production:					
Concentrates	117,606	118,388	102,073	103,140	108,156
Milled zircon	64,393	54,699	43,886	44,403	45,074
Exports	21,794	48,071	30,195	31,333	27,853
Imports for consumption[1]	76,331	73,129	26,783	35,706	37,439
Consumption, apparent[1]	176,991	145,683	102,713	r111,148	119,951
Stocks, Dec. 31: Dealers and consumers[2]	34,370	32,133	28,081	r24,446	21,572
Zirconium oxide:					
Production[3]	6,845	10,030	7,483	9,747	8,691
Exports	1,809	NA	NA	NA	NA
Imports for consumption	1,089	NA	NA	NA	NA
Consumption, apparent	3,548	NA	NA	NA	NA
Stocks, Dec. 31: Producer[3]	507	502	737	r872	719

rRevised. NA Not available.
[1]Includes insignificant amounts of baddeleyite.
[2]Excludes foundries.
[3]Excludes intermediate oxide associated with metal production.

TABLE 2
ESTIMATED CONSUMPTION OF ZIRCON, BY END USE, BASED ON TOTAL APPARENT CONSUMPTION

(Metric tons)

End use	1991	1992
Zircon refractories[1]	18,000	21,000
AZS refractories[2]	9,000	9,000
Zirconia and AZ abrasives[3]	W	W
Alloys[4]	W	W
Foundry applications	32,000	35,000
Other[5]	38,000	40,000
Total	112,000	120,000

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Dense and pressed zircon brick and shapes.
[2]Fused cast and bonded alumina-zirconia-silica-base refractories.
[3]Alumina-zirconia-base abrasives.
[4]Excludes alloys more than 90% zirconium.
[5]Includes chemicals, zirconium metal, welding rods, sandblasting, and other miscellaneous uses.

TABLE 3

PUBLISHED YEAREND PRICES OF ZIRCONIUM AND HAFNIUM MATERIALS

Specification of material	1991	1992
Zircon:		
Domestic, standard-grade, f.o.b. Starke, FL, bulk, per short ton[1]	$331.00	$265.00
Domestic, 75% minimum quantity zircon and aluminum silicates, Starke, FL, bulk, per short ton[1]	184.00	242.00
Domestic, premium-grade zircon, Starke, FL, bulk, per short ton[1]	368.00	294.00
Imported sand, minimum 65% ZrO_2, f.o.b., bulk, per metric ton[2]	228.00-266.00	309.00-386.00
Imported sand, minimum 65.5% to 66% ZrO_2, f.o.b., bulk, per metric ton[2]	228.00-266.00	348.00-425.00
Imported sand, minimum 66% ZrO_2, f.o.b., bulk, per metric ton[2]	228.00-266.00	386.00-464.00
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	340.00-600.00
Baddeleyite, imported concentrate:[4]		
96% to 98% ZrO_2, minus 100-mesh, c.i.f. Atlantic ports, per pound	.45- .60	.50- .75
99%+ ZrO_2, minus 325-mesh, c.i.f. Atlantic ports, per pound	1.07- 1.20	1.16- 1.40
Zirconium oxide:[3]		
Powder, commercial grade, drums, 2,000-pound minimum, per pound	2.00- 7.00	3.00- 6.60
Electronic, same basis, per pound	3.50- 8.00	3.50- 8.00
Insulating, stabilized, 325° F, same basis, per pound	4.50	3.35- 4.00
Insulating, unstabilized, 325° F, same basis, per pound	5.00	3.35- 4.00
Dense, stabilized, 300° F, same basis, per pound	3.00	3.60
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 pound[5]	75.00- 95.00	75.00- 95.00

[1]E. I. du Pont de Nemours & Co. Inc. price list, July 8, 1991, and July 1, 1992, respectively.
[2]Industrial Minerals (London). No. 291, Dec. 1991, p. 63; and No. 303, Dec. 1992, p. 67.
[3]Chemical Marketing Reporter. V. 240, No. 26, Dec. 23, 1991, p. 32; and v. 242, No. 26, Dec. 28, 1992.
[4]The Applegate Group and American Vermiculite Corp. baddeleyite price lists.
[5]American Metal Market. V. 99, No. 239, Dec. 13, 1991, p. 6; and V. 101, No. 1, Jan. 4, 1992, p. 6.

TABLE 4

U.S. EXPORTS OF ZIRCONIUM, BY CLASS AND COUNTRY

Class and country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ore and concentrates:				
Argentina	445	$390	336	$258
Australia	92	128	39	46
Belgium	171	111	113	64
Brazil	694	310	644	214
Canada	6,074	3,829	3,561	1,981
Chile	36	53	7	3
Colombia	1,521	1,663	2,000	1,591
Costa Rica	20	23	54	57
Dominican Republic	92	115	227	262
Ecuador	419	314	191	108
Egypt	196	140	188	124
France	724	532	427	286
Germany	5,048	4,595	10,325	4,342
Ireland	—	—	16	12
Italy	239	117	20	10
Japan	584	186	291	459
Korea, Republic of	166	219	204	91
Mexico	6,303	2,721	6,206	1,963
Netherlands	5,993	2,656	—	—
Pakistan	97	106	285	414
Peru	200	137	—	—
Singapore	170	163	175	150
Spain	17	11	—	—
Taiwan	36	42	54	49
United Kingdom	458	642	491	299
Uruguay	59	60	29	17
Venezuela	1,078	945	1,092	883
Other	403	398	880	639
Total[1]	31,333	20,607	27,853	14,323
Unwrought zirconium and waste and scrap:				
Belgium	13	147	43	444
Canada	4	165	—	—
France	13	275	109	3,077
Germany	44	504	24	724
Italy	9	96	—	—
Japan	94	3,442	124	6,450
Netherlands	14	192	1	36
Switzerland	6	185	41	966
Taiwan	5	62	—	—
United Kingdom	25	524	28	844
Other	11	191	18	529
Total[1]	238	5,785	389	13,070

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

Source: Bureau of the Census.

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF ZIRCONIUM AND HAFNIUM, BY CLASS AND COUNTRY

Class and country	1991		1992	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Zirconium ore and concentrates:[1]				
Australia	20,865	$8,383	24,482	$4,876
Canada	—	—	40	9
France	23	110	—	—
Japan	13	156	—	—
Netherlands	20	14	101	120
South Africa, Republic of	14,615	4,725	12,708	1,707
United Kingdom	166	371	108	178
Other	4	13	(2)	16
Total	35,706	13,772	37,439	6,906
Zirconium, unwrought and waste and scrap:				
Canada	24	141	61	281
France	53	358	18	55
Germany	37	363	13	259
Japan	36	239	17	147
Sweden	6	34	—	—
United Kingdom	38	184	—	—
Other	3	28	6	79
Total	197	1,347	115	821
Hafnium, unwrought and waste and scrap:				
France	3	475	2	430
Germany	(2)	14	(2)	1
Total	3	489	2	431

[1]Australia and the Republic of South Africa are believed to be point of origin; other countries are point of shipment.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 6

ZIRCONIUM MINERAL CONCENTRATES: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1988	1989	1990	1991	1992e
Australia	480,049	511,000	437,000	292,000	300,000
Brazil[2]	28,029	32,970	16,907	r18,590	19,000
China e	15,000	15,000	15,000	15,000	15,000
India e	15,000	17,200	18,000	18,200	18,000
Indonesia e	—	2,500	2,500	2,500	2,500
Malaysia	25,671	18,704	4,279	5,579	3,2,608
Russia[4]	—	—	—	—	3,000
Sierra Leone	—	—	—	1,119	1,200
South Africa, Republic of e 5	150,000	150,000	3,151,536	230,000	230,000
Sri Lanka	e3,000	21,983	19,727	26,123	30,000
Thailand	5,098	1,496	490	2,573	2,500
Ukraine[4]	—	—	—	—	75,000
U.S.S.R. e 6	90,000	90,000	85,000	80,000	—
United States	117,606	118,388	102,073	103,140	3,108,156
Total	929,453	979,241	852,512	r794,824	806,964

eEstimated. rRevised.

[1]Includes data available through June 3, 1993.

[2]Includes production of zircon and caldasite.

[3]Reported figure.

[4]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[5]Includes production of zircon and baddeleyite.

[6]Dissolved in Dec. 1991.

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