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Minerals Yearbook

U.S.
DEPARTMENT
OF THE
INTERIOR

BUREAU OF MINES

1990

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UNITED STATES DEPARTMENT OF THE INTERIOR • Manuel Lujan, Jr., Secretary

BUREAU OF MINES • T S Ary, Director

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

U.S. GOVERNMENT PRINTING OFFICE

WASHINGTON : 1993

Foreword

This edition of the Minerals Yearbook discusses the performance of the worldwide minerals industry during 1990 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. A chapter on organic materials also has been added to the Minerals Yearbook series beginning with the 1990 volume. In addition, a chapter on survey methods used in data collection with a statistical summary of nonfuel minerals and a chapter on trends in mining and quarrying in the metals and industrial mineral industries are included.

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

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

T S Ary, *Director*

Acknowledgments

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

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

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

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

Statistics on world production were compiled in the Branch of Geographic Data, 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 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 5 years of Government experience, has been with the U.S. Bureau of Mines Branch of Statistics and Methods Development since 1990.

Mr. Smith, Mineral Data Assistant in the Branch of Data Collection and Coordination, was assisted in the preparation of the Statistical Summary by Sarah P. Guerrino, Chief, Section of Ferrous Metals Data; Imogene P. Bynum, Chief, Section of Nonferrous Metals Data; Barbara E. Gunn, Chief, Section of Industrial Minerals Data; and William L. Zajac, Chief, Section of International Data.

SURVEY METHODS

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

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

Data Collection Surveys

The Bureau begins the collection of domestic nonfuel minerals and materials statistics by appraising the information requirements of Government and private organizations of the United States. Information needs that can be satisfied by data from the minerals industries are expressed as questions on U.S. Bureau of Mines survey forms. 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 169 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. U.S. Bureau of Mines State Mineral Officers, State geologists, Federal organizations (e.g., Mine Safety and Health Administration), trade associations, industry representatives, and trade publications and directories are some of the sources that are used to develop and update survey listings. With few exceptions, a complete canvass of the list of establishments is employed rather than a sample survey. The iron and steel scrap industry is one of the exceptions where a sample survey is conducted.

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

Survey Processing

Approximately 26,000 establishments yield more than 50,000 responses to 169 surveys annually. Each completed survey form returned to the Bureau undergoes extensive scrutiny to ensure the highest possible accuracy of the mineral data. The statistical staff monitors all surveys to ensure that errors are not created by reporting in physical units different from the units requested on the form. Relationships between related measures, such as produced crude ore and marketable crude ore, are analyzed for consistency. Engineering relationships, such as recovery factors from ores and concentrates, are also employed. The totals for each form are verified, and currently reported data are checked against prior reports to detect possible errors or omissions.

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

The U.S. Bureau of Mines is modernizing and automating all of its survey processing and data dissemination functions. Automated commodity data system functions include computerized preparation of statistical tables; the use of desktop publishing to integrate text and tables; and the implementation of a microcomputer bulletin board, known as MINES-DATA, for electronic dissemination of minerals data.

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

FIGURE 1

A TYPICAL SURVEY FORM

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

A03

O.M.B.No. 1032-0006.
Approval Expires: 12/31/92

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.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
WASHINGTON, D.C. 20241

IRON ORE (Usable ore)

FACSIMILE NUMBER
1-800-543-0661

(Please correct if name or address has changed.)

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

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

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

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

SECTION 1. Mine or group covered by this report.

Name _____ State _____ County _____

SECTION 2. Stocks, production, and shipments of usable ore for the report month.
Report only ore products as shipped to consumer, such as direct-shipping ore, concentrates, or agglomerates.
Report ores produced in the United States only; do not include imports.

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

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

Remarks:

Name of person to be contacted regarding this report			Tel. area code	No.	Ext.
Address	No.	Street	City	State	Zip

May tabulations be published which could indirectly reveal the data reported above? ☐ (1) Yes ☐ (2) No

Signature	Title	Date

percentage, and the method of estimating the production or consumption for nonrespondents.

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

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

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

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

International Data

International data are collected by country specialists in the U.S. Bureau of Mines Division of International Minerals with assistance from the Section of International Data. The data are gathered from various sources, including published reports of foreign Government mineral and statistical agencies, international organizations, the U.S. Department of State, the United Nations, the Organization of Petroleum Exporting Countries, and personal contact by specialists traveling abroad. Each February an annual "Minerals Questionnaire" is sent through the Department of State to more than 130 U.S. Embassies asking them to provide estimates of mineral production for the host country for the preceding year. Missing data are estimated by Bureau country specialists based on historical trends and specialists' knowledge of current production capabilities in each country.

Publications

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

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

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

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

Volume III of the Minerals Yearbook presents the latest available mineral statistics for more than 160 countries with a summary review of the role of minerals in the world economy.

Mineral Industry Surveys contain timely statistical and economic data on minerals. The surveys are designed to keep Government agencies and the public, particularly the mineral industry and the business community, informed of trends in the production, distribution, inventories, and consumption of minerals. Frequency of issue depends on the demand for current data. Mineral Industry Surveys are released monthly, quarterly, semiannually, or annually.

Mineral Commodity Summaries, up-to-date summaries 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 provides 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, which began monthly publishing on a trial basis in 1991, contains an index that measures the current and future short-term performance of four U.S. minerals industries. For each of the four industries, a composite coincident index and a composite leading index have been developed based on procedures and data similar to those used to construct the U.S. Department of Commerce's coincident and leading cyclical indicators for the national economy.

Information Circulars are primarily concerned with Bureau economic reviews and interpretative analyses. The series also includes surveys of mining and operating

activities, guides to marketing of mineral commodities, and compilations of historical information and statistical and economic data on minerals.

To purchase Volumes I, II, and III of the Minerals Yearbook and Minerals Today, contact the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. For free copies of individual annual reports of the Minerals Yearbook, the Mineral Industry Surveys, the Mineral Commodity Summaries, the State Mineral Summaries, and Information Circulars, contact Publications Distribution, U.S. Bureau of Mines, Cochrans Mill Road, P.O. Box 18070, Pittsburgh, PA 15236. To receive a copy of the Metal Industry Indicators, contact the Branch of Statistics and Methods Development, U.S. Bureau of Mines, MS 9701, 810 7th Street, NW, Washington, DC 20241.

Electronic Data Dissemination

In addition to the Bureau's printed publications, current Mineral Industry Surveys for several commodities and selected annual reports from the Minerals Yearbook are now available through the Bureau's MINES-DATA computer bulletin board. Using this system, the public may obtain information up to 4 weeks before published copies of the reports would arrive in the mail. The MINES-DATA system may be accessed by calling (202) 501-9825 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) 501-9554.

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		1988		1989		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
METALS							
Bauxite metric tons, dried equivalent		587,889	$10,566	W	W	W	W
Beryllium concentrates	metric tons	5,308	6	4,592	$5	4,548	e$5
Copper[2]	do.	1,416,928	3,764,353	r1,497,818	r4,323,965	1,587,191	4,309,693
Gold[2]	kilograms	200,914	2,831,281	r265,731	r3,268,548	290,202	3,609,954
Iron ore (includes byproduct material)	thousand metric tons	57,113	1,716,661	58,299	r1,839,873	57,010	1,740,925
Iron oxide pigments (crude	metric tons	39,711	3,815	r40,202	r4,561	37,071	4,615
Lead[2]	do.	384,983	315,222	410,915	356,477	473,992	480,917
Magnesium metal	do.	141,983	469,767	152,066	508,668	139,333	433,119
Molybdenum[3]	do.	45,941	271,039	r61,168	r427,477	61,580	346,262
Nickel[3]	short tons	—	—	382	r4,662	4,080	32,811
Palladium metal[4]	kilograms	3,730	14,750	4,850	22,454	5,930	21,735
Platinum metal[4]	do.	r1,240	r20,950	r1,430	r23,310	1,810	26,478
Silver[2]	metric tons	1,661	349,339	2,007	354,973	2,170	336,382
Zinc[2]	do.	244,314	324,249	275,883	499,103	515,355	847,485

See footnotes at end of table.

TABLE 1—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES

Mineral		1988		1989		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
Combined value of antimony, 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	$116,954	XX	r$233,783	XX	$237,523
Total metals[5]		XX	10,209,000	XX	11,868,000	XX	12,428,000
INDUSTRIAL MINERALS (EXCEPT FUELS)							
Abrasives[6]	metric tons	13,313	1,183	1,257	189	3,734	231
Asbestos	do.	W	W	17,427	W	W	W
Barite	thousand metric tons	404	15,512	290	12,625	439	15,554
Boron minerals[7]	metric tons	1,149,404	429,667	1,114,007	429,806	1,093,919	436,176
Bromine[e]	thousand kilograms	163,293	144,000	175,000	188,650	177,000	97,350
Cement:							
Masonry	thousand short tons	3,574	243,941	3,329	229,441	3,274	225,404
Portland	do.	74,074	3,575,906	74,202	3,592,255	75,596	3,683,400
Clays	metric tons	44,515,041	1,400,820	42,254,269	1,515,300	42,904,437	1,619,826
Diatomite	do.	628,680	143,774	617,164	136,754	631,062	137,982
Feldspar	do.	649,077	28,082	654,313	28,029	630,000	27,400
Fluorspar	do.	e63,500	W	e66,000	W	e63,500	W
Garnet (abrasive)	do.	42,506	4,707	42,604	4,408	47,009	6,937
Gem stones		NA	43,580	NA	42,901	NA	52,867
Gypsum (crude)	thousand short tons	16,390	109,205	17,624	128,448	16,406	99,567
Helium (Grade-A)	million cubic feet	2,574	95,238	2,879	106,523	3,059	113,183
Iodine	kilograms	998,000	W	1,508,000	23,947	1,972,84	930,486
Lime	thousand short tons	17,052	817,893	17,152	852,113	17,452	901,549
Mica (scrap)	thousand metric tons	130	6,793	119	6,273	109	5,841
Peat	thousand short tons	908	20,320	r775	17,636	795	19,200
Perlite	short tons	645,000	17,652	601,000	16,301	639,300	15,311
Phosphate rock	thousand metric tons	45,389	887,809	49,817	1,082,797	46,343	1,075,093
Potash (K_2O equivalent)	do.	1,521	240,300	1,595	271,515	1,716	303,337
Pumice	metric tons	352,895	4,129	424,000	8,213	442,848	10,687
Salt	thousand short tons	37,997	680,174	38,356	776,846	40,693	826,659
Sand and gravel:							
Construction	do.	923,400	3,126,000	e897,300	e3,249,100	910,600	3,249,400
Industrial	do.	28,480	388,000	29,205	410,200	28,406	436,200
Sodium compounds:							
Soda ash	thousand metric tons	8,738	644,973	8,995	764,146	9,156	836,188
Sodium sulfate (natural)	do.	361	31,377	340	31,104	349	33,748
Stone:[8]							
Crushed	thousand short tons	e1,247,800	e5,558,000	1,213,400	5,325,800	e1,222,000	e5,591,300
Dimension	short tons	e1,189,333	e196,289	1,206,995	208,311	e1,186,216	e209,691
Sulfur (Frasch)	thousand metric tons	4,341	430,814	3,780	378,712	3,676	335,189
Talc and pyrophillite	metric tons	1,233,716	31,185	1,253,128	W	W	W
Tripoli	do.	99,928	864	105,229	2,537	94,389	3,188

See footnotes at end of table.

TABLE 1—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES

Mineral		1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)	1990 Quantity	1990 Value (thousands)
INDUSTRIAL MINERALS (EXCEPT FUELS)—Continued							
Vermiculite	short tons	303,544	$33,948	293,320	$32,550	229,584	$19,075
Combined value of aplite, brucite, calcium chloride (natural), emery, graphite (natural, 1988-89), helium (crude), kyanite, lithium minerals, magnesite, magnesium compounds, marl (greensand), olivine, pyrites, staurolite, wollastonite, and values indicated by symbol W		XX	452,436	XX	483,672	XX	473,453
Total industrial minerals[5]		XX	19,805,000	XX	20,357,000	XX	20,891,000
Grand total[5]		XX	30,014,000	XX	32,225,000	XX	33,319,000

[e]Estimated. [r]Revised. 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]Recoverable content of ores, etc.
[3]Content of ore and concentrate.
[4]Revised due to the separation of palladium metal from platinum metal.
[5]Data may not add to totals shown because of independent rounding.
[6]Grindstones, pulpstones, and sharpening stones; excludes mill liners and grinding pebbles.
[7]Beginning with 1989 data reported in B_2O_3, 1988 data converted.
[8]Excludes abrasive stone and bituminous limestone and sandstone; all included elsewhere in table.

TABLE 2

NONFUEL MINERALS PRODUCED IN THE UNITED STATES AND PRINCIPAL PRODUCING STATES IN 1990

Mineral	Principal producing States, in order of quantity	Other producing States
Abrasives[1]	AR, WI, OH	
Antimony (content of ores, etc.)	ID	
Aplite	VA	
Asbestos	CA and VT	
Barite	GA, NV, MO, CA	IL and MT.
Bauxite	AR and AL	
Beryllium concentrate	UT	
Boron minerals	CA	
Bromine[e]	AR	
Brucite	NV	
Calcium chloride (natural)	MI and CA	
Cement:		
Masonry	IN, FL, MI, PA	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 CT, DE, LA, MA, MN, NH, NJ, NC, ND, RI, VT, WI.
Clays	GA, CA, WY, SC	All other States except AK, DE, HI, RI, VT, WI.
Copper (content of ores, etc.)	AZ, NM, UT, MT	CA, CO, ID, IL, MI, MO, NV, TN.
Diatomite	CA, NV, WA, OR	AZ.
Emery	OR	
Feldspar	NC, CA, CT, GA	ID, OK, SD.
Fluorspar	IL, UT, NV	
Garnet (abrasive)	ID and NY	
Gold (content of ores, etc.)	NV, CA, UT, SD	AK, AZ, CO, ID, MT, NM, OR, SC, WA.
Graphite (natural)	MT	

See footnotes at end of table.

TABLE 2—Continued

NONFUEL MINERALS PRODUCED IN THE UNITED STATES AND PRINCIPAL PRODUCING STATES IN 1990

Mineral	Principal producing States, in order of quantity	Other producing States
Gypsum (crude)	IA, MI, OK, NV	AR, AZ, CA, CO, IN, KS, LA, NM, NY, OH, SD,TX, UT, VA, WA, WY.
Helium	KS, WY, TX, NM	CO.
Iodine	OK	
Iron ore (includes byproduct)	MN, MI, MO, UT	CA, MT, NM, SD, TX.
Iron oxide pigments (crude)	GO, MO, VA, MI	AZ.
Kyanite	VA	
Lead (content of ores, etc.)	MO, AK, ID, CO	IL, KY, MT, NM, NV, NY, TN.
Lime	MO, OH, PA, KY	All other States except AK, CT, DE, FL, GA, HI, KS, ME, MD, MS, NH, NJ, NM, NY, NC, RI, SC, VT.
Lithium minerals	NC and NV	
Magnesite	NV.	
Magnesium compounds	MI, CA, FL, DE	UT and TX.
Magnesium metal	TX, UT, WA	
Manganiferous ore	SC	
Marl (greensand)	NJ	
Mercury	NV, UT, CA	
Mica (scrap)	NC, GA, NM, SC	CT, PA, SD.
Molybdenum	CO, AZ, ID, MT	CA, NM, NV, UT.
Nickel	OR	
Olivine	NC and WA	
Palladium metal	MT	
Peat	MI, FL, MN, IL	CO, GA, IA, IN, MA, MD, ME, MT, NC, ND, NJ, NY, OH, PA, SC, WA, WI, WV.
Perlite	NM, AZ, CA, ID	CO and NV.
Phosphate rock	FL, NC, ID, TN	MT and UT.
Platinum metal	MT	
Potash	NM, UT, CA, MI	
Pumice	CA, OR, AZ, NM	HI, ID, KS.
Pyrites (ore and concentrate)	AZ	
Rare-earth metal concentrates	CA and FL	
Salt	NY, OH, LA, MI	AL, AZ, CA, KS, NM, NV, OK, TX, UT, WV.
Sand and gravel:		
Construction	CA, OH, TX, MI	All other States.
Industrial	IL, CA, TX, NJ	All other States except AK, DE, HI, IA, ME, NH, NM, ND, OR, SD, VT, WY.
Silver (content of ores, etc.)	NV, ID, AK, MT	AZ, CA, CO, IL, KY, MI, MO, NM, NY, OR, SC, SD, TN, UT, WA.
Sodium compounds:		
Soda ash	WY and CA	
Sodium sulfate (natural)	CA, TX, UT	
Staurolite	FL	
Stone:		
Crushed	PA, VA, FL, GA	All other States except DE.
Dimension	IN, VT, MN, SD	All other States except AL, AR, AZ, CA, CO, CT, GA, IA, ID, IL, IN, KS, MA, MD, ME, MI. MO, MT, NC, NH, NM, NY, OH, OK, PA, SC, TN, TX, VA, WA, WI.
Sulfur (Frasch)	TX and LA	
Talc and pyrophyllite	MT, TX, NC, VT	AL, AR, CA, GA, NY, OR, VA.
Tin	AK	
Titanium concentrates	FL and CA	

See footnotes at end of table.

TABLE 2—Continued

NONFUEL MINERALS PRODUCED IN THE UNITED STATES AND PRINCIPAL PRODUCING STATES IN 1990

Mineral	Principal producing States, in order of quantity	Other producing States
Tripoli	IL, AR, OK, PA	
Tungsten (content of ores, etc.)	CA	
Vanadium (content of ores, etc.)	CO, ID, AR, UT	
Vermiculite (crude)	SC, MT, VA	
Wollastonite	NY	
Zinc (content of ores, etc.)	AK, TN, NY, MO	CO, ID, IL, KY, MT, NM, NV.
Zircon concentrates	FL and NJ	

[e]Estimated.

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

TABLE 3

VALUE OF NONFUEL MINERAL PRODUCTION IN THE UNITED STATES AND PRINCIPAL NONFUEL MINERALS PRODUCED IN 1990

State	Value (thousands)	Rank	Percent of U.S. total	Principal minerals, in order of value
Alabama	$560,639	21	1.68	Stone (crushed and broken), cement (portland), lime, sand and gravel.
Arkansas	302,640	33	.91	Bromine, stone (crushed and broken), sand and gravel (industrial), cement (portland).
California	2,779,799	2	8.34	Sand and gravel (construction), cement (portland), boron, gold.
Colorado	386,192	27	1.16	Molybdenum, sand and gravel (construction), cement (portland), stone (crushed and broken).
Connecticut	117,893	41	.35	Stone (crushed and broken), sand and gravel (construction), feldspar, sand and gravel (industrial).
Delaware[1]	6,968	50	.02	Sand and gravel (construction), and gem stones.
Florida	1,564,204	4	4.69	Phosphate rock, stone (crushed and broken), cement (portland), sand and gravel (construction).
Georgia	1,495,124	5	4.49	Clays, stone (crushed and broken), cement (portland), sand and gravel (construction).
Hawaii[1]	106,095	43	32	Stone (crushed and broken), cement (portland), sand and gravel (construction), cement (masonry).
Idaho	399,761	26	1.20	Phosphate rock, silver, molybdenum, zinc.
Illinois	665,134	16	2.00	Stone (crushed and broken), cement (portland), sand and gravel (construction), sand and gravel (industrial).
Indiana	431,766	25	1.30	Stone (crushed and broken), cement (portland), sand and gravel (construction), stone (dimension).
Iowa	316,370	32	.95	Cement (portland), stone (crushed and broken), sand and gravel (construction), gypsum (crude).
Kansas	346,119	31	1.04	Salt, stone (crushed and broken), cement (portland), helium (Grade-A).
Kentucky	358,864	30	1.08	Stone (crushed and broken), lime, cement (portland), sand and gravel (construction).
Louisiana	367,918	29	1.10	Sulfur (Frasch), salt, sand and gravel (construction), stone (crushed and broken).
Maine	62,544	46	19	Sand and gravel (construction), cement (portland), stone (crushed and broken), stone (dimension).
Maryland	368,614	28	1.11	Stone (crushed and broken), sand and gravel (construction), cement (portland), cement (masonry).
Massachusetts	127,498	40	.38	Stone (crushed and broken), sand and gravel (construction), stone (dimension), lime.
Michigan	1,438,123	8	4.32	Iron ore (usable), cement (portland), sand and gravel (construction), stone (crushed and broken).

See footnote at end of table.

TABLE 3—Continued

VALUE OF NONFUEL MINERAL PRODUCTION IN THE UNITED STATES AND PRINCIPAL NONFUEL MINERALS PRODUCED IN 1990

State	Value (thousands)	Rank	Percent of U.S. total	Principal minerals, in order of value
Minnesota	$1,469,922	6	4.41	Iron ore (usable), sand and gravel (construction), stone (crushed and broken), stone (dimension).
Mississippi	112,313	42	.34	Sand and gravel (construction), clays, cement (portland), stone (crushed and broken).
Missouri	1,093,618	11	3.28	Lead, stone (crushed and broken), cement (portland), lime.
Montana	567,684	19	1.70	Gold, copper, molybdenum, silver.
Nebraska	90,329	44	.27	Cement (portland), sand and gravel (construction), stone (crushed and broken), clays.
Nevada	2,610,876	3	7.84	Gold, silver, sand and gravel (construction), cement (portland).
New Hampshire[1]	35,166	47	.11	Sand and gravel (construction), stone (dimension), stone (crushed and broken), gem stones.
New Jersey	229,470	37	.69	Stone (crushed and broken), sand and gravel (construction), sand and gravel (industrial), zircon concentrates.
New Mexico	1,097,550	10	3.29	Copper, potash, sand and gravel (construction), molybdenum.
New York	772,839	14	2.32	Stone (crushed and broken), salt, cement (portland), sand and gravel (construction).
North Carolina	564,591	20	1.69	Stone (crushed and broken), phosphate rock, lithium minerals, sand and gravel (construction).
North Dakota	26,568	48	.08	Sand and gravel (construction), lime, stone (crushed and broken), clays.
Ohio	728,840	15	2.19	Stone (crushed and broken), sand and gravel (construction), salt, lime.
Oklahoma	260,177	35	.78	Stone (crushed and broken), cement (portland), iodine (crude), sand and gravel (construction).
Oregon	237,406	36	.71	Stone (crushed and broken), sand and gravel (construction), cement (portland), nickel.
Pennsylvania	1,030,042	12	3.09	Stone (crushed and broken), cement (portland), sand and gravel (construction), lime.
Rhode Island[1]	17,844	49	.05	Sand and gravel (construction), stone (crushed and broken), gem stones.
South Carolina	449,853	24	1.35	Stone (crushed and broken), cement (portland), gold, clays.
South Dakota	298,452	34	.90	Gold, cement (portland), sand and gravel (construction), stone (crushed and broken).
Tennessee	662,560	17	1.99	Stone (crushed and broken), zinc, cement (portland), gem stones.
Texas	1,457,225	7	4.37	Cement (portland), stone (crushed and broken), magnesium metal, sulfur (Frasch).
Utah	1,334,010	9	4.00	Copper, gold, magnesium metal, cement (portland).
Vermont	81,954	45	.25	Stone (crushed and broken), stone (dimension), sand and gravel (construction), talc and pyrophyllite.
Virginia	507,275	22	1.52	Stone (crushed and broken), sand and gravel (construction), cement (portland), lime.
Washington	473,229	23	1.42	Sand and gravel (construction), gold, magnesium metal, cement (portland).
West Virginia	136,338	39	.41	Stone (crushed and broken), cement (portland), sand and gravel (construction), salt.
Wisconsin	212,047	38	.64	Stone (crushed and broken), sand and gravel (construction), lime, sand and grave (industrial).
Wyoming	910,848	13	2.73	Soda ash, clays, helium (Grade-A), sand and gravel (construction).
Undistributed	5,938	—	—	
Total[2]	33,319,000	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]Data may not add to totals shown because of independent rounding.

TABLE 4

VALUE OF NONFUEL MINERAL PRODUCTION[2] PER CAPITA AND PER SQUARE MILE IN 1990, BY STATE

State	Area (square miles)	Population (thousands)	Total (thousands)	Per square mile		Per capita	
				Dollars	Rank	Dollars	Rank
Alabama	51,705	4,041	$560,639	10,843	24	139	16
Alaska	591,004	550	576,620	976	49	1,048	3
Arizona	114,000	3,665	3,065,448	26,890	3	836	4
Arkansas	53,187	2,351	302,640	5,690	32	129	19
California	158,706	29,760	2,779,799	17,515	11	93	26
Colorado	104,091	3,294	386,192	3,710	43	117	21
Connecticut	5,018	3,287	117,893	23,494	8	36	45
Delaware	2,044	666	[1]6,968	3,409	44	10	50
Florida	58,664	12,938	1,564,204	26,664	4	121	20
Georgia	58,910	6,478	1,495,124	25,380	5	231	11
Hawaii	6,471	1,108	[1]106,095	16,395	13	96	25
Idaho	83,564	1,007	399,761	4,784	36	397	9
Illinois	56,345	11,431	665,134	11,805	23	58	38
Indiana	36,185	5,544	431,766	11,932	22	78	34
Iowa	56,275	2,777	316,370	5,622	34	114	22
Kansas	82,277	2,478	346,119	4,207	37	140	15
Kentucky	40,409	3,685	358,864	8,881	28	97	23
Louisiana	47,751	4,220	367,918	7,705	30	87	27
Maine	33,265	1,228	62,544	1,880	47	51	40
Maryland	10,460	4,781	368,614	35,240	1	77	35
Massachusetts	8,284	6,016	127,498	15,391	18	21	48
Michigan	58,527	9,295	1,438,123	24,572	6	155	13
Minnesota	84,402	4,375	1,469,922	17,416	12	336	10
Mississippi	47,689	2,573	112,313	2,355	46	44	41
Missouri	69,697	5,117	1,093,618	15,691	17	214	12
Montana	147,046	779	567,684	3,861	39	729	6
Nebraska	77,355	1,578	90,329	1,168	48	57	39
Nevada	110,561	1,202	2,610,876	23,615	7	2,172	1
New Hampshire	9,279	1,109	[1]35,166	3,790	40	32	46
New Jersey	7,787	7,730	229,470	29,468	2	30	47
New Mexico	121,593	1,515	1,097,550	9,026	27	724	7
New York	49,107	17,990	772,839	15,738	14	43	43
North Carolina	52,669	6,629	564,591	10,720	25	85	30
North Dakota	70,703	639	26,568	376	50	42	44
Ohio	41,330	10,847	728,840	17,635	10	67	37
Oklahoma	69,956	3,146	260,177	3,719	42	83	32
Oregon	97,073	2,842	237,406	2,446	45	84	31
Pennsylvania	45,308	11,882	1,030,042	22,734	9	87	28
Rhode Island	1,212	1,003	[1]17,844	14,723	19	18	49
South Carolina	31,113	3,487	449,853	14,459	20	129	18
South Dakota	77,116	696	298,452	3,870	38	429	8
Tennessee	42,144	4,877	662,560	15,721	15	136	17
Texas	266,807	16,987	1,457,225	5,462	35	86	29
Utah	84,899	1,723	1,334,010	15,713	16	774	5
Vermont	9,614	563	81,954	8,524	29	146	14
Virginia	40,767	6,187	507,275	12,443	21	82	33
Washington	68,138	4,867	473,229	6,945	31	97	24
West Virginia	24,231	1,793	136,338	5,627	33	76	36
Wisconsin	56,153	4,892	212,047	3,776	41	43	42
Wyoming	97,809	454	910,848	9,313	26	2,006	2
Undistributed	XX	XX	5,938	XX	XX	XX	XX
Total[3] or average	3,618,700	248,082	33,319,000	9,207	XX	134	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 606,900.
[3]Data may not add to totals shown because of independent rounding.

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

TABLE 5

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

Mineral		1988		1989		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
ALABAMA							
Cement:							
Masonry	thousand short tons	273	$16,457	252	$13,852	262	$15,462
Portland	do.	3,524	7,214	3,169	130,590	3,585	165,344
Clays[2]	metric tons	2,282,670	16,039	1,878,070	18,537	2,049,776	27,747
Gem stones		NA	5	NA	W	NA	W
Lime	thousand short tons	1,450	66,576	1,481	70,361	1,526	70,816
Sand and gravel:							
Construction	do.	11,742	41,417	e10,400	e36,500	14,103	50,243
Industrial	do.	871	8,507	805	8,092	878	9,075
Stone (crushed)	do.	e29,700	e140,100	[3]31,737	[3]167,332	e[3]36,100	e[3]202,400
Combined value of bauxite, clays (bentonite, kaolin 1990), salt, stone (crushed granite 1989-90, dimension), talc and pyrophyllite, zircon concentrates, (1988-89), and values indicated by symbol W		XX	13,180	XX	r15,489	XX	19,552
Total		XX	459,495	XX	460,753	XX	560,639
ALASKA							
Gem stones		NA	50	NA	W	NA	W
Gold[4]	kilograms	4,210	59,320	5,756	70,800	3,232	40,200
Sand and gravel (construction)	thousand short tons	17,200	48,749	e17,000	e48,500	15,100	41,800
Silver[4]	metric tons	1	135	W	W	W	W
Stone (crushed)	thousand short tons	e1,800	e8,400	2,900	20,300	e2,700	e19,800
Combined value of cement (portland), lead (1989-90), tin, zinc (1989-90), and values indicated by symbol W		XX	2,040	XX	73,752	XX	474,820
Total		XX	118,694	XX	213,352	XX	576,620
ARIZONA							
Clays	metric tons	168,392	1,590	188,211	2,506	140,162	2,318
Copper[4]	do.	842,728	2,238,875	r898,466	r2,593,734	978,767	2,657,649
Diatomite	do.	7,257	1,208	W	W	W	W
Gem stones		NA	3,300	NA	2,821	NA	2,098
Gold[4]	kilograms	4,549	64,106	r2,768	r34,047	5,000	62,191
Lime	thousand short tons	674	29,637	W	W	W	W
Pumice	metric tons	907	7	—	—	W	W
Sand and gravel:							
Construction	thousand short tons	32,399	123,854	e33,900	e133,900	27,915	92,166
Industrial	do.	119	3,045	W	W	W	W
Silver[4]	metric tons	152	31,974	171	30,186	173	26,836
Stone:							
Crushed	thousand short tons	e7,400	e33,000	6,649	28,552	e5,300	e13,500
Dimension	short tons	W	e1	W	W	W	W
Combined value of cement, gypsum (crude), iron oxide pigments (crude, 1989-90), lead (1988-89), molybdenum, perlite, pyrites, salt, tin (1988-89), and values indicated by symbol W		XX	235,596	XX	r220,594	XX	208,690
Total		XX	2,766,193	XX	3,046,340	XX	3,065,448

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)	1990 Quantity	1990 Value (thousands)
ARKANSAS							
Abrasives[5]	metric tons	1,120	$429	W	W	W	W
Bromine[e]	thousand kilograms	W	W	W	W	177,000	$97,350
Clays	metric tons	844,466	15,376	871,313	$17,391	989,383	21,578
Gem stones		NA	2,300	NA	4,041	NA	1,503
Sand and gravel:							
Construction	thousand short tons	7,722	26,201	e7,500	e25,500	9,663	35,475
Industrial	do.	669	6,784	545	5,507	742	7,209
Stone:							
Crushed	do.	e17,100	e70,100	318,791	376,419	e 317,800	e 376,900
Dimension	short tons	e10,541	e629	W	W	W	W
Combined value of bauxite, cement, gypsum (crude), lime, stone (crushed slate and dolomite, 1989-90), talc and pyrophyllite, tripoli, vanadium (1989-90), and values indicated by symbol W		XX	184,785	XX	253,051	XX	62,625
Total		XX	306,604	XX	381,909	XX	302,640
CALIFORNIA							
Boron minerals[6]	metric tons	577,877	429,667	562,311	429,806	1,093,919	436,176
Cement:							
Masonry	thousand short tons	8	730	W	W	W	W
Portland	do.	10,423	601,152	10,911	642,020	10,032	604,080
Clays	metric tons	2,015,488	31,620	2,195,830	39,243	32,163,515	340,217
Gem stones		NA	3,365	NA	2,982	NA	1,501
Gold[4]	kilograms	22,442	316,246	29,804	366,595	29,607	368,300
Gypsum (crude)	thousand short tons	1,490	11,222	1,734	13,066	W	W
Lime	do.	458	20,242	395	24,503	345	19,425
Mercury	metric tons	W	W	W	W	(7)	(7)
Peat	thousand short tons	2	119	—	—	—	—
Pumice	metric tons	31,752	1,245	79,000	4,612	71,739	5,088
Sand and gravel:							
Construction	thousand short tons	141,946	622,074	e138,300	e670,800	132,214	626,000
Industrial	do.	2,444	42,078	2,426	43,863	2,452	48,055
Silver[4]	metric tons	15	3,148	21	3,650	21	3,209
Stone:							
Crushed	thousand short tons	e49,100	e275,000	54,887	238,034	e42,500	e200,600
Dimension	short tons	e42,048	e5,991	28,829	5,564	e30,077	e5,213
Combined value of asbestos, barite (1988, 1990), calcium chloride (natural), clay (fuller's earth, 1990), copper, diatomite, feldspar, iron ore (by-product material [1988-89], usable), magnesium compounds, molybdenum, perlite, potash, rare-earth metal concentrates, salt, soda ash, sodium sulfate (natural), talc and pyrophyllite, titanium concentrates (ilmenite, 1989-90), tungsten ore concentrates, and values indicated by symbol W		XX	334,755	XX	r369,664	XX	421,935
Total		XX	2,698,654	XX	2,854,402	XX	2,779,799
COLORADO							
Clays	metric tons	247,471	1,890	265,435	2,064	262,292	$1,864
Copper[4]	do.	898	2,386	W	W	W	W
Gem stones		NA	100	NA	240	NA	66
Gold[4]	kilograms	5,126	72,237	3,448	42,411	2,338	29,084

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988		1989		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
COLORADO—Continued							
Peat	thousand short tons	W	W	W	$412	W	W
Sand and gravel (construction)	thousand short tons	21,566	$69,882	e25,300	e104,000	24,938	$86,541
Silver[4]	metric tons	27	5,588	W	W	23	3,557
Stone:							
Crushed	thousand short tons	e10,600	e42,400	37,261	332,435	e 37,600	e 336,100
Dimension	short tons	e3,450	e143	5,310	398	e8,490	e1,394
Combined value of cement, clay (bentonite, 1990), gypsum (crude), helium (Grade-A, 1990), lead, lime, molybdenum, perlite, sand and gravel (industrial), stone (crushed traprock, 1989-90), vanadium, zinc, and values indicated by symbol W		XX	169,379	XX	r275,765	XX	227,586
Total		XX	364,005	XX	457,725	XX	386,192
CONNECTICUT							
Gem stones		NA	2	NA	2	NA	2
Sand and gravel (construction)	thousand short tons	8,275	32,102	e5,800	e24,700	8,542	37,943
Stone :							
Crushed	do.	e11,400	e76,900	311,480	378,734	e 310,200	e 370,600
Dimension	short tons	e19,718	e1,914	W	W	W	W
Combined value of clays (common), feldspar, mica (scrap, 1988, 1990), sand and gravel (industrial), stone (crushed granite, 1989-90), and values indicated by symbol W		XX	7,198	XX	9,780	XX	9,348
Total		XX	118,116	XX	113,216	XX	117,893
DELAWARE							
Gem stones		NA	1	NA	1	NA	1
Marl (greensand)	short tons	750	10	—	—	—	—
Sand and gravel (construction)	thousand short tons	1,933	5,988	e1,900	e6,200	2,184	6,967
Total[8]		XX	5,999	XX	6,201	XX	6,968
FLORIDA							
Cement:							
Masonry	thousand short tons	411	25,892	477	31,231	442	27,777
Portland	do.	3,682	168,719	4,357	207,857	3,954	186,404
Clays	metric tons	536,922	44,423	2563,687	246,941	2391,334	239,625
Peat	thousand short tons	266	5,091	235	4,515	252	4,381
Sand and gravel:							
Construction	do.	18,654	53,083	e17,900	e55,500	18,472	59,123
Industrial	do.	636	6,928	681	7,768	520	7,024
Stone (crushed)	do.	e 383,200	e 3374,400	83,995	341,397	e74,000	e317,400
Combined value of clays (common, 1989-90), gem stones, magnesium compounds, phosphate rock, rare-earth metal concentrates, staurolite, stone (crushed marl 1988), titanium concentrates (ilmenite and rutile), and zircon concentrates		XX	713,345	XX	913,054	XX	922,470
Total		XX	1,391,881	XX	1,608,263	XX	1,564,204
GEORGIA							
Clays	metric tons	10,274,358	908,771	9,768,312	1,004,954	9,855,248	1,060,539
Gem stones		NA	20	NA	21	NA	20

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)	1990 Quantity	1990 Value (thousands)
GEORGIA—Continued							
Sand and gravel:							
Construction	thousand short tons	9,526	$30,185	e6,100	e$18,900	5,158	$16,644
Industrial	do.	W	W	537	7,013	W	W
Stone:							
Crushed	do.	e57,400	e317,200	50,417	262,805	e53,000	e317,300
Dimension	short tons	e190,472	e27,768	3145,545	312,087	e3147,068	e312,483
Talc and pyrophyllite	do.	23,587	260	W	W	W	W
Combined value of barite, bauxite (1988-89), cement, feldspar, iron oxide pigments (crude), mica (scrap), peat, stone (dimension marble [1989-90]), and values indicated by symbol W		XX	89,621	XX	81,515	XX	88,138
Total		XX	1,373,825	XX	1,387,295	XX	1,495,124
HAWAII							
Cement:							
Masonry	thousand short tons	10	1,531	10	1,566	12	1,870
Portland	do.	354	28,880	493	40,495	532	46,311
Gem stones		NA	W	NA	44	NA	55
Sand and gravel (construction)	do.	652	3,173	e600	e3,200	438	2,459
Stone (crushed)	do.	e5,700	e41,000	6,205	46,746	e7,000	e55,400
Combined value of other industrial minerals and values indicated by symbol W		XX	348	XX	(9)	XX	(9)
Total		XX	74,932	XX	892,051	XX	8106,095
IDAHO							
Clays[2]	metric tons	8,519	W	W	W	W	W
Copper[4]	do.	2,269	6,028	2,950	8,516	W	W
Feldspar	do.	—	—	11,612	720	W	W
Gem stones		NA	500	NA	500	NA	320
Gold[4]	kilograms	3,218	45,349	3,057	37,602	W	W
Phosphate rock	thousand metric tons	4,706	81,011	W	W	4,380	101,610
Pumice	metric tons	W	W	W	W	31,333	220
Sand and gravel:							
Construction	thousand short tons	6,914	19,897	e5,800	e18,900	9,222	25,590
Industrial	do.	483	5,089	459	5,037	552	6,234
Silver[4]	metric tons	340	71,512	439	77,651	436	67,565
Stone (crushed)	thousand short tons	e3,400	e13,100	3,298	12,609	e4,300	e12,900
Combined value of antimony, cement, clays, (bentonite, 1989-90, common, kaolin), garnet (abrasive), lead, lime, molybdenum (1989-90), perlite, stone (dimension, 1988-89), vanadium, zinc, and values indicated by symbol W		XX	48,130	XX	r203,075	XX	185,322
Total		XX	290,616	XX	364,610	XX	399,761
ILLINOIS							
Cement (portland)	thousand short tons	2,307	101,760	2,776	117,224	2,842	116,781
Clays[2]	metric tons	163,571	704	142,207	641	598,479	2,516
Gem stones		NA	30	NA	W	NA	W
Sand and gravel:							
Construction	thousand short tons	30,098	93,504	e33,000	e108,900	32,380	104,728
Industrial	do.	4,328	56,142	4,582	52,935	4,486	62,531
Stone:							
Crushed	do.	e57,900	e251,200	360,829	3256,832	e362,700	e3283,100

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)	1990 Quantity	1990 Value (thousands)
ILLINOIS—Continued							
Stone—Continued							
Dimension	short tons	e1,175	e$129	W	W	W	W
Combined value of barite (1989-90), cement (masonry), clays (fuller's earth), copper, fluorspar, lead, lime, peat, silver, stone (crushed sandstone,1989-90), tripoli, zinc, and values indicated by symbol W		XX	84,157	XX	$96,829	XX	$95,478
Total		XX	587,626	XX	633,361	XX	665,134
INDIANA							
Cement:							
Masonry	thousand short tons	405	27,442	357	24,054	368	27,813
Portland	do.	2,315	107,179	2,364	108,297	2,417	114,414
Clays	metric tons	1,035,837	4,630	871,179	3,836	2,1,051,703	2,3,273
Gem stones		NA	10	NA	W	NA	W
Peat	thousand short tons	54	W	34	607	37	W
Sand and gravel:							
Construction	do.	25,923	79,985	e29,600	e99,200	23,879	76,886
Industrial	do.	362	1,829	W	W	W	W
Stone:							
Crushed	do.	e36,600	e130,000	3,36,188	3,136,252	e,3,36,700	e,3,147,700
Dimension	short tons	e195,444	e24,956	3,198,531	3,27,212	e,3,194,728	e,3,29,504
Combined value of abrasives (1988-89), clays (ball, 1990), gypsum (crude), lime, stone (crushed marl and miscellaneous stones [1989-90], dimension sandstone, 1989-90), and values indicated by symbol W		XX	30,358	XX	34,657	XX	32,176
Total		XX	406,389	XX	434,115	XX	431,766
IOWA							
Cement:							
Masonry	thousand short tons	W	W	47	4,450	53	5,054
Portland	do.	2,029	98,930	2,072	102,387	2,525	122,466
Clays	metric tons	403,923	1,588	439,323	1,773	423,227	1,376
Gem stones		NA	W	NA	10	NA	14
Gypsum (crude)	thousand short tons	2,047	13,710	2,273	16,884	2,192	14,243
Peat	do.	15	433	W	W	W	W
Sand and gravel (construction)	do.	11,880	36,087	e12,800	e37,800	14,953	46,432
Stone:							
Crushed	do.	e29,200	e128,500	28,049	111,182	e29,000	e118,600
Dimension	short tons	W	e588	15,151	613	W	W
Combined value of other industrial minerals and values indicated by symbol W		XX	10,420	XX	7,603	XX	8,185
Total		XX	290,256	XX	282,702	XX	316,370
KANSAS							
Cement:							
Masonry	thousand short tons	50	2,988	42	2,514	39	2,011
Portland	do.	1,569	72,805	1,505	69,390	1,707	76,564
Clays[2]	metric tons	555,739	2,632	533,099	2,700	625,969	4,056
Gem stones		NA	3	NA	W	NA	W
Salt[10]	thousand short tons	1,284	55,753	1,948	82,212	2,390	92,119
Sand and gravel:							
Construction	do.	10,760	25,329	e13,000	e33,200	10,863	24,170

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)	1990 Quantity	1990 Value (thousands)
KANSAS—Continued							
Sand and gravel—Continued							
Industrial	thousand short tons	W	W	230	$2,690	W	W
Stone:							
Crushed	do.	e17,300	e$72,700	315,850	356,976	e 320,800	e 3$79,200
Dimension	short tons	e6,889	e219	W	W	W	W
Combined value of clay (bentonite, 1989-90), gypsum (crude), helium (crude and Grade-A), pumice, salt (brine), stone (crushed sandstone and quartzite, 1989-90), and values indicated by symbol W		XX	59,284	XX	68,449	XX	67,999
Total		XX	291,713	XX	318,131	XX	346,119
KENTUCKY							
Clays[2]	metric tons	762,324	3,217	716,990	3,357	826,205	8,282
Gem stones		NA	3	NA	W	NA	W
Sand and gravel (construction)	thousand short tons	6,325	15,243	e5,500	e15,100	8,802	29,581
Stone (crushed)	do.	e50,700	e207,900	348,178	3187,849	e 350,100	e 3182,900
Combined value of cement, clays (ball clay, fire clay, 1988-89), lead (1990), lime, sand and gravel (industrial, 1988-89), silver (1990), stone (crushed dolomite, 1989-90), zinc (1988, 1990), and values indicated by symbol W		XX	118,616	XX	124,353	XX	138,101
Total		XX	344,979	XX	330,659	XX	358,864
LOUISIANA							
Clays	metric tons	340,900	9,535	233,992	6,115	368,322	1,066
Gem stones		NA	3	NA	14	NA	7
Salt	thousand short tons	14,274	108,982	13,218	115,203	14,348	120,827
Sand and gravel:							
Construction	do.	14,233	52,820	e13,600	e54,400	14,589	55,902
Industrial	do.	318	4,786	572	9,664	559	10,003
Stone (crushed)	do.	e 23,700	e 229,200	3,206	24,414	e2,100	e16,800
Sulfur (Frasch)	thousand metric tons	1,719	W	1,334	W	1,337	W
Combined value of cement (masonry, [1988], portland, [1988]), gypsum (crude), lime, stone (crushed miscellaneous, 1988), and values indicated by symbol W		XX	229,210	XX	169,912	XX	163,313
Total		XX	434,536	XX	379,722	XX	367,918
MAINE							
Gem stones		NA	150	NA	W	NA	W
Sand and gravel (construction)	thousand short tons	10,183	33,007	e8,600	e30,100	7,865	29,349
Stone:							
Crushed	thousand short tons	e1,400	e5,300	1,591	8,801	e1,700	e8,700
Dimension	short tons	e7,512	e5,924	W	W	W	W
Combined value of cement, clays (common), garnet (abrasive 1988), peat, and values indicated by symbol W		XX	23,379	XX	25,753	XX	24,495
Total		XX	67,760	XX	64,654	XX	62,544
MARYLAND							
Cement (portland)	thousand short tons	1,808	89,083	1,871	94,002	1,798	91,172
Clays	metric tons	357,833	2,016	351,464	1,882	338,775	1,712
Gem stones		NA	5	NA	3	NA	3

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988		1989		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
MARYLAND—Continued							
Lime	thousand short tons	6	329	—	—	—	—
Peat	do.	7	W	3	W	3	W
Sand and gravel (construction)	do.	19,266	$95,169	e16,900	$e84,500	18,271	$104,023
Stone:							
Crushed	do.	e32,700	e167,000	30,841	153,375	e30,500	e163,900
Dimension	short tons	e20,729	e1,515	27,529	2,072	e24,102	e1,751
Combined value of other industrial minerals and values indicated by symbol W		XX	7,804	XX	6,216	XX	6,053
Total		XX	362,921	XX	342,050	XX	368,614
MASSACHUSETTS							
Gem stones		NA	1	NA	3	NA	1
Sand and gravel:							
Construction	thousand short tons	22,168	79,364	e13,900	e57,000	12,774	51,466
Industrial	do.	W	W	34	601	30	401
Stone:							
Crushed	do.	e17,500	e91,900	11,880	67,768	e9,200	e54,500
Dimension	short tons	W	W	67,533	10,302	e56,254	e10,992
Combined value of clays (common), lime, peat, and values indicated by symbol W		XX	20,973	XX	8,452	XX	10,138
Total		XX	192,238	XX	144,126	XX	127,498
MICHIGAN							
Cement:							
Masonry	thousand short tons	265	22,915	255	22,286	272	23,880
Portland	do.	5,253	231,141	5,449	253,324	5,906	263,607
Clays	metric tons	1,248,121	4,432	1,249,198	4,599	1,201,542	4,094
Gem stones		NA	25	NA	10	NA	11
Gypsum (crude)	thousand short tons	1,958	11,630	2,089	15,589	2,000	11,511
Iron ore	thousand metric tons	14,623	W	15,045	W	10,034	W
Lime	thousand short tons	714	36,088	621	32,479	622	30,898
Peat	do.	322	6,256	286	6,082	280	6,264
Sand and gravel:							
Construction	do.	53,508	138,171	e48,000	e132,000	53,729	153,057
Industrial	do.	3,045	27,150	2,865	24,577	2,310	19,285
Stone (crushed)	do.	e38,800	e120,300	40,905	123,678	e43,100	e129,000
Combined value of bromine (1988), calcium chloride (natural), copper, gold (1988-89), iron oxide pigments (crude), magnesium compounds, potash (1989-90), salt, silver, stone (dimension), and values indicated by symbol W		XX	989,453	XX	984,347	XX	796,516
Total		XX	1,587,561	XX	1,598,971	XX	1,438,123
MINNESOTA							
Gem stones		NA	40	NA	42	NA	46
Iron ore	thousand metric tons	40,735	1,134,539	41,044	r1,223,909	45,139	1,308,920
Peat	thousand short tons	29	1,414	r33	1,415	48	2,972
Sand and gravel (construction)	do.	33,769	72,678	e33,700	e82,600	33,869	77,502
Stone:							
Crushed	do.	e8,300	e28,200	8,760	30,218	e9,100	e31,900
Dimension	short tons	e45,000	e13,000	44,605	16,031	e60,195	e20,836

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)	1990 Quantity	1990 Value (thousands)
MINNESOTA—Continued							
Combined value of clays (common, kaolin), lime, and sand and gravel (industrial)		XX	$18,015	XX	$22,022	XX	$27,746
Total		XX	1,267,886	XX	1,376,237	XX	1,469,922
MISSISSIPPI							
Clays[2]	short tons	1,093,316	24,564	899,373	23,573	817,828	16,196
Gem stones		NA	1	NA	5	NA	1
Sand and gravel (construction)	thousand short tons	13,314	38,806	e15,600	e51,500	13,032	45,817
Stone (crushed)	do.	e1,500	e9,000	1,069	3,994	e1,400	e5,500
Combined value of cement, clays (ball, fuller's earth, [1990]), sand and gravel (industrial)		XX	31,029	XX	28,539	XX	44,799
Total		XX	103,400	XX	107,611	XX	112,313
MISSOURI							
Barite	thousand metric tons	24	1,930	W	W	W	W
Cement:							
Masonry	thousand short tons	153	6,310	W	W	W	W
Portland	do.	4,679	184,755	4,922	182,005	4,481	180,090
Clays[2]	metric tons	1,435,045	12,171	1,479,898	14,665	1,347,558	12,864
Iron ore	thousand metric tons	816	W	1,060	W	1,002	W
Lead[4]	metric tons	353,194	289,194	366,931	318,320	372,383	377,824
Sand and gravel:							
Construction	thousand short tons	11,217	32,941	e10,000	e32,500	9,243	25,097
Industrial	do.	744	9,876	750	9,972	W	W
Silver[4]	metric tons	45	9,550	53	9,456	35	5,462
Stone:							
Crushed	thousand short tons	e52,100	e183,000	51,754	171,848	e53,100	e190,900
Dimension	short tons	e3,644	e547	W	W	W	W
Zinc[4]	metric tons	41,322	54,842	50,790	91,885	48,864	80,355
Combined value of clays (fuller's earth), copper, gem stones, iron oxide pigments (crude), lime, and values indicated by symbol W		XX	182,833	XX	r219,236	XX	221,026
Total		XX	967,949	XX	1,049,887	XX	1,093,618
MONTANA							
Clays[2]	metric tons	91,802	1,416	95,743	1,835	29,741	193
Gem stones		NA	1,602	NA	2,500	NA	3,692
Gold[4]	kilograms	9,175	129,291	r12,434	r152,941	13,012	161,861
Gypsum (crude)	thousand short tons	27	W	W	W	—	—
Lead[4]	metric tons	8,266	6,768	W	W	W	W
Palladium metal[11]	kilograms	r3,730	r14,750	r4,850	r22,454	5,930	21,735
Platinum metal[12]	do.	r1,240	r20,850	r1,430	r23,310	1,810	26,478
Sand and gravel (construction)	thousand short tons	7,984	20,225	e5,800	e13,900	5,114	14,319
Silver[4]	metric tons	192	40,457	194	34,367	220	34,114
Stone (crushed)	thousand short tons	e1,800	e4,500	2,846	9,718	e4,000	e15,300
Talc and pyrophyllite	metric tons	415,642	14,524	453,978	12,718	430,125	18,883
Zinc[4]	do.	18,935	25,130	W	W	W	W

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)	1990 Quantity	1990 Value (thousands)
MONTANA—Continued							
Combined value of barite (1989-90), cement, clay (bentonite, [1990], fire clay, [1988-89]), copper, graphite (natural, 1988-89), iron ore, lime, molybdenum, peat, phosphate rock, sand and gravel (industrial), stone (dimension), vermiculite, and values indicated by symbol W		XX	$265,008	XX	$r292,394	XX	$271,109
Total		XX	544,521	XX	566,137	XX	567,684
NEBRASKA							
Clays	metric tons	215,419	786	224,624	880	227,292	1,685
Gem stones		NA	10	NA	2	NA	7
Sand and gravel (construction)	thousand short tons	11,229	28,928	e15,200	e41,800	11,453	30,056
Stone (crushed)	do.	e4,900	e22,000	3,978	20,050	e4,000	e21,200
Combined value of cement, lime, and sand and gravel (industrial)		XX	39,468	XX	41,085	XX	37,381
Total		XX	91,192	XX	103,817	XX	90,329
NEVADA							
Barite	thousand metric tons	289	5,053	209	3,473	337	5,884
Clays[2]	metric tons	26,186	2,143	57,264	5,457	34,625	4,098
Gem stones		NA	280	NA	1,402	NA	407
Gold[4]	kilograms	114,322	1,611,020	r153,995	r1,894,172	176,551	2,196,191
Lead[4]	metric tons	W	W	—	—	830	842
Perlite	short tons	5,000	42	5,000	136	W	W
Sand and gravel:							
Construction	thousand short tons	15,729	50,928	e20,000	e70,000	18,377	59,008
Industrial	do.	602	W	718	W	07	W
Silver[4]	metric tons	608	127,760	625	110,442	708	109,653
Stone (crushed)	thousand short tons	e41,300	e45,700	1,560	4,638	e1,600	e5,000
Zinc[4]	do.	—	—	—	—	7,889	12,973
Combined value of brucite (1989-90), cement (portland), clays (fuller's earth [1990], kaolin), copper, diatomite, fluorspar, gypsum (crude), lime, lithium minerals, magnesite, mercury, molybdenum (1990), salt, stone (crushed dolomite, 1988), and values indicated by symbol W		XX	151,356	XX	r220,441	XX	216,820
Total		XX	1,954,382	XX	2,310,161	XX	2,610,876
NEW HAMPSHIRE							
Gem stones		NA	$100	NA	$51	NA	$8
Sand and gravel (construction)	thousand short tons	9,089	32,614	e6,000	e20,400	7,901	26,599
Stone:							
Crushed	do.	e2,400	e9,800	771	4,020	e600	e2,500
Dimension	short tons	e73,393	e10,546	55,305	8,769	e45,073	e6,029
Total[8]		XX	53,060	XX	33,240	XX	35,166
NEW JERSEY							
Clays[2]	metric tons	14,954	368	18,492	400	W	W
Gem stones		NA	3	NA	3	NA	3
Peat	thousand short tons	43	797	W	638	W	527
Sand and gravel:							
Construction	do.	18,318	74,183	e15,200	e68,400	13,862	64,245
Industrial	do.	1,860	25,437	1,797	26,138	1,762	26,190

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)	1990 Quantity	1990 Value (thousands)
NEW JERSEY—Continued							
Stone (crushed)	thousand short tons	[3]e19,300	[3]e$123,500	20,799	$140,998	e21,200	e$131,700
Zircon concentrates	metric tons	W	W	W	8,988	W	W
Combined value of clays (common and fire [1990]), marl (greensand), stone (crushed limestone 1988), and values indicated by symbol W		XX	10,044	XX	3,318	XX	6,805
Total		XX	234,332	XX	248,883	XX	229,470
NEW MEXICO							
Clays	metric tons	28,555	83	31,012	94	[2]27,994	[2]74
Copper[4]	do.	258,660	687,182	r259,640	r749,540	262,815	713,622
Gem stones		NA	200	NA	279	NA	225
Gold[4]	kilograms	W	W	1,076	13,231	888	11,041
Perlite	short tons	458,000	14,294	487,000	13,080	501,000	11,049
Potash	thousand metric tons	1,271	213,800	1,365	242,619	1,451	245,571
Pumice	metric tons	76,204	852	77,000	795	W	W
Sand and gravel (construction)	thousand short tons	8,787	31,367	e11,800	e45,400	10,362	39,708
Silver[4]	metric tons	W	W	W	W	48	7,431
Stone:							
Crushed	thousand short tons	e3,500	e13,900	2,784	11,672	e2,400	e12,800
Dimension	short tons	e21,893	e626	W	W	W	W
Combined value of cement, clays (fire, 1990), gypsum (crude), helium (Grade-A), iron ore (includes by-product material), lead, mica (scrap), molybdenum, salt, zinc (1989-90), and values indicated by symbol W		XX	60,368	XX	r45,593	XX	56,029
Total		XX	1,022,672	XX	1,122,303	XX	1,097,550
NEW YORK							
Clays	metric tons	551,375	3,654	531,559	3,429	490,552	2,906
Gem stones		NA	200	NA	350	NA	365
Peat	thousand short tons	W	W	W	10	W	W
Salt	do.	4,614	127,994	5,424	161,427	5,401	162,900
Sand and gravel:							
Construction	do.	33,884	124,341	e31,600	e118,500	29,750	121,525
Industrial	do.	53	625	53	633	W	W
Stone:							
Crushed	thousand short tons	e39,900	e193,500	39,851	201,749	e39,900	e207,600
Dimension	short tons	e30,751	e4,333	23,756	3,575	e23,437	e3,589
Combined value of cement, emery (1988), garnet, gypsum (crude), iron ore (includes byproduct material, 1988-89), lead, silver, talc and pyrophyllite, wollastonite, zinc, and values indicated by symbol W		XX	241,053	XX	255,495	XX	273,954
Total		XX	695,700	XX	745,168	XX	772,839
NORTH CAROLINA							
Clays	metric tons	2,880,103	16,349	2,270,384	15,529	[2]2,179,428	[2]9,356
Feldspar	do.	460,838	17,312	435,845	14,024	418,402	13,389
Gem stones		NA	688	NA	784	NA	1,057
Mica (scrap)	thousand metric tons	79	4,512	73	4,192	65	3,796
Peat	thousand short tons	21	W	W	W	13	W
Sand and gravel:							
Construction	do.	11,076	38,459	e11,200	e43,700	11,733	44,872

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)	1990 Quantity	1990 Value (thousands)
NORTH CAROLINA—Continued							
Sand and gravel—Continued							
Industrial	thousand short tons	1,246	$15,953	1,627	$19,902	1,177	$15,338
Stone:							
Crushed	do.	e50,500	e250,000	51,519	257,976	e52,900	e276,200
Dimension	short tons	e31,977	e5,0266	2,665	10,477	e66,531	e11,551
Combined value of clays (kaolin, 1990), lithium minerals, olivine, phosphate rock, talc and pyrophyllite, and values indicated by symbol W		XX	181,135	XX	214,984	XX	189,032
Total		XX	529,434	XX	581,568	XX	564,591
NORTH DAKOTA							
Clays	metric tons	76,918	147	47,903	W	50,485	W
Gem stones		NA	2	NA	10	NA	10
Lime	thousand short tons	108	7,094	107	5,439	82	4,623
Sand and gravel (construction)	do.	3,772	8,079	e3,600	e8,100	7,644	17,219
Stone (crushed)	short tons	W	W	—	—	e1,000	e4,600
Combined value of other industrial minerals and values indicated by symbol W		XX	3,485	XX	111	XX	116
Total		XX	18,807	XX	13,660	XX	26,568
OHIO							
Cement:							
Masonry	thousand short tons	129	11,140	128	11,233	124	10,880
Portland	do.	1,424	70,816	1,446	73,230	1,426	72,883
Clays	metric tons	3,365,164	14,423	3,519,668	14,983	2,546,151	13,334
Gem stones		NA	10	NA	18	NA	W
Lime	thousand short tons	2,065	87,431	1,888	94,157	1,884	92,817
Peat	do.	W	W	8	182	12	182
Salt	do.	3,795	115,860	W	W	W	W
Sand and gravel:							
Construction	do.	46,104	156,318	e44,400	e148,700	44,552	165,394
Industrial	do.	1,361	23,441	1,394	24,662	1,349	24,205
Stone:							
Crushed	thousand short tons	e48,000	e252,000	46,426	183,190	e48,400	e190,900
Dimension	short tons	e38,300	e3,137	59,923	3,455	e61,783	e3,468
Combined value of other industrial minerals and values indicated by symbol W		XX	2,676	XX	145,346	XX	154,777
Total		XX	737,252	XX	699,156	XX	728,840
OKLAHOMA							
Cement (portland)	thousand short tons	1,4324	2,131	1,236	39,360	1,544	60,457
Clays	metric tons	684,067	1,803	565,956	1,619	631,302	3,156
Gem stones		NA	18	NA	W	NA	W
Gypsum (crude)	thousand short tons	2,1731	3,393	2,523	14,369	2,184	11,154
Iodine (crude)	kilograms	1,015,210	W	1,505,714	23,947	1,972,849	30,486
Sand and gravel:							
Construction	thousand short tons	9,273	22,654	e8,500	e20,000	9,235	21,993
Industrial	do.	1,268	17,381	1,216	18,310	1,258	22,984
Stone:							
Crushed[3]	do.	e26,300	e92,000	23,598	81,969	e25,300	e89,500
Dimension	short tons	e7,746	e785	8,290	762	e8,138	e684

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988		1989		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
OKLAHOMA—Continued							
Tripoli	metric tons	W	W	W	W	18,801	$155
Combined value of cement (masonry), feldspar, lime, salt (1988, 1990), stone (crushed dolomite [1988], crushed granite [1989-90]), and values indicated by symbol W		XX	$29,972	XX	$18,695	XX	19,608
Total		XX	220,137	XX	219,031	XX	260,177
OREGON							
Clays	metric tons	225,001	1,049	210,893	875	223,452	1,390
Gem stones		NA	894	NA	1,304	NA	1,683
Nickel (content of ores and concentrates)	short tons	—	—	382	r4,662	4,080	W
Sand and gravel (construction)	thousand short tons	14,880	52,657	e14,400	e49,700	15,785	60,928
Stone (crushed)	do.	e22,200	e77,600	218,407	281,204	e218,000	e286,600
Talc and pyrophyllite	metric tons	W	W	204	18	105	10
Combined value of cement, diatomite, emery (1989-90), gold, lime, pumice, silver, stone (crushed dolomite and quartzite, 1989), value indicated by symbol W		XX	45,988	XX	r49,965	XX	86,795
Total		XX	178,188	XX	187,728	XX	237,406
PENNSYLVANIA							
Cement:							
Masonry	thousand short tons	391	28,713	349	26,473	303	22,594
Portland	do.	6,309	329,634	5,757	301,980	5,621	286,185
Clays[2]	metric tons	1,248,139	5,843	1,049,973	4,936	840,646	2,900
Gem stones		NA	5	NA	5	NA	5
Lime	thousand short tons	1,641	91,214	1,660	92,139	1,626	92,557
Peat	do.	21	736	20	746	18	730
Sand and gravel (construction)	do.	19,826	91,966	e19,500	e94,600	20,883	97,348
Stone:							
Crushed	thousand short tons	e104,600	e470,700	393,123	3455,004	e395,800	e3502,700
Dimension	short tons	e59,022	e9,584	44,267	10,032	e43,952	e9,898
Combined value of clays (fire, [1990], kaolin), mica (scrap), sand and gravel (industrial), stone (crushed granite, 1989-90), and tripoli		XX	14,098	XX	14,754	XX	15,125
Total		XX	1,042,493	XX	1,000,669	XX	1,030,042
RHODE ISLAND							
Gem stones		NA	1	NA	2	NA	2
Sand and gravel (construction)	thousand short tons	1,853	7,847	e1,100	e3,900	1,969	9,042
Stone (crushed)	do.	e1,500	e9,400	131,208	7,170	e1131,600	e8,800
Total[8]		XX	17,248	XX	11,072	XX	17,844
SOUTH CAROLINA							
Cement (portland)	thousand short tons	2,533	118,670	2,188	99,083	2,464	109,644
Clays	metric tons	1,867,829	40,541	1,596,153	39,075	2,062,824	44,486
Gem stones		NA	10	NA	10	NA	10
Sand and gravel:							
Construction	thousand short tons	7,529	20,751	e7,500	e23,300	8,627	24,941
Industrial	do.	859	15,271	842	16,635	844	15,972

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)	1990 Quantity	1990 Value (thousands)
SOUTH CAROLINA—Continued							
Stone:							
Crushed[3]	thousand short tons	e23,500	e$105,800	24,429	$111,656	e26,200	e$135,400
Dimension	short tons	e353	e31	W	W	W	W
Combined value of cement (masonry), gold, manganiferous ore, mica (scrap), peat, silver, stone (crushed shell), vermiculite, and values indicated by symbol W		XX	56,728	XX	135,538	XX	119,400
Total		XX	357,802	XX	425,297	XX	449,853
SOUTH DAKOTA							
Cement:							
Masonry	thousand short tons	4	W	W	W	W	W
Portland	do.	490	W	W	W	W	W
Gem stones		NA	100	NA	150	NA	110
Gold[4]	kilograms	13,981	197,026	16,123	198,318	16,860	209,732
Lead[4]	metric tons	—	—	4	3	—	—
Sand and gravel (construction)	thousand short tons	7,929	18,681	e6,400	e20,800	9,689	23,689
Silver[4]	metric tons	3	552	4	705	6	940
Stone:							
Crushed	thousand short tons	e5,500	e20,600	3,833	14,303	e4,800	e16,800
Dimension	short tons	e43,297	e16,472	54,623	17,738	e50,688	e12,871
Combined value of clays (common), feldspar, gypsum (crude), iron ore, lime, mica (scrap) and values indicated by symbol W		XX	32,288	XX	32,341	XX	34,310
Total		XX	285,719	XX	284,358	XX	298,452
TENNESSEE							
Clays[2]	metric tons	1,165,736	27,696	1,137,152	26,292	1,060,66	225,776
Sand and gravel (construction)	thousand short tons	6,836	23,343	e6,100	e21,900	7,619	23,474
Stone:							
Crushed	do.	e52,200	e235,000	52,917	252,785	e54,600	e268,600
Dimension	short tons	e3,942	e567	4,888	437	e10,108	e2,051
Zinc[4]	metric tons	119,954	159,201	W	W	W	W
Combined value of barite (1988-89), cement, clays (bentonite [1988], common [1989], fuller's earth), copper, gem stones, lead, lime, phosphate rock, sand and gravel (industrial), silver, and values indicated by symbol W		XX	139,842	XX	336,993	XX	342,659
Total		XX	585,649	XX	638,407	XX	662,560
TEXAS							
Cement:							
Masonry	thousand short tons	136	10,800	133	10,735	142	10,106
Portland	do.	7,000	292,256	7,200	286,236	7,678	296,680
Clays[2]	metric tons	2,714,451	17,468	2,276,629	15,962	2,162,095	14,652
Gem stones		NA	340	NA	W	NA	W
Gypsum (crude)	thousand short tons	1,943	15,790	1,993	17,044	1,868	10,166
Lime	do.	1,192	55,935	1,304	60,829	1,337	76,181
Salt	do.	7,802	62,925	7,856	69,934	8,212	75,149
Sand and gravel:							
Construction	do.	50,370	171,167	e43,900	e155,800	46,083	158,080

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988		1989		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
TEXAS—Continued							
Sand and gravel—Continued							
Industrial	thousand short tons	1,631	$26,645	1,661	$29,107	1,849	$40,880
Stone:							
Crushed	do.	e82,000	e271,300	76,823	252,982	e81,800	e285,700
Dimension	short tons	e66,354	e8,310	81,268	12,449	e84,500	e12,600
Sulfur (Frasch)	thousand metric tons	2,622	W	2,446	W	2,340	W
Talc and pyrophyllite	metric tons	236,729	4,466	241,777	4,564	227,138	4,844
Combined value of clays (ball clay, [1988-89], bentonite [1990], fuller's earth [1990], kaolin), helium (crude and Grade-A), iron ore, magnesium compounds, magnesium metal, sodium sulfate (natural), and values indicated by symbol W		XX	531,416	XX	546,812	XX	472,187
Total		XX	1,468,818	XX	1,462,454	XX	1,457,225
UTAH							
Beryllium concentrates	metric tons	5,308	6	4,592	5	4,548	5
Cement (portland)	thousand short tons	772	39,664	W	W	W	W
Clays	metric tons	308,585	2,469	321,949	2,633	2277,795	21,774
Gem stones		NA	370	NA	659	NA	713
Lime	thousand short tons	365	17,252	373	17,974	354	18,878
Salt	do.	1,006	35,294	1,183	40,421	1,171	50,436
Sand and gravel:							
Construction	do.	17,843	49,796	e14,300	e41,500	13,601	44,881
Industrial	do.	3	60	3	60	2	42
Silver[3]	metric tons	W	W	W	W	147	22,750
Stone:							
Crushed	thousand short tons	e7,300	e20,600	4,683	19,176	e4,600	e20,200
Dimension	short tons	e2,004	e93	—	—	—	—
Combined value of cement (masonry), clays (bentonite, 1990), copper, fluorspar, gold, gypsum (crude), iron ore, magnesium copmpounds, magnesium metal, mercury, molybdenum, phosphate rock, potash, silver, sodium sulfate (natural), vanadium, and values indicated by symbol W		XX	849,243	XX	r1,168,065	XX	1,174,331
Total		XX	1,014,847	XX	1,290,493	XX	1,334,010
VERMONT							
Gem stones		NA	10	NA	10	NA	10
Sand and gravel (construction)	thousand short tons	6,047	17,478	e6,900	e20,400	3,675	11,948
Stone:							
Crushed	do.	e2,000	e18,000	3,119	28,110	e3,700	e35,000
Dimension	short tons	e105,000	e30,500	100,698	31,413	e99,243	e28,950
Combined value of other industrial minerals		XX	9,667	XX	8,969	XX	6,046
Total		XX	75,655	XX	88,902	XX	81,954
VIRGINIA							
Clays[2]	metric tons	1,010,114	6,614	1,001,394	6,302	882,383	3,741
Gem stones		NA	20	NA	27	NA	34
Lime	thousand short tons	741	33,875	821	38,353	846	39,784
Sand and gravel (construction)	do.	12,551	42,573	e12,900	e49,700	13,096	48,950
Stone:							
Crushed	do.	e66,000	e326,700	64,061	328,050	e59,400	e320,000
Dimension	short tons	e10,000	e2,900	W	W	W	W

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1988		1989		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
VIRGINIA—Continued							
Combined value of aplite, cement, clays (fuller's earth), gypsum (crude), iron oxide pigments (crude), kyanite, sand and gravel (industrial), talc and pyrophyllite, vermiculite, and values indicated by symbol W		XX	$81,830	XX	r$86,669	XX	$94,766
Total		XX	494,512	XX	509,101	XX	507,275
WASHINGTON							
Cement (portland)	thousand short tons	979	48,233	W	W	W	W
Clays	metric tons	376,924	2,235	233,267	1,591	158,257	1,357
Gem stones		NA	200	NA	208	NA	281
Gold[3]	kilograms	W	W	W	W	9,620	119,671
Peat	thousand short tons	5	142	W	W	W	W
Sand and gravel (construction)	do.	31,170	94,402	e37,800	e124,700	40,251	133,067
Stone:							
Crushed	do.	e13,900	e48,700	13,259	55,624	e12,700	e41,900
Dimension	short tons	e697	e60	W	W	W	W
Combined value of calcium chloride (natural, 1988), cement (masonry), diatomite, gypsum (crude), lime, magnesium metal, olivine, sand and gravel (industrial), silver, and values indicated by symbol W		XX	265,362	XX	298,756	XX	176,953
Total		XX	459,334	XX	480,879	XX	473,229
WEST VIRGINIA							
Clays	metric tons	239,473	586	251,385	553	164,257	384
Gem stones		NA	1	NA	1	NA	1
Sand and gravel (construction)	thousand short tons	1,653	6,099	e2,300	e6,700	e3,208	e14,950
Stone (crushed)	do.	e11,600	e47,600	310,904	342,538	e[3]12,000	e[3]45,200
Combined value of cement, lime, peat (1988, 1990), salt, sand and gravel (industrial), and stone (crushed granite, 1989-90)		XX	73,169	XX	75,706	XX	75,803
Total		XX	127,455	XX	125,498	XX	136,338
WISCONSIN							
Gem stones		NA	15	NA	W	NA	W
Lime	thousand short tons	452	23,986	437	18,129	461	24,608
Peat	do.	11	270	13	309	12	256
Sand and gravel:							
Construction	do.	25,048	60,080	e21,700	e56,400	29,572	73,750
Industrial	do.	1,351	15,458	1,514	22,399	W	W
Stone:							
Crushed	do.	e[2]28,500	e[2]98,300	26,520	83,664	e26,600	e91,000
Dimension	short tons	e49,900	e6,200	35,587	4,376	e31,316	e3,811
Combined value of other industrial minerals and value indicated by symbol W		XX	564	XX	(9)	XX	18,622
Total		XX	204,873	XX	[8]185,277	XX	212,047
WYOMING							
Clays[2]	metric tons	2,138,796	72,174	2,166,497	74,697	2,523,573	76,082
Gem stones		NA	150	NA	157	NA	151
Lime	thousand short tons	26	1,640	W	W	W	W
Sand and gravel (construction)	do.	3,413	11,351	e4,500	e15,400	4,329	14,446
Stone (crushed)	do.	e2,500	e11,400	2,990	12,120	e2,200	e14,000

See footnotes at end of table.

TABLE 5—Continued

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

Mineral	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)	1990 Quantity	1990 Value (thousands)
WYOMING—Continued						
Combined value of cement, clays (common), gypsum (crude), helium (Grade-A), soda ash, and values indicated by symbol W	XX	$613,097	XX	$724,987	XX	$806,169
Total	XX	709,812	XX	827,361	XX	910,848
UNDISTRIBUTED						
Delaware, Hawaii, Hew Hampshire, Rhode Island, Wisconsin (1989), and undistributed (1989)	XX	7,812	XX	9,043	XX	5,938

[e]Estimated. [r]Revised. 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]Beginning with 1989 data reported in B_2O_3, 1988 data converted.
[7]Less than 1/2 unit.
[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]Value excluded to avoid disclosing company proprietary data.
[10]Excludes salt in brines; value included with "Combined value" figure.
[11]Palladium metal separated from platinum-group metals in 1990. 1988-89 data revised.
[12]Platinum metal separated from platinum-group metals in 1990. 1988-89 data revised.
[13]Excludes traprock.

TABLE 6

NONFUEL MINERAL PRODUCTION[1] IN THE ISLANDS ADMINISTERED BY THE UNITED STATES

Mineral	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)	1990 Quantity	1990 Value (thousands)
American Samoa: Stone (crushed) thousand short tons	—	—	48	$476	—	—
Guam: Stone (crushed) do.	—	—	1,063	11,133	—	—
Virgin Islands: Stone (crushed) do.	—	—	312	3,159	—	—
Total	XX	—	XX	14,768	XX	—

XX Not applicable.
[1]Production as measured by mine shipments, sales, or marketable production (including consumption by producers).

TABLE 7

NONFUEL MINERAL[1] PRODUCTION IN THE COMMONWEALTH OF PUERTO RICO

Mineral		1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)	1990 Quantity	1990 Value (thousands)
Cement (portland)	thousand short tons	1,397	$113,966	1,374	$112,318	1,486	$122,027
Clays	metric tons	148,218	365	136,873	311	W	W
Lime	thousand short tons	25	3,802	26	3,800	29	3,483
Salt	do.	40	900	—	—	—	—
Sand and gravel (industrial)	do.	31	624	30	600	55	825
Stone (crushed)	do.	[e]9,350	[e]47,400	8,389	46,648	NA	NA
Total[2]		XX	167,057	XX	163,677	XX	126,335

[e]Estimated. 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 item withheld.

TABLE 8

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

Mineral		1989[r]		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS					
Aluminum:					
Aluminum sulfate	metric tons	941	$1,208	6,807	$1,299
Castings and forgings	do.	20,482	128,974	7,003	67,981
Metals and alloys, crude	do.	593,103	1,260,475	679,803	1,160,509
Plates, sheets, bars, etc.	do.	446,233	1,379,982	437,662	1,406,498
Scrap	do.	575,419	769,380	537,298	719,017
Other aluminum compounds (fluorides and chlorides)	do.	34,315	23,993	13,915	18,129
Antimony:					
Metal, alloys, crude, waste and scrap	do.	293	694	588	1,143
Oxide	do.	2,229	6,106	8,605	13,962
Bauxite (dried and calcined)	thousand metric tons	44	9,830	74	12,644
Beryllium, alloys, waste and scrap	kilograms	34,261	3,847	45,227	4,831
Bismuth metal, alloys, waste, and scrap	do.	122,171	540	121,677	878
Cadmium metal, alloys, dross, flue dust, etc.	metric tons	369	857	385	1,174
Chromium (gross weight):					
Chemicals	metric tons	23,303	23,626	22,500	26,449
Chromite ore and concentrate	do.	40,445	5,014	6,321	1,488
Metal and alloys:					
Chromium metal	do.	196	4,097	338	3,447
Chromium ferroalloys	do.	9,464	11,037	9,118	10,537
Pigments	do.	2,264	7,654	2,643	9,252
Cobalt:					
Cobalt ores and concentrates (gross weight)	do.	28	253	49	416
Metal (unwrought cobalt, powders, matte, waste and scrap (estimated cobalt content)	do.	355	9,452	543	8,880
Oxides and hydroxides (estimated cobalt content)	do.	603	6,073	922	6,776
Salts and compounds (estimated cobalt content)	do.	101	1,724	542	2,477
Wrought cobalt and cobalt articles (gross weight)	do.	171	7,033	481	12,300
Columbium metal, compounds, and alloys (gross weight)	thousand pounds	NA	NA	NA	NA
Copper:					
Blister and anodes	metric tons	5,475	14,664	6,422	14,701
Matte, ash, and precipitates (copper content)	do.	14,945	35,363	31,709	40,977
Ore and concentrate (copper content)	do.	266,831	539,325	258,235	401,785
Refined copper	do.	130,189	303,013	211,164	554,833
Scrap:					
Alloy	do.	212,522	314,521	184,766	292,723
Unalloyed scrap only	do.	154,935	244,195	139,624	227,418
Semimanufactures, copper and copper alloy	do.	70,984	270,587	68,519	278,528
Ferroalloys not elsewhere listed:					
Ferrophosphorous	do.	22,587	3,511	5,981	2,344
Ferroalloys, n.e.c.	do.	6,026	9,068	3,893	5,229
Gold:					
Bullion, refined	kilograms	123,599	1,490,151	140,923	1,719,470
Dore and precipitates	do.	42,935	242,690	88,203	413,980
Ores and concentrates	do.	16	165	328	3,721
Wastes and scrap	do.	44,541	542,150	66,943	729,150

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1989[r]		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Iron ore (gross weight):					
Coarse ores	thousand metric tons	—	—	6	$213
Concentrates	do.	353	$13,887	11	333
Fine ores	do.	[1]145	[1]559	10	346
Pellets	do.	4,852	177,980	3,018	116,845
Roasted pyrites	do.	1	117	19	840
Other	do.	14	252	136	5,498
Iron chemicals (gross weight):					
Chlorides	metric tons	172	202	1,781	1,218
Sulfates	do.	—	—	—	—
Iron and steel:					
Iron and steel products (major):					
Fabricated steel products	thousand short tons	520	400,588	698	[e]420,000
Steel mill products	do.	4,578	2,063,103	4,303	[e]2,800,000
Other steel products	do.	120	117,995	131	[e]55,000
Iron and steel scrap: Ferrous scrap used rails for rerolling and other uses, and ships, boats, and other vessels for scrapping	thousand short tons	12,477	1,785,403	12,842	1,653,445
Pig iron	short tons	11,747	1,334	15,933	1,618
Lead:					
Ash and residues (lead content)	metric tons	9,960	5,612	12,765	8,096
Blocks, pigs, anodes, etc. (lead content)	do.	28,512	30,091	57,226	59,080
Ore and concentrate (lead content)	do.	57,038	23,516	56,600	33,369
Scrap (gross weight)	do.	59,909	26,165	75,507	33,934
Wrought and alloy	do.	5,365	14,113	6,759	19,923
Magnesium, metal and alloys, scrap, semimanufactured forms, n.e.c. (gross weight)	do.	56,631	170,374	51,834	164,413
Manganese:					
Ferromanganese (all grades)	short tons	9,014	7,310	8,302	6,565
Metal (includes alloys, waste, and scrap)	do.	5,667	10,632	6,773	14,043
Ore and concentrates	do.	57,191	5,014	77,101	9,297
Silicomanganese	do.	5,858	4,068	1,974	1,666
Mercury metal	metric tons	221	1,874	NA	NA
Molybdenum:					
Ferromolybdenum (gross weight)	do.	75	615	300	2,372
Molybdates, all (gross weight)	do.	295	2,338	680	3,963
Ore and concentrates (molybdenum content)	do.	51,231	272,336	41,380	169,888
Powder (gross weight)	do.	634	3,846	292	4,565
Unwrought (gross weight)	do.	253	3,215	180	2,453
Wire (gross weight)	do.	340	10,867	338	12,863
Wrought (gross weight)	do.	336	8,219	190	7,595
Nickel:					
Compound catalysts and waste and scrap	short tons	14,205	80,614	17,828	89,476
Primary (cathodes, pellets, briquets [unwrought], electroplating, ferronickel, powder, and flakes)	do.	2,302	XX	3,642	XX
Stainless steel scrap (nickel content)	do.	21,871	320,683	19,260	212,368
Wrought (bars, rods, profiles, wire, sheets, strips, foil, tubes, and pipes)	do.	592	11,951	457	5,047

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1989[r]		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Platinum-group metals:					
Iridium, ruthenium, and osmium	kilograms	507	$4,232	782	$4,409
Platinum	do.	8,414	135,469	7,510	113,329
Palladium	do.	13,005	72,849	10,887	49,576
Rhodium	do.	1,156	28,519	969	45,050
Waste and scrap	do.	15,046	157,040	34,487	201,538
Rare-earth metals:					
Cerium compounds	do.	1,432,672	7,026	1,729,771	9,983
Rare-earth metals, including scandium and yttrium	do.	424,837	4,801	201,122	1,250
Thorium ore and concentrates	metric tons	2,000	30	—	—
Selenium	do.	372,126	3,429	194,608	1,458
Silicon:					
Ferrosilicon	do.	49,054	40,883	50,079	43,993
Silicon metal	do.	5,045	84,074	8,980	92,229
Silver:					
Bullion, refined	kilograms	430,110	77,812	735,993	119,892
Doré and precipitates	do.	78,664	15,478	13,184	2,353
Ores and concentrates	do.	607	166	21,861	3,994
Waste and scrap	do.	770,788	145,340	1,077,421	159,194
Tantalum:					
Unwrought (waste and scrap, powders, alloys, and metal)	do.	389	25,962	406	29,200
Wrought	do.	180	21,715	132	20,068
Tin:					
Ingots, pigs, and bars	metric tons	904	8,915	658	3,344
Tinplate and terneplate	do.	178,884	101,279	145,396	78,687
Tin scrap and other tin bearing material, except tinplate scrap, (includes bars, rods, profiles, wire, powders, flakes, tubes, and pipes	thousand pounds	100,703	54,135	106,288	55,913
Titanium:					
Ore and concentrates	do.	19,832	5,900	18,765	7,398
Other unwrought (billet, blooms and sheet bars, ingots, etc.)	do.	3,875	63,772	5,472	69,235
Pigments and oxides	do.	212,197	437,645	202,288	434,560
Scrap	do.	5,474	22,909	5,487	22,443
Sponge	do.	136	910	331	2,073
Wrought (bars, rods, etc.)	do.	3,857	110,511	4,526	148,290
Tungsten (tungsten content):					
Ammonium paratungstate	do.	178	1,503	356	2,456
Carbide powder	do.	1,360	27,209	1,074	21,946
Metal and alloy	do.	762	15,554	988	18,587
Miscellaneous tungsten-bearing materials (wire, crude form, waste and scrap, ferrotungsten, ferrosilicon tungsten, and compounds	do.	896	36,367	795	36,683
Ore and concentrate	do.	203	1,539	139	765
Vanadium:					
Ferrovanadium	kilograms	493,055	5,299	334,272	5,480
Other compounds	do.	1,550,381	4,262	976,481	6,024
Pentoxide, anhydride	do.	3,741,234	35,204	1,461,453	10,142

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1989[r]		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Zinc:					
Blocks, pigs, anodes, etc.	metric tons	7,955	$14,433	5,804	$11,304
Dust and flakes	do.	8,137	13,861	8,701	17,039
Ore and concentrate	do.	78,877	64,224	220,446	188,686
Waste and scrap (zinc content)	do.	108,086	75,947	109,316	85,749
Wrought zinc and zinc alloys	do.	19,168	18,488	15,612	18,541
Zinc oxide	do.	12,286	17,872	7,141	10,032
Zirconium:					
Ore and concentrates	do.	48,071	31,134	30,195	21,101
Unwrought waste and scrap	do.	232	5,974	188	3,057
INDUSTRIAL MINERALS					
Abrasives (includes reexports):					
Diamond grinding wheels	thousand wheels	770	10,195	777	14,069
Abrasives (includes reexports)—Continued					
Industrial diamond, natural or synthetic:					
Powder or dust	thousand carats	78,235	124,180	71,041	109,500
Other	do.	2,755	33,248	1,698	20,120
Other natural and artificial metallic abrasives and products		XX	126,810	XX	151,784
Asbestos:					
Exports (includes reexports):					
Products		NA	153,081	NA	120,328
Unmanufactured	metric tons	27,004	7,690	27,965	7,964
Barite: Natural barium sulfate	do.	9,709	1,622	9,227	1,675
Boron:					
Boric acid	thousand metric tons	42	32,613	39	31,679
Sodium borates	do.	646	361,000	585	208,433
Bromine:					
Compounds (contained bromine)	thousand kilograms	28,998	24,093	14,443	18,166
Elemental	do.	3,557	3,165	2,932	4,008
Calcium chloride	metric tons	20,316	5,695	23,300	6,615
Cement: Hydraulic and clinker	thousand short tons	512	25,561	554	38,306
Clays:					
Bentonite	thousand metric tons	671	52,946	699	57,112
Kaolin and china clay	do.	2,337	370,919	2,826	427,890
Other	do.	748	126,478	566	98,237
Diatomite	metric tons	137	41,290	144	42,327
Feldspar, leucite, nepheline syenite	do.	9,329	829	24,795	2,167
Fluorspar	do.	5,134	694	14,921	1,891
Gem stones (including reexports):					
Diamonds	thousand carats	1,050	1,243,700	1,004	1,899
Pearls		NA	7,300	NA	900
Other		NA	222,200	NA	41,106
Graphite, natural and artificial[2]	metric tons	48,729	33,387	44,622	41,106
Gypsum:					
Boards	thousand short tons	97	25,140	69	30,959
Crude	do.	108	2,286	129	5,056
Plasters	do.	106	15,914	94	18,381
Other	do.	NA	16,972	30,056	84,452

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1989[r]		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
INDUSTRIAL MINERALS—Continued					
Helium (Grade-A)	million cubic feet	796	$33,830	892	$33,450
Iron oxide pigments:					
Pigment grade	metric tons	9,966	15,700	9,510	18,533
Other grade	do.	34,631	54,567	198,631	110,732
Lime	short tons	32,241	3,893	44,287	4,755
Lithium compounds:					
Lithium carbonate	kilograms	9,045,732	28,214	9,312,903	30,160
Lithium hydroxide	do.	4,691,991	17,914	3,147,248	12,953
Lithium metal	do.	141,225	NA	111,737	NA
Magnesium compounds:					
Calcined dolomite	metric tons	39,639	10,683	10,379	2,213
Caustic-calcined magnesia	do.	4,375	2,263	2,313	1,406
Compounds, includes magnesium hydroxide, magnesium peroxide, magnesium chloride, and magnesium sulfate	metric tons	14,851	6,100	14,162	14,165
Dead-burned and fused magnesia	do.	22,525	10,685	58,610	19,709
Magnesite, natural	do.	10,380	8,299	8,009	8,060
Other magnesia	do.	15,843	9,213	37,747	16,108
Mica:					
Crude and rifted	do.	1,082	476	572	427
Powder	do.	1,230	1,634	4,319	2,050
Waste	do.	202	235	156	491
Worked	do.	415	7,227	612	7,567
Nitrogen compounds (major):					
Fertilizer materials	thousand short tons	13,569	NA	13,032	NA
Industrial chemicals	do.	192	150,813	89	126,658
Phosphate rock (ground and unground)	thousand metric tons	8,323	288,990	6,959	254,104
Phosphatic fertilizers:					
Diammonium and monoammonium phosphates	thousand metric tons	9,102	1,608,264	8,493	1,414,219
Elemental phosphorus	metric tons	19,934	28,294	17,916	29,620
Phosphoric acid	thousand metric tons	703	124,074	555	95,881
Superphosphates	do.	534	151,861	747	100,630
Potash:					
Potassium chloride	metric tons	496,575	NA	445,810	NA
Potassium sulfate, all grades	do.	448,880	NA	561,914	NA
Quartz crystal:					
Cultured	thousand kilograms	57	2,600	39	1,745
Natural	do.	NA	NA	NA	NA
Salt, crude and refined	thousand short tons	1,567	20,211	2,498	32,944
Sand and gravel:					
Construction:					
Gravel	do.	852	7,703	NA	NA
Sand	do.	273	5,888	468	11,880
Industrial sand and gravel	do.	2,060	78,308	1,155	83,826
Sodium compounds:					
Soda ash	thousand metric tons	2,648	365,469	2,392	346,693

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1989[r]		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
INDUSTRIAL MINERALS—Continued					
Sodium compounds—Continued					
Sodium sulfate	thousand metric tons	62	$6,241	62	$6,704
Stone:					
Crushed	thousand short tons	3,900	23,345	5,100	41,400
Dimension		NA	34,610	NA	42,668
Strontium compounds	metric tons	3,200	NA	1,300	NA
Sulfur, elemental	thousand metric tons	1,024	107,126	972	109,327
Talc, crude and ground	do.	319	28,949	238	32,909
Total[3]		XX	21,558,000	XX	20,868,000

[r]Revised. NA Not available. XX Not applicable.
[1]Either quantity or value data are incorrect. The U.S. Bureau of Mines and Bureau of the Census were unable to verify the correct data at time of publication.
[2]Artificial graphite includes a large amounts of materials made from petroleum coke.
[3]Data may not add to totals shown because of independent rounding.

TABLE 9

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

Mineral		1989[r]		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS					
Aluminum:					
Aluminum oxide (alumina)	thousand metric tons	4,311	$1,228,123	4,070	$1,268,973
Metals and alloys, crude	metric tons	923,030	1,898,132	959,615	1,596,886
Plates, sheets, bars, etc.	do.	340,382	950,902	340,334	340,334
Scrap	do.	206,610	309,122	214,196	259,674
Antimony:					
Antimony metal	do.	10,621	21,143	13,940	23,380
Antimony oxides	do.	12,041	19,770	14,472	19,574
Ore and concentrate (antimony content)	do.	4,550	8,462	3,454	4,835
Arsenic:					
Acid	do.	48	67	21	31
Arsenic trioxide	do.	28,348	13,526	26,256	12,570
Metallic	do.	928	2,150	796	4,091
Sulfides	do.	2	19	—	—
Bauxite:					
Calcined	thousand metric tons	531	34,677	558	35,564
Crude and dried	do.	10,893	NA	12,142	NA
Beryllium ore	metric tons	601	655	342	418
Bismuth, metals and alloys (gross weight)	kilograms	1,880,321	21,586	1,611,862	11,747
Cadmium metal	metric tons	2,787	30,161	1,741	11,904
Chromium (gross weight):					
Chemicals	do.	12,895	23,677	10,130	24,136
Chromite ore and concentrate	do.	525,044	43,949	305,507	22,150
Metals and alloys:					
Chromium ferroalloys	do.	343,732	330,427	415,893	246,439
Chromium metal	do.	4,202	27,590	6,664	43,161
Pigments and preparation based chromiuum	do.	5,963	13,355	5,652	13,708

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1989[r]		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Cobalt:					
Metal (estimated cobalt content)	metric tons	5,444	$91,960	6,027	$106,902
Other forms (estimated cobalt)	do.	75	1,426	547	3,227
Oxide and hydroxides (estimated cobalt content)	do.	273	6,598	351	8,539
Unwrought cobalt alloys (gross weight)	do.	90	3,301	65	2,398
Wrought cobalt and cobalt articles (gross weight)	do.	84	3,627	48	3,729
Other cobalt: matte, waste, and scrap (gross weight)	do.	364	5,054	250	1,806
Columbium:					
Ferrocolumbium	thousand pounds	8,178	28,657	6,435	24,685
Mineral concentrates	do.	4,910	8,060	4,964	7,898
Oxide	do.	1,454	9,470	2,145	15,348
Wrought and unwrought	do.	26	514	5	150
Copper (copper content):					
Blister and anode	do.	77,218	242,106	44,278	125,238
Matte, ash, and precipitates	do.	2,721	6,571	7,961	19,802
Ore and concentrate	metric tons	46,516	51,311	91,493	131,038
Refined copper	do.	303,803	865,684	261,672	674,774
Semimanufactures, copper and copper alloy	do.	100,254	398,605	NA	NA
Scrap:					
Alloy	do.	79,320	151,265	98,710	192,777
Scrap—Continued					
Unalloyed scrap only	metric tons	31,577	87,919	25,904	80,976
Ferroalloys not elsewhere listed, including spiegeleisen	do.	2,339	7,737	2,404	8,351
Gallium	kilograms	15,284	5,665	9,894	3,250
Germanium	do.	40,105	23,789	49,769	27,968
Gold:					
Bullion, refined	do.	96,967	1,198,734	64,755	795,007
Dore and precipitates	do.	13,159	157,952	4,245	50,635
Ore and concentrates	do.	2,426	7,103	5,346	8,355
Wastes and scrap	do.	39,952	115,685	23,173	206,975
Hafnium: Waste and scrap	metric tons	4	976	9	1,662
Indium	kilograms	26,813	8,944	30,158	6,555
Iron ore (gross weight):					
Coarse ores	thousand metric tons	662	15,566	545	14,445
Concentrates	do.	371	7,760	294	7,733
Fine ores	do.	11,629	297,913	7,338	181,696
Other	do.	1,186	23,251	2	179
Pellets	do.	5,628	175,728	9,875	355,470
Roasted iron pyrites	do.	121	2,045	(1)	2
Iron chemicals (gross weight):					
Chlorides	metric tons	1,116	494	2,447	731
Sulfates	do.	7,554	1,429	19,427	2,888
Iron and steel:					
Direct-reduced iron	short tons	188,038	22,621	367,782	40,974
Iron and steel products (major):					
Steel mill products	thousand short tons	17,321	7,590,841	17,162	[e]8,300,000
Fabricated steel products	do.	2,378	2,884,328	2,232	[e]1,450,000

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1989[r]		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Iron and steel—Continued					
Iron and steel products (major)—Continued					
Iron products	thousand short tons	264	$173,910	229	[e]$92,000
Pig iron	short tons	488,175	73,184	382,737	60,069
Scrap, including tinplate and terneplate	thousand short tons	1,120	149,109	1,443	171,510
Lead:					
Ash and residue (lead content)	metric tons	677	286	281	102
Blocks, pigs, anodes, etc. (lead content)	do.	121,463	84,401	93,351	76,031
Miscellaneous products (lead content)	do.	852	11,908	515	6,782
Ore and concentrates (lead content)	do.	2,939	1,123	7,790	3,456
Pigments and compounds	do.	20,770	27,030	22,165	30,530
Scrap	do.	—	—	—	—
Wrought and alloys	do.	6,068	9,076	6,722	9,945
Magnesium metal and alloys, scrap, semimanufactured forms, n.e.c. (magnesium content)	do.	12,289	37,859	26,755	80,308
Manganese:					
Chemicals (manganese dioxide, potassium permanganate)	short tons	8,899	10,448	9,806	12,453
Ferromanganese (all grades)	do.	370,483	246,540	328,352	234,329
Ferrosilicon-manganese	do.	166,484	151,241	162,612	117,847
Metal	do.	16,147	22,283	14,279	19,741
Ore and concentrates (contained manganese)	do.	298,485	43,794	164,180	40,054
Mercury: Metal, waste and scrap	metric tons	131	1,247	15	231
Molybdenum:					
Ferromolybdenum	do.	772	9,062	871	6,990
Molybdates, all	do.	27	375	2	13
Ore and concentrates (molybdenum content)	do.	238	1,791	733	2,874
Powder	do.	198	2,077	71	1,771
Unwrought	do.	46	2,391	39	2,147
Wire	do.	8	553	3	249
Wrought	do.	50	3,311	61	4,217
Other	do.	3	637	2	720
Nickel:					
Primary; (cathodes, pellets, briquets and shot [unwrought], ferronickel, powder, flakes, oxide and oxide sinter, salts, and other [including slurry], nickel content)	short tons	130,725	378,936	144,530	1,177,611
Waste and scrap	do.	5,666	78,089	4,379	46,764
Wrought; (bars, rods, profiles, wire, sheets, strips, foil, tubes and pipes, [nickel content])	do.	911	16,511	1,140	15,495
Platinum-group metals:					
Iridium	kilograms	688	6,565	603	6,063
Palladium	do.	51,135	263,790	51,992	210,438
Platinum	do.	49,238	801,728	52,277	779,507
Ores	do.	12	83	109	671
Osmium	do.	58	605	75	678
Rhodium	do.	7,105	270,466	13,098	869,869
Ruthenium	do.	2,883	7,512	2,586	6,133
Waste and scrap	do.	2,159	30,944	4,614	32,471

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1989[r]		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Rare-earth metals:					
Monazite	metric tons	774	$530	850	$686
Rare-earth metals, (including scandium and yttrium)	kilograms	294,236	4,181	198,840	3,050
Cerium compounds	do.	250,806	1,940	359,230	2,041
Rare-earth oxides, (excluding cerium oxide)	do.	501,898	6,986	150,728	8,018
Other rare-earth metals	do.	1,402,448	8,086	1,362,951	12,813
Other mixtures of rare-earth oxides or other rare-earth chlorides	do.	7,390,689	30,709	498,964	37,325
Ferrocerium and other pyrophoric alloys	do.	244,271	1,690	NA	NA
Rhenium:					
Metal including scrap	do.	3,785	4,197	6,068	6,864
Ammonium perrhenate (rhenium content)	do.	948	949	15,353	4,531
Selenium and selenium dioxide (selenium content)	do.	417,095	8,934	382,860	8,353
Silicon:					
Ferrosilicon	metric tons	177,895	131,631	238,983	134,993
Silicon metal	do.	43,196	80,388	66,383	114,385
Silver:					
Bullion, refined	kilograms	3,061,548	578,781	2,697,926	437,380
Dore and precipitates	do.	142,739	27,943	48,449	8,741
Ore and concentrates	do.	7,013	2,301	90,202	23,203
Waste and scrap	do.	90,753	96,254	507,649	86,421
Tantalum:					
Mineral concentrates	thousand pounds	3,850	52,762	2,240	25,589
Unwrought	do.	239	11,595	209	9,761
Wrought	do.	2	431	7	1,028
Tellurium	kilograms	42,871	3,249	34,012	3,928
Thallium	do.	1,173	123	450	61
Tin:					
Concentrates (tin content)	metric tons	216	1,938	—	—
Dross, skimmings, residues, scrap, tin alloys, n.s.p.f.	do.	10,270	34,695	6,788	35,291
Metal (unwrought)	do.	33,988	288,118	33,810	215,863
Tin compounds	do.	314	2,720	426	2,493
Tinfoil, powder, flitters, metallics and manufactures, n.s.p.f.	do.	XX	4,570	XX	2,086
Titanium:					
Ilmenite[2]	do.	797,897	110,611	719,530	112,412
Other unwrought (ingots, billets, powder, etc.)	do.	309	8,336	375	2,932
Pigments	do.	166,346	277,140	147,592	279,602
Rutile, natural and synthetic	do.	264,895	119,928	274,605	127,664
Sponge	do.	903	8,181	1,093	10,398
Titaniferous iron ore	do.	37,922	1,876	28,818	2,169
Waste and scrap	do.	5,308	41,898	3,037	17,550
Wrought	do.	1,250	34,085	1,266	35,746
Tungsten (tungsten content):					
Ammonium tungstate	do.	431	4,560	462	3,463
Ferrotungsten	do.	360	1,986	493	2,739
Ore and concentrates	do.	7,896	45,077	6,420	31,301

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1989[r]		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Miscellaneous tungsten-bearing materials (waste and scrap, unwrought, wrought, tungstic acid, potassium tungstate, sodium tungstate, carbide, and other compounds)	metric tons	3,014	$48,751	2,537	$36,594
Vanadium:					
Ferrovanadium (vanadium content)	kilograms	486,705	13,493	244,250	3,720
Pentoxide, anhydride (vanadium content)	do.	92,079	1,911	82,627	719
Vanadium-bearing materials (slags and dross) (pentoxide content)	do.	4,072,778	18,762	3,321,890	6,702
Vanadium-bearing ash and residues (pentoxide content)	do.	1,432,094	5,035	1,801,071	4,786
Zinc:					
Blocks, pigs, slabs	metric tons	711,554	1,183,523	631,742	991,562
Dross, ashes, and fume (zinc content)	do.	9,031	7,856	6,411	5,942
Dust, powder, flakes	do.	7,253	15,123	8,834	17,724
Ore and concentrates (zinc content)	do.	40,974	23,047	46,684	17,970
Pigments and compounds	do.	71,825	105,089	61,107	83,449
Sheets, plates, strips, and other forms	do.	3,066	5,436	929	1,641
Waste and scrap	do.	9,367	6,674	31,720	15,101
Zirconium:					
Ore and concentrates	do.	73,129	33,917	26,783	12,407
Unwrought waste and scrap	do.	259	2,209	128	880
INDUSTRIAL MINERALS					
Abrasives:					
Diamond, natural and synthetic	thousand carats	70,342	105,295	96,483	137,607
Other		XX	313,789	XX	332,174
Asbestos	metric tons	55,306	14,031	41,348	10,773
Barite:					
Crude and ground	thousand metric tons	1,034	44,679	1,044	46,300
Witherite	metric tons	76	30	34	23
Chemicals	do.	32,637	24,041	28,429	22,165
Boron (contained boric oxide):					
Boric acid	thousand metric tons	3	2,197	22	8,120
Colemanite	do.	15	4,202	12	3,310
Ulexite	do.	27	1,552	29	7,360
Bromine:					
Compounds	thousand kilograms	30,524	55,599	20,359	84,871
Elemental	do.	460	293	756	508
Calcium metal	kilograms	679,603	3,210	651,000	3,779
Calcium chloride:					
Crude	metric tons	119,296	20,856	145,534	21,541
Other	do.	8,048	3,817	16,837	6,102
Cement: Hydraulic and clinker	thousand short tons	15,741	605,325	13,273	533,047
Clays	metric tons	27,794	10,928	29,550	11,988
Cryolite, natural and synthetic	do.	8,429	7,647	7,306	6,775
Diatomite	thousand short tons	838	[e]294	689	268
Feldspar, crude, ground and crushed or pulverized	metric tons	12,003	873	11,318	723
Fluorspar	do.	655,590	79,875	513,921	65,938

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1989[r]		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
INDUSTRIAL MINERALS—Continued					
Gem stones:					
Diamond	thousand carats	10,059	$4,358,147	7,528	$3,955,222
Emeralds	do.	3,402	207,546	3,720	162,375
Pearls (natural, cultured, and imitation)	do.	NA	154,173	NA	26,645
Rubies and sapphires	do.	6,666	183,344	5,817	180,375
Other precious or semiprecious stones		NA	211,339	NA	284,688
Graphite,natural and synthetic	metric tons	62,319	33,707	50,213	35,222
Gypsum:					
Boards	thousand short tons	355	29,355	272	22,786
Crude	do.	9,304	59,107	8,726	61,009
Plasters	do.	3	2	701	236
Other	do.	NA	22,280	26,174	110,205
Hydrofluoric acid	metric tons	118,902	117,919	101,792	409,384
Iodine (includes crude, potassium iodide, and resublimed iodine)	thousand kilograms	3,326	58,980	3,168	43,553
Iron oxide pigments:					
Natural	metric tons	4,961	1,354	1,859	991
Synthetic	do.	31,708	29,186	32,141	35,918
Lime:					
Hydrated	short tons	36,952	2,219	29,920	2,147
Other lime	do.	180,704	9,749	8,245	173,197
Lithium:					
Carbonate	metric tons	3,326	6,629	4,197	8,381
Compounds	do.	7,191	7,108	—	—
Lithium—Continued					
Hydroxide	metric tons	23	164	1	20
Metal	do.	15	31	—	—
Ores	do.	31,660	3,049	—	—
Salt	do.	14	14	—	—
Magnesium compounds:					
Calcined dolomite	do.	21,788	2,871	38,441	3,639
Caustic-calcined magnesia	do.	75,584	13,657	83,885	13,957
Compounds, includes magnesium hydroxide, magnesium peroxide, magnesium chloride, and magnesium sulfate	do.	29,002	6,942	33,046	9,238
Dead-burned and fused magnesia	do.	202,790	38,555	155,010	32,858
Natural magnesite	do.	8,372	1,354	1,957	722
Other magnesia	do.	5,874	9,194	5,037	8,573
Mica:					
Crude and rifted	do.	4,612	2,740	5,444	2,915
Powder	do.	8,902	4,971	9,142	5,133
Waste	do.	1,189	542	205	123
Worked	do.	1,129	6,711	1,085	7,431
Nepheline syenite, crude, ground, crushed, etc.	short tons	303,000	12,273	276,000	12,200
Nitrogen compounds (major):					
Fertilizer materials	thousand short tons	8,325	920,785	7,719	847,304
Industrial chemicals	do.	138	108,392	71	65,852
Peat moss (poultry and fertilizer grade)	short tons	529,706	69,931	598,802	87,533
Phosphate rock and phosphate materials	thousand metric tons	814	80,284	477	46,365

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1989[r]		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
INDUSTRIAL MINERALS—Continued					
Potash (includes potassium chloride, postassium sulfate, potassium nitrate, and potassium sodium nitrate)	metric tons	5,618,300	$501,300	6,951,700	$545,700
Pumice:					
Crude or unmanufactured	do.	273,464	12,483	266,604	7,858
Wholly or partially manufactured	do.	23,691	3,649	13,704	2,021
Salt crude and refined	thousand short tons	6,084	74,474	6,580	88,419
Sand and gravel:					
Industrial sand and gravel	do.	35	2,057	73	3,148
Other sand and gravel	do.	427	6,618	1,742	22,912
Sodium compounds:					
Soda ash	do.	128,790	17,396	145,534	20,495
Sodium sulfate	do.	173	13,900	162	13,155
Stone:					
Calcium carbonate fines	do.	4	1,234	3	864
Crushed and chips	do.	4,352	35,631	4,969	34,442
Dimension		NA	525,052	NA	523,891
Strontium:					
Celestite (strontium sulfate)	metric tons	25,640	1,956	48,724	4,189
Compounds and metal	do.	19,112	11,068	20,162	12,982
Sulfur, elemental	thousand metric tons	2,260	209,465	2,571	206,450
Talc, unmanufactured	thousand short tons	77,716	12,128	65,099	11,056
Total[3]		XX	35,537,000	XX	33,389,000

[r]Revised. NA Not available. XX Not applicable.
[1]Less than 1/2 unit.
[2]Includes titanium slag averaging about 70% TiO_2. For details, see "Titanium" chapter.
[3]Data may not add to totals shown because of independent rounding.

TABLE 10

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

Mineral		1989			1990[p]		
		World production[1]	U.S. production	U.S. percent of world production	World production[1]	U.S. production	U.S. percent of world production
METALS, MINE BASIS							
Antimony[2]	metric tons	66,283	W	NA	62,004	W	NA
Arsenic trioxide[3]	do.	48,562	—	—	47,632	—	—
Bauxite[4]	thousand metric tons	105,695	W	NA	112,180	W	NA
Beryllium concentrates (gross weight)	metric tons	7,532	[5]4,592	61	7,138	[5]4,548	64
Bismuth	do.	3,556	W	NA	3,200	W	NA
Chromite (gross weight)	thousand metric tons	13,542	—	—	12,846	—	—
Cobalt[2]	metric tons	43,030	—	—	37,136	—	—
Columbium-tantalum concentrate (gross weight)	thousand pounds	73,435	—	—	65,448	—	—
Copper[2]	thousand metric tons	8,730	1,498	17	8,815	1,587	18
Gold[2]	kilograms	1,999,458	265,541	13	2,049,946	290,202	14
Iron ore (gross weight)	thousand metric tons	924,869	59,032	6	920,778	56,408	6
Lead[2]	do.	3,368	420	12	3,367	495	15

See footnotes at end of table.

TABLE 10—Continued

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

Mineral		1989			1990[p]		
		World production[1]	U.S. production	U.S. percent of world production	World production[1]	U.S. production	U.S. percent of world production
METALS, MINE BASIS—Continued							
Manganese ore (gross weight)	thousand short tons	27,626	—	—	27,192	—	—
Mercury	metric tons	6,263	W	NA	5,785	W	NA
Molybdenum[2]	do.	116,799	63,105	54	111,652	61,611	55
Nickel[2]	thousand short tons	1,067	—	—	1,029	(6)	(6)
Platinum-group metals[3]	kilograms	283,158	6,280	2	286,704	7,740	3
Silver[2]	metric tons	14,760	2,007	14	15,108	2,170	14
Tin[2]	do.	233,773	W	NA	219,333	W	NA
Titanium concentrates (gross weight):							
Ilmenite	thousand metric tons	4,236	W	NA	4,051	W	NA
Rutile	do.	454	W	NA	452	W	NA
Tungsten[2]	metric tons	42,099	W	NA	40,350	W	NA
Vanadium[2]	short tons	33,549	W	NA	33,868	W	NA
Zinc[2]	thousand metric tons	7,191	288	4	7,325	543	7
METALS, SMELTER BASIS							
Aluminum (primary)	do.	18,020	4,030	22	17,817	4,048	23
Cadmium	metric tons	21,075	1,550	7	20,207	1,678	8
Cobalt	do.	25,516	—	—	25,775	—	—
Copper (primary and secondary)[7]	thousand metric tons	9,510	1,480	16	9,378	1,463	16
Iron, pig	thousand short tons	602,790	55,873	9	593,699	54,750	9
Lead, refined (primary and secondary)[8]	thousand metric tons	5,987	1,288	22	5,942	1,327	22
Magnesium (primary)	metric tons	344,043	152,066	44	351,198	139,333	40
Nickel[9]	short tons	958,323	382	(6)	928,465	4,080	(6)
Selenium[10]	kilograms	1,614,716	253,427	16	1,817,747	286,755	16
Steel, raw	thousand short tons	862,268	97,943	11	850,982	98,906	12
Tellurium[10]	kilograms	64,031	W	NA	67,001	W	NA
Tin (primary and secondary)	metric tons	249,757	[11]1,569	1	249,804	W	NA
Zinc (primary and secondary)	thousand metric tons	7,203	358	5	7,041	358	5
INDUSTRIAL MINERALS							
Asbestos	do.	4,243	17	(9)	3,980	W	NA
Barite	do.	5,577	[12]290	5	5,577	[12]439	8
Boron minerals	do.	2,926	[12]1,114	38	2,906	[12]1,094	38
Bromine	metric tons	442,479	[12]174,600	39	438,000	[12]177,000	40
Cement, hydraulic	thousand short tons	1,248,916	[13]78,559	6	1,251,112	[13]78,606	6
Clays:							
Bentonite[3]	thousand metric tons	8,987	[12]3,112	35	9,472	[12]3,474	37
Fuller's earth[10]	do.	3,060	[12]1,882	62	3,471	[12]2,307	66
Kaolin[3]	do.	24,522	[12]8,974	37	25,024	[12]9,762	39
Diamond, natural	thousand carats	97,743	—	—	99,096	—	—
Diatomite	thousand metric tons	1,852	617	33	1,821	613	34
Feldspar	do.	5,176	655	13	5,023	630	13
Fluorspar	do.	5,586	661	5,107	64	1	
Graphite, natural	metric tons	648,827	W	NA	660,600	—	—
Gypsum	thousand short tons	109,023	17,624	16	107,671	16,406	15
Iodine, crude	metric tons	15,459	1,508	10	17,017	1,973	12
Lime	thousand short tons	152,846	[12 13]17,178	11	150,151	[12 13]17,481	12
Magnesite, crude	thousand metric tons	11,343	W	NA	10,713	W	NA

See footnotes at end of table.

TABLE 10—Continued

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

Mineral		1989			1990[p]		
		World production[1]	U.S. production	U.S. percent of world production	World production[1]	U.S. production	U.S. percent of world production
INDUSTRIAL MINERALS—Continued							
Mica (including scrap and ground)	metric tons	229,523	119,142	52	214,560	108,845	51
Nitrogen: N content of ammonia	thousand short tons	109,142	13,449	12	108,056	13,940	13
Peat	do.	217,531	761	(6)	198,489	763	(6)
Perlite	do.	1,973	[12]601	30	1,959	[12]639	33
Phosphate rock (gross weight)	thousand metric tons	158,966	48,866	31	154,106	46,343	30
Potash (K_2O equivalent)	do.	29,210	1,595	5	28,310	1,713	6
Pumice[10]	do.	10,913	424	4	10,964	443	4
Salt	thousand short tons	209,949	[12 13]38,902	19	202,339	[12 13]40,738	20
Sand, industrial (silica)	do.	133,973	[12]29,205	22	133,198	[12]28,406	21
Sodium compounds, n.e.s. (natural and manufactured):							
Soda ash	thousand metric tons	31,939	8,995	28	32,429	9,156	28
Sulfate	do.	5,009	685	14	4,998	665	13
Strontium[10]	metric tons	234,189	—	—	234,600	—	—
Sulfur, all forms	thousand metric tons	58,717	11,592	20	57,668	11,560	20
Talc and pyrophyllite	do.	8,271	1,253	15	8,251	1,267	15
Vermiculite[10]	short tons	694,700	[12]275,000	40	645,933	[12]230,000	36

[e]Estimated. [p]Preliminary. NA Not available. W Withheld to avoid disclosing company proprietary data; not included in world total.

[1]For those commodities for which U.S. data are withheld to avoid disclosing company proprietary data, the world total excludes U.S. output and the U.S. percent of world production cannot be reported.

[2]Content of ore and concentrate.

[3]World total does not include an estimate for China.

[4]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 eqiuivalent basis, but for some countries available data are insufficient to permit this adjustment.

[5]Shipments.

[6]Less than 1/2 unit.

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

[8]Includes bullion

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

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

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

[12]Quantity sold or used by producers.

[13]Includes Puerto Rico.

MINING AND QUARRYING TRENDS IN THE METALS AND INDUSTRIAL MINERALS INDUSTRIES

By R. Lindsay Mundell and Steven J. Schatzel

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MINING HIGHLIGHTS

In the first half of 1990, lessening of cold war tensions was welcome. But Iraq's invasion of Kuwait in August led to the Persian Gulf War in January and February 1991. The subsequent oil shock contributed to a dampening of the U.S. economy, and the U.S. gross national product rose only 0.9% to $5,463 billion (U.S. billion = 10^9).

The buildup of military forces in the Persian Gulf area focused greater attention not only on petroleum but also on other strategic materials. The U.S. Department of Defense continued to review stockpile goals and upgrade several mineral materials. In addition, the U.S. Bureau of Mines continued to maintain the standby Emergency Minerals Administration. After the Defense Production Act, which authorizes priorities, allocations, and supply expansion, lapsed on October 20, 1990, the Selective Service Act of 1967 became the authority to ensure that orders of the Armed Forces and defense atomic energy programs were given priority treatment.

Imports of crude and refined petroleum, costing $61 billion, increased 2% to 3 billion barrels (bbl). Domestic petroleum production fell 2% to 3.6 billion bbl. In February 1991, a National Energy Strategy was announced to encourage domestic production of fossil fuels and nuclear and renewable energy and to stimulate efficiencies in use. Petroleum supplied about 40% of U.S. energy, and natural gas and coal each supplied about 22%.[1]

Although most nongold metal mining and beneficiation production finished below that of 1988-89, almost all production was at levels well ahead of a few years ago. This fact, together with the reduced lure of gold, might be expected to increase the funds available for exploration and development in the ferrous and base metals sectors.

By January 1991, a general consensus was reached among traders and analysts that base metals prices will weaken through 1991 because of economic recession. In January, the price of copper, so often a general indicator, was at a 29-month low and silver was at a 15-year low.[2]

Experts speculate that over the next few years the international mining industry will be dominated by three issues: increasingly widespread environmental concerns; a change in the balance of activity between precious-metals and base-metals operations; and the impact of newly generated base metal demand from Eastern Europe.

Production Overview

Total processed nonfuel mineral materials produced in the United States during 1990 were valued at approximately $310 billion, essentially unchanged from that of 1989. However, metals from U.S. ores rose 3% over those of 1989 to $12.5 billion, and industrial minerals rose 5% over those of 1989 to $20.9 billion. Recycled scrap, largely steel and aluminum, rose a tremendous 50% over that of 1989 to $15 billion.

Steel production—a major consumer of many minerals—fell 2% to 96 million short tons (st). Iron ore mining fell 8% to 60 million st, 97% of which was pelletized. Net iron ore imports fell 14% to 13 million st. There was no domestic mining of chromium, cobalt, manganese, or nickel.

Primary aluminum smelters operated at capacity, producing 4.4 million st. Some bauxite was mined, but most came from net imports of 14.0 million st. This was supplemented by net imports of 3.1 million st of alumina.

Imports of nonfuel, mineral-based materials were valued at $44 billion and exports at $38 billion. Canada, with which the United States has a free-trade agreement and which is a partner in the North American Defense Industrial Base, was a major supplier of many minerals.

Discussions were under way with Mexico, looking toward a possible free-trade agreement that, in turn, might be a prelude to a Western Hemisphere agreement. Concerns about apartheid in the Republic of South Africa continued despite reform efforts. Imports from that country were limited to 10 minerals essential for defense or the economy.

Magnesium and titanium production totaled 165,000 st and 28,000 st, respectively. Copper mine production rose 4% over that of 1989 to 1.7 million st, and refinery production was 2.1 million st. Lead mining rose 18% over that of 1989 to 546,000 st. Primary refined lead production of 435,000 st was supplemented by 865,000 st refined from scrap. Primary slab zinc tonnage of 292,000 st was supplemented by 116,000 st of secondary production and net imports of 496,000 st.

Cement production rose 3% to 80 million st. About 3,400 quarries produced 1.2 billion st of crushed stone, and 5,700 sand and gravel pits produced 920 million st. Nearly 1,100 clay pits produced 49 million st, and 65 gypsum mines produced 18 million st.

Magnesium compounds totaling 700,000 st were produced from brines and seawater. Titanium dioxide pigments totaling 1.1 million st were produced from domestic and imported minerals. Sulfur production totaled 12.4 million st, 32% by the Frasch process. Production of other major nonmetallics included 39 million st of salt, 17 million st of lime, 10 million st of soda ash, and 625,000 st of B_2O_3.

Phosphate rock mining fell 8% to 51 million st, and ammonia rose 3% to 14

million st. Potash mining rose 3% to 1.8 million st of K_2O. Significant quantities of ammonia and potash were imported, but fertilizer exports totaled $4.1 billion.

Gold production edged up to 65 million ounces (oz) worldwide during 1990. This 2% gain over that of 1989 was low in comparison to 6% gains prevailing in recent years. The rankings of the million-oz-per-year producing countries remained unchanged. U.S. mines yielded 9.6 million oz of gold and 64 million oz of silver. About 10% of the gold and 75% of the silver was a byproduct of base metal mining. Approximately 50% of the U.S. gold production was from surface leaching operations. The 1990 average price of $387 per oz was little changed above that of 1989. However, the 1990 price was more volatile than during the previous year. Gold mine openings and expansions were on the decline in 1990.

The gold industry entered a period of economic hardship during 1990. As a result, North American exploration and new mine developments were greatly curtailed. In addition, increasing regulatory burden and pending legislation regarding mineral tenure could drive small miners offshore or out of business. Small miners, ultimately, are responsible for most U.S. mineral discoveries.

Australian output is forecast to drop by 20% per year following imposition of an income tax on gold mining that was effective on January 1, 1991. Output of silver mined in the world, at 469 million oz, was up only 1% over that of 1989. An estimated 60% of newly mined silver is recovered as a byproduct of gold and polymetallic base metal deposits. In 1990, the price briefly slipped below $4 per oz.[3]

Incentive Systems on the Rise

More mining companies used incentive bonus plans as part of their wage systems in 1990. A survey by Mining Cost Service of Spokane, WA, found that of the 156 mines responding to inquiries, a remarkable 42% reported using some sort of incentive bonus plan in 1990. This represents the continuation of a steady growth pattern in the use of incentive systems by the mining industry. In 1987, only 20% reported having a bonus system in place compared with 23% in 1988 and 35% in 1989. According to the survey, metal mines were the largest users of incentive bonus plans this year. About 33% of the responding coal mines and 25% of the responding industrial mineral mines also had bonus systems in place. In the metal mines, production was the most commonly mentioned incentive factor. Development advance, safety, ore grade, cost saving, profits, commodity prices, housekeeping, and length of service were also mentioned. Attendance, production, safety, and profits were all mentioned by industrial mineral mines. Of the 24 industrial mineral mines responding, 21 reported wage increases ranging from 1% to 13%. The remaining three reported no change. Forty of the 66 metal mines reported wage increases ranging from 1% to 18%. No metal or industrial mineral mines reported wage decreases in 1990.[4]

Reclamation Bonds

New Federal reclamation bonding requirements were not expected to have a significant impact on large mining concerns, but might put smaller companies and prospectors out of business. The new policy was drafted to ensure that reclamation bonds are posted, but in a manner that companies would not pay both Federal and State bonds. Several mining company officials said the new policy will burden small miners who may not be able to afford bonds. Many States currently do not require bonds for small prospectors.[5]

Soviets Open Mineral Deposits to Joint Ventures

Because the U.S.S.R. does not have sufficient funds to develop many of its natural resources, the Soviets were forced to pare mining activities. In an effort to raise much-needed hard currency, the U.S.S.R. prepared a list of 100 mineral deposits made available to foreign companies for joint ventures. This marked the first large-scale effort by the Soviets to encourage joint ventures in mining.

The U.S.S.R.'s joint-venture master plan included proven deposits of aluminum, chromium, gold, iron, lead, manganese, nickel, silver, tungsten, and zinc. The Soviet Ministry of Geology explored the deposits and determined that they are minable.[6]

The Soviet North East Gold Mining Association and Bering Straits Trading Co. awarded a contract for a joint venture between Cominco Engineering Services Ltd. of Vancouver, British Columbia, Canada, and Watts, Griffis and McOuat, geologists and engineers, of Toronto for a planned silver recovery system with a capacity of 1 million st of ore annually. Plans call for construction of a plant in Dukat, northeast of Magadan in the extreme northeast U.S.S.R.[7]

LEGISLATION AND GOVERNMENT ACTIONS

Pending Legislation

Efforts were put forth in 1990 to amend the General Mining Law of 1872. House bill S. 1126 was introduced in June 1989. Hearings were held in June 1989 and again in September 1990. As introduced, the bill would withdraw certain types of lands presently open to mineral entry. Jurisdiction over Forest Service lands would move to the Department of Agriculture. It would eliminate exploration or development by joint ventures, partnerships, and multiple mineral development within the same operating area unless under a single operator and would eliminate different types of mining operations in the same area. It would also eliminate lode and placer distinction as well as larger sized claims currently allowed for placers.

All prospectors would be required to notify the land management agency before initiating mineral exploration. The claim recordation fee would be raised to $100 per claim. Mining claims would be for exploration purposes only and would be limited to 20 acres. Jurisdiction would be divided among the Departments of Agriculture and Interior, who would have total discretion to deny the application without appeal. The exploration claim would be void after 10 years unless the locator applied for a mineral patent.

Prior to any mineral development or production, the locator of an exploration claim would be required to have an approved exploration plan and reclamation plan and would have to submit an application for mineral patent. A hard-rock mineral deposit capable of commercial development would have to exist on the property, and a mining and reclamation plan would have to be approved before a mineral patent could be issued. Such a patent would not, however, convey possessory title to the minerals. The patent would be void if mineral production did not begin within 15 years.

Exploration claims would require annual diligence, or in lieu of payments, of $50 per acre until production began. Patents would require annual diligence from $100 per acre for the first 5 years to $300 per

acre during years 10 through 15. Once production commences, an 8% overriding royalty on production would be assessed. The bill also provides for payment of an annual $100 "holding fee" for each exploration claim or mineral patent and a $5 per acre surface-use fee.

All mined areas would have to be reclaimed and restored to a condition supporting the original use prior to mining. This work would have to be done with concurrent reclamation when feasible. Bonding sufficient to ensure complete and timely reclamation would be required for exploration claims and mineral patents. Further, the bill requires that land-managing agencies address mining and exploration activities in their land use plans and provide conditions and restrictions on these activities.

The bill also addresses the conversion of existing claims. It would eliminate the right to patent claims located under the 1872 Mining Law and would take away valid existing rights. Further, it would require that within 3 years existing claimholders either relocate their claims under the terms of the new law, with some exceptions, or maintain them by performing assessment work fixed at $5,000 per mining claim per year.

House of Representatives bill 3866 was introduced in January 1990. A hearing was held in September 1990. As introduced, the bill established procedures to locate and record mining claims. It eliminated distinctions between lode and placer claims and claims for "uncommon varieties." It would move jurisdiction over minerals on Forest Service lands to the Department of Agriculture. Mill sites and tunnel sites would be eliminated.

Claims would be 40 acres and would have to conform to the public land survey, where possible. Extralateral rights would be eliminated. The legal description in the notice of location would supersede the physical boundaries on the ground. A claimholder who relinquishes a claim or fails to maintain all requirements would not be permitted to file a new claim on the same ground for 6 months.

All mining activities on mining claims would have to prevent unnecessary degradation and minimize adverse environmental impacts on surface resources. A plan of operation would be required for prospecting and exploration. Adequate financial or other guarantees would be required to ensure reclamation, and the Secretaries of Agriculture and Interior would establish reclamation standards. Land use plans would be required to include numerous specific requirements to ensure protection of nonmineral values. The bill also authorizes quarterly compliance inspections by the Office of Surface Mining and Regulation Enforcement.

A mining claim would be valid when the rental fee requirements and the diligence expenditures or the in-lieu-of-payment were met. The annual rental fee would be $1.50 per acre prior to approval of a mining plan and $5.00 per year after approval. Diligence would be required on a 5-year incremental scale ranging from $20 per acre in the first 5 years to $160 per acre after the 15th diligence year following recordation of the claim. Payments in lieu of diligence could not be made until the 6th year; these payments would also be graduated, ranging from $20 per acre in the 6th through 10th years to $80 after the 15th year. The bill further directs the appropriate Secretary to establish user fees to reimburse the United States for expenses incurred under the legislation. Failure to submit payments or file a diligence affidavit would void the claim.

Patenting of existing mining claims would be eliminated. Unpatented mining claims located under the Mining Law of 1872 would have to be converted to the new system within 3 years. Unconverted claims would be null and void.

The bill also directs that all monies received from rental fees collected be put into a fund for the reclamation and restoration of land and water resources adversely affected by past mineral mining.

The Resource Conservation and Recovery Act

In April 1991, the comprehensive Resource Conservation and Recovery Act (RCRA) bill (S. 976) was introduced. Although mine and mineral-processing wastes were not directly addressed in the bill, several provisions of the bill may still have an impact on the management of mines or mineral-processing facilities, such as requirements affecting recycling, secondary materials, and pollution-prevention activities.

EPA Activities—Mining- and Mineral-Processing Wastes

In May 1988, the U.S. Environmental Protection Agency (EPA) released a document that outlined an approach to manage noncoal mining wastes and materials, referred to as "Strawman I," for public comment. In May 1990, EPA issued "Strawman II," incorporating comments and responding to raised issues. After court action, EPA was ordered to define large-volume, low-hazard wastes, and a final ruling was published January 23, 1991. EPA established that the temporary exemption from subtitle C requirements, established by the exclusion for mineral-processing wastes, was limited to 20 mineral-processing wastes, including (1) slag from elemental phosphorus production, and (2) phosphogypsum and phosphoric acid process wastewater. If the exclusion is retained, the wastes would be subject to regulation under the Resource Conservation and Recovery Act subtitle D and as solid wastes.

The mine waste regulatory program, as currently viewed by EPA, will be one in which the States have the lead role and will be responsible to develop, oversee, and enforce a mining waste and materials management plan. Consequently, the States will be expected to identify a lead agency; incorporate a multimedia approach that addresses air, surface water, ground water, and soil contamination; and incorporate any necessary permits under the National Pollution Discharge Elimination System (NPDES), the Clean Air Act, and the Underground Injection Control program. To be approved by EPA, the mining waste and materials management plan would need to provide for a State program adequate to meet established technical design criteria and performance standards.

Mineral-processing wastes are being addressed separately by EPA. The number of processing wastes afforded protection by the Bevill amendment from hazardous waste regulation under RCRA subtitle C was reduced. In EPA's July 1990 Report to Congress, the Agency concluded that no more than 4 of the 20 conditionally exempted wastes under Bevill needed to be regulated as a hazardous waste. The findings of the report will be the basis of a final regulatory determination. All other mineral-processing wastes are now potentially subject to regulation as hazardous wastes under subtitle C of RCRA.

Basel Convention

In March 1990, the United States signed the Basel Convention, an international agreement dealing with the international transboundary movement of hazardous waste. The Basel Convention is intended to put an end to the shipment of hazardous wastes for disposal in other nations,

particularly developing nations. However, the convention could affect the way metal waste and scrap, as well as other recyclable materials, are imported or exported because all of these materials are considered to be hazardous wastes in some countries, particularly in the European Community (EC). Materials that are likely to be affected include metal waste and scrap, scrap batteries, precious-metal wastes and residues, and materials recovered from municipal waste.

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

The Basel Convention was submitted to the U.S. Senate for ratification, and legislation was introduced to provide the authority to implement its provisions in the United States. It could take effect as early as 1992.

Ocean Mining Leases Offered

For the first time since the sale of phosporite leases on California's 40-mile (mi) bank in 1963, the U.S. Department of the Interior issued a proposed leasing notice for minerals other than oil, gas, or sulfur on the Continental Shelf. The notice was published by the Minerals Management Service on June 11, 1990, in accordance with new regulations for leasing (30 CFR Part 281) under the authority of the OCS Lands Act of 1953, as amended.

About 150,000 acres is being proposed for leasing to include the right to explore for and recover gold and any other mineral, such as mineral sands, using similar technology. The proposed lease areas are along the boundary of Alaskan State waters 3 mi offshore and adjacent to the city of Nome and the town of Solomon, about 20 mi to the east. Both areas offered are of similar dimension.[8]

Lead-Acid Battery Recycling

Lead-acid battery recycling has been revived in recent years. The primary reason has been relatively high prices for lead scrap and spent batteries. With RCRA and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, looming over the secondary lead industry, they have been quite effective in getting the batteries into the recycling chain. An important factor in this respect has probably been State and local interest in collecting lead batteries by providing incentives; some States are offering $2.00 bounties on spent lead-acid batteries. A further objective is to reduce the number of spent batteries going to landfills and municipal incinerators.

Federal legislation related to the recycling of lead-acid batteries that was introduced in the 101st Congress was not acted upon, but some bills were reintroduced into the 102d Congress. Bill H.R. 870, introduced in February 1991, in particular is essentially written to affect lead-acid battery recycling. The bill would require manufacturers and importers of lead-acid batteries to recycle an equivalent amount of batteries sold. In the case of importers, they would be required to purchase credits from others who recycle batteries. Another bill, S. 391, also introduced in February 1991, is designed to address all issues related to lead in general, with specific provisions for prohibiting disposal in landfills and incinerators.

Another important activity in lead-acid battery recycling is the regulatory negotiation in progress sponsored by the EPA. The regulatory negotiation was established under the Federal Advisory Committee Act (FACA). The committee's purpose is to negotiate issues leading to regulating the recycling of lead-acid batteries under section 6 of the Toxic Substances Control Act (TSCA).

Clean Air Act Amendments

The Clean Air Act Amendments of 1990, signed in November, will likely substantially affect the economics and viability of the minerals industry. For example, coke ovens are specifically mentioned as subject to stringent toxic emission limitations. Most other minerals processing facilities will also be required to limit their emissions of 189 listed air toxics, including such substances as cadmium, chromium, cobalt, lead, manganese, mercury, and nickel compounds. Also, the acid rain provisions of the act will bring about increased electric rates to many mineral producers, in particular to about one-half of the energy-intensive aluminum smelting and ferroalloy-producing industries.

Public Land Use

In 1989-90, Congress considered two bills to set aside areas of the California desert as new national park or wilderness areas. These were S. 11/H.R. 780 (California Desert Protection Act) and H.R. 3460. Both actions would have precluded or limited mineral access in large areas, including the East Mojave National Scenic Area (EMNSA). Neither bill was released from committee by the end of the Congress. At the outset of the 102d Congress in 1990, the California Desert Protection Act was reintroduced.

Potential impacts of the proposed legislation relating to the EMNSA were estimated in a study done by the U.S. Bureau of Mines, entitled "Minerals in the East Mojave National Scenic Area, California" (MLA 6-90, available from the U.S. Bureau of Mines). The study included economic analysis because the proposals raised questions about the profitability of mining in the affected area, as well as the regional economic benefits derived from mining. The study found that 24 deposits in the EMNSA would be profitable to develop under current economic conditions. If all 24 were to be developed, economic benefits would include $3 billion in cumulative production revenues. That development could generate about 2,400 jobs for mines and supporting industries in San Bernardino County, plus jobs in transporting the minerals. The study also included estimates of the impact of proposed withdrawals on employment, personal income, and tax revenues.

Trade Issues

The United States and Mexico continued negotiations begun in late 1989 to eliminate barriers to trade (of goods and services) and investments between both countries. Mexico's foreign investments restrictions prohibit foreign majority ownership of Mexican mines. The United States has no such restrictions against foreign mineral investment. Many issues, including those related to Mexican foreign investment barriers and environmental standards, have to be resolved before both countries can conclude a formal United States-Mexico Free-Trade Agreement.

During 1990, as part of the continuing Uruguay Round of General Agreement on

Tariffs and Trade (GATT) tariff negotiations, the United States sought reductions in Japanese tariffs on processed minerals and metals. U.S. exporters of aluminum products and refined copper faced Japanese tariffs ranging from 5.8% to 12.8% for aluminum products and 7% for refined copper. At the same time, the United States and Japan continued to discuss nontariff trade barriers in both countries during the Structural Impediment Initiative (SII) talks that began in March 1989. The goal of the SII is to eliminate structural trade barriers (i.e., barriers to market access) and thus reduce the imbalance of payments in both countries. U.S. soda ash producers maintain that in 1990, Japanese imports of soda ash were unfairly limited by collusion among Japan's domestic producers. Two U.S. steel producers seeking to bid on nine Japanese Government contracts waited 2 years to be qualified before submitting any bids. In 1990, the Japan Fair Trade Commission drafted new guidelines to open the Japanese market. Japan also announced that in 5 years it would reduce its patent processing time to 2 years, similar to that of the United States.

Two mineral-related trade disputes involving the United States were resolved satisfactorily in 1990. In January 1990, the United States Trade Representative (USTR) negotiated an agreement with the EC. EC member countries agreed not to renew export restrictions on copper scrap that had expired in December 1989. The Copper and Brass Fabricators Council had filed a petition with the USTR charging that the EC had unfairly maintained export controls on copper scrap. After discussions between the United States and the EC failed, both asked GATT to resolve the dispute. The United States argued that there was no shortage of supply or national emergency to justify the EC's export controls on copper scrap. Before the GATT could reach a decision, the USTR and the EC reached an agreement.

In September 1990, the United States and Japan agreed that Japan would create opportunities for U.S.-produced amorphous metals to be marketed in Japan for a 2-year period. Allied-Signal Corp., a U.S. producer of amorphous metal, filed a petition with the USTR requesting an investigation of Japan's business practices. The company felt that with the consent and cooperation of the Japanese government, Japanese steel companies were refusing to enter into licensing agreements on terms with Allied-Signal. In addition, Japanese electric utility companies were refusing to purchase electric power transformers made by Allied-Signal, and Allied-Signal felt that the composition and process patents applied for by Allied-Signal were unfairly delayed (11 and 12 years, respectively). Allied-Signal concluded that the Japanese government had targeted amorphous metals technology for its own use. It was simply using the time until 1993, when the Allied composition patent expired, to develop Japan's own amorphous metals technology while denying U.S.-made amorphous metals access to the Japanese market. Although an agreement was reached, Japan will not grant an extension of Allied-Signal's composition patent when it expires in 1993.

National Defense Stockpile

According to section 3301 of the National Defense Authorization Act for fiscal years 1990 and 1991 (Public Law 101-189, November 29, 1989), the Assistant Secretary of Defense determined that, effective in June, the National Defense Stockpile (NDS) goal for antimony was increased from 36,000 st to 88,500 st.

The Defense Logistics Agency (DLA) announced the awarding of the first in a planned series of contracts to upgrade metal-grade bauxite ore in the NDS to aluminum metal. The contract, awarded to a company headquartered in Pittsburgh, PA, called for the conversion of 243,852 st of bauxite ore to 55,157 st of aluminum ingots. Work on this contract was expected to be completed by September 1992. The Agency also awarded a contract to a domestic company to upgrade some of the beryl ore in the NDS to vacuum-hot-pressed beryllium billets over a 2-year period, beginning in early 1991. The contract also had an option for the Government to purchase an additional 43,000 pounds (lb) of beryllium in 1993 for about $13 million.

The DLA also initiated a number of other actions in June 1990. The Agency approved a reduction in the goal for bismuth in the NDS from 990 st to 480 st. The DLA began sales of excess bismuth from the NDS in August. Requirements for the columbium (niobium) group in the NDS were almost tripled from 4.85 million lb of contained columbium to 12.52 million lb of contained columbium. The Agency revised the goals for both acid-grade and metallurgical-grade fluorspar. The goal for acid grade went from 1.4 million st to 900,000 st. The goal for metallurgical grade went from 1.7 million st to 310,000 st. The Agency also lowered the goal for the battery-grade group from 87,000 to 50,000 st. Accordingly, within that group, the goal for the battery ore subsequently was decreased from 62,000 to 25,000 st, while that for synthetic dioxide remained unchanged. Goals for palladium and iridium were lowered to 147,430 and 5,897 lb, respectively. New goals for rhodium and ruthenium were established at 2,057 and 4.9 lb, respectively. In addition, the Agency accepted sale offers from two of six bidding firms for the DLA to purchase a total of 200,000 lb of tantalum pentoxide contained in tantalum natural minerals and concentrates for the NDS at an average purchase price of $36.81 per lb of contained tantalum pentoxide.

Commodities

Presidential Proclamation 6123, in April 1990, made acid-grade fluorspar from Mexico eligible for preferential tariff treatment under the Generalized System of Preferences, pursuant to title V of the Trade Act of 1974, as amended. Effective July 1, 1990, this material was exempted from duty upon entering the United States. The preferential tariff treatment applies as long as Mexico's share of the import market does not exceed 50% or $89.9 million. In August 1990, the 13.5% ad valorem tariff on imports of metallurgical-grade fluorspar was suspended through December 31, 1992. Imports of both acid-grade and metallurgical-grade fluorspar were down from those of 1989. The largest decrease was for acid grade, which was down more than 23% compared with that of 1989. This was a result of decreased production of chlorofluorocarbons (CFC's) owing to production restraints imposed by the Montreal Protocol and the new excise tax on CFC's.

In June 1990, at a congressional hearing, the Executive Director and two members of the Institute of Scrap Recycling Industries Inc. testified before a subcommittee on the fate of more than 100 mothballed ships that belong to the National Defense Reserve Fleet. Carnegie Mellon's Center for Materials Production conducted a case study of cryogenic scrap preparation to determine if the process is worth looking at again. The world's first dezincing line began commercial operation in Canada. The EPA listed electric furnace dust as hazardous waste and issued regulations requiring dust containing 15% or more zinc

to be processed with the best demonstrated available technology after August 8, 1991.

Changes in Eastern Europe probably would have little impact on the world's metal and scrap industries in the short term. However, for the long term, these changes most likely would have considerable influence. Reportedly, there has been a gradual decline in iron and steel content and growth in the use of other materials in U.S.-built cars. The U.S.S.R.'s Minister of Metallurgy called for a cut in ferrous scrap exports to avoid domestic shortages. The Brazilian Government shut down 20 pig iron producers in May for not reforesting areas cut down to make charcoal.

The principal issue that continued to confront the U.S. slag industry was the proposed Federal regulation that would classify iron and steel slags as solid wastes. In July 1990, the EPA published its required report to the Congress on the 20 mineral-processing waste streams proposed for retention under the Mining Waste exclusion, or the Bevill exclusion, of the RCRA. Blast furnace slag and those steel slags generated from open-hearth and basic oxygen furnaces were among the 20 waste streams proposed.

At midyear, the EPA's "third-third" rule became effective for landfilled process wastes. This rule required pretreatment for most secondary smelter slags at significant cost. However, the industry won a 2-year temporary reprieve to a less strict interim standard on appeal. In October, EPA proposed the "final" lead in drinking water standard, which eventually could result in a required 80% reduction of lead in process effluents and discharges at considerable cost to producers and battery plants. After 2 years of intense study, EPA completed a long-range, multimedia pollution prevention strategy for lead that will result in significantly stricter regulations imposed on both the producing and consuming sectors of the industry over the next several years.

The first stage of EPA's three-stage phaseout of asbestos went into effect in August. The first stage bans the manufacture, import, and processing of asbestos-containing flooring and roofing felt, pipeline wrap, asbestos-cement, corrugated and flat sheet, vinyl asbestos floor tile, and asbestos clothing after August 27, 1990. The sale of these products is banned after August 25, 1992. Stages two and three of the phaseout go into effect on August 25, 1993, and August 26, 1996, respectively.

In August 1990, the EPA, in cooperation with the domestic paint industry, banned the use of mercury in indoor latex paint, citing a risk of poisoning, especially to children, when the paint is used in poorly ventilated areas. The decision also required outdoor latex paint containing mercury to carry a warning label.

In addition, in August 1990, U.S. producers filed a petition with the U.S. International Trade Commission and the U.S. Department of Commerce (DOC) requesting the imposition of antidumping duties on imports of silicon metal from Argentina, Brazil, and China and the imposition of countervailing duties on imports from Brazil. Preliminary investigations determined that the petition warranted a full investigation of the allegations.

The Clean Air Act of 1990 was passed by the Congress and signed by the President in November 1990. Provisions of the new law require a 35% reduction in hydrocarbons and a 60% cut in nitrogen oxides beginning in 1994. In addition, catalytic converters must be guaranteed by manufacturers to last double the current 50,000 mi. As a result of these changes, increased amounts of platinum-group metals (PGM) are expected to be used in each catalytic converter.

EXPLORATION

International Overview

After the days of increased base metal prices and frantic gold exploration of the late 1980's, mineral exploration in 1990 continued at a reduced level. The lower gold price forced a reassessment of the viability of smaller and more remote discoveries. Many junior exploration companies were forced to make radical writeoffs of exploration expenditure on these prospects.[9]

Exploration for nonfuel minerals continued to decline after 1988 as recessionary pressures slowed growth in the industrialized economies. However, 1990 expenditures were still significantly greater than the low levels experienced in the mid-1980's. The Persian Gulf crisis introduced increased instability in energy prices and more uncertainty to the global economic picture.

Exploration funding levels are generally determined by cash-flows. Therefore, commodity price and production levels affect funds available for exploration. Average gold prices for 1990 were slightly below the 1989 levels and significantly below 1987 levels. However, gold remained the major focus of mineral exploration in 1990. In addition to the lower gold prices, three factors had a large impact on worldwide exploration: the ending of flow-through funding in Canada, the introduction of the Australian gold tax, and the squeezing of margins on the deep South African gold mines. Estimates by the Prospectors and Developers Association of Canada suggest that spending will be about Can$610 million for 1990, with a projected 30% cut in 1991.[10]

Base metal exploration was not encouraged by the recession in North America and Europe and the uncertainty surrounding events in the Gulf at yearend. Exploration of platinum-group elements continued at a reduced rate compared to that of 1989.[11]

Although many Western economies were in various stages of recession, copper, steel, and zinc prices remained steady or declined only slightly. Prices were nowhere near the low levels experienced in the early 1980's, and production in domestic and world markets was above 1989 levels.

One note of hope was the opening of Eastern Europe and, less certainly, the U.S.S.R., to commercial exploration. Although a considerable amount of discussion occurred on the formation of joint ventures with state companies, few contracts were signed.[12]

Domestic Overview

The U.S. Bureau of Land Management's (BLM) claimstaking data reflect a subtle shift to base metals in the United States. Arizona was the only State with a significant increase in new claims on Federal land. New claims in nearly all other States declined precipitously. The number of new claims follows the gold price very closely. Data for 1990 show claimstaking at about one-half of 1988 levels.

Data on domestic exploration expenditures by U.S. firms were collected in the Society of Economic Geologists (SEG) annual survey. It showed that a substantial decline in exploration occurred in 1989. For 1989, the inventory of claims serviced by BLM did not change significantly. However, in fiscal year 1990, there were about 50,000 more claims released than new claims accepted by BLM. The SEG survey also shows that about 30 cents of every exploration dollar spent by U.S. firms went outside the United States.[13]

Antarctic Exploration.—Antarctica is the last continent unspoiled by man, and environmental proponents want to keep it that way. However, mineral industry executives and some governmental officials believe that Antarctica is too potentially rich in minerals to be completely conserved. Although an exploration prohibition is not in place, no Antarctic exploration has been conducted owing to the uncertain legal status of owning and developing a deposit, which is expected to be costly, considering accessibility, environmental concerns, and weather conditions.

An agreement regulating exploration, the Convention on the Regulation of Antarctic Mineral Resource Activities (CRAMRA), was adopted in 1987, but it still needs three votes to come into force. The United States is among the nations that have not signed the pact. The 101st Congress passed two bills that opposed ratification. The Administration has not yet decided whether it will sign the bills, but is thought to be leaning away from any measure that would impose a "permanent" ban on exploration. Some members of Congress believe a "permanent" ban would restrict any exploration for at least 100 years. Administration officials, including the head of the U.S. delegation, are thought to be in favor of a 30-year moratorium. Administration and industry representatives believe it will take at least this long for the Antarctic mining technology to be developed and made cost-efficient.[14]

The American Mining Congress (AMC) told a House subcommittee that a legal regime for mineral exploration in Antarctica should be in place before companies can be expected to invest in the region. The AMC criticized the CRAMRA because "explorers for hard minerals would face too much uncertainty and too much red tape under its terms." A spokesman stated the national agreement would provide "absolutely no incentive" for mining concerns that may be interested in mineral exploration in the future.[15]

Because of constraints on mineral development in Antarctica, minerals with the best prospects of recovery would have to be low-volume, high-value minerals such as gold. Even if a major oil deposit were found in the near future, oil recovery in the region is unlikely before the year 2020, according to the study. It is also unlikely that anything smaller than a giant (500 million to 5 billion bbl) or supergiant (more than 5 billion bbl) field would ever be economical to develop.[16]

Alaska.—Exploration expenditures rose 19%, from $47.8 million in 1989 to $56.7 million in 1990. Almost one-half of that, $24.9 million, was spent on the three gold properties in advanced exploration near Juneau—the Kensington (Echo Bay-Coeur d'Alene Mines), the AJ-Treadwell (Echo Bay), and the Jualin (Placer Dome-Granges). Another $11 million was invested in the Fairbanks area. This was predominantly spent on drilling the Ester Dome by Citigold and American Copper and Nickel Co., and on the Fort Knox property by Fairbanks Gold Inc. There was also significant exploration activity on the Seward Peninsula at Rock Creek, Anvil Creek, and Mount Distin by a complex joint venture that included Tenneco Minerals, Aspen Exploration, and the Sitnasuak and Bering Straits Native Corps. Moneta Porcupine Mines drilled three holes in the Lik deposit in 1990 and agreed to buy GCO Minerals' 50% stake in the project. The other 50% is owned by Echo Bay Mines. Stated reserves at Lik, which is only 12 mi from Cominco's Red Dog Mine, are 18 million st grading 10% zinc, 3% lead, and 1.5 oz per st silver. Initial plans consider milling 12 million st/yr, but an additional 10,000 to 15,000 feet (ft) of drilling will probably be necessary to refine the reserve picture.[17]

***Drilling Technology.* — Arctic Gold Placer Drilling.**—Exploration drilling and the mining of marine placer gold deposits was initiated in the Arctic off Alaska. Prospecting and ore reserve drilling was done both in the winter on the pack ice and in summer from a modified Landing Craft Tank (LCT). Weather was a major controlling factor, and both drilling seasons lasted approximately 4 months each, on the ice from December to April and at sea from July to October.

Western Gold Exploration and Mining adapted a Becker[18] diesel top hammer drill to operate on a special broad-based skid in winter. This spreads the 41-st rig load over an 883-square foot (ft^2) area; the rig can safely work on ice only 2.5 ft thick. This modified rig can be lifted by crane onto the drill ship in about 4 hours. The drill pipe used is dual-walled, 5.5 inches (in) outside diameter (OD) and 3.3 in inside diameter (ID) and, in sea depths up to 115 ft deep, can penetrate to 164 ft below the seabed. With a high-pressure booster compression, holes down to 230 ft have been achieved.

After bit-design trials, the most satisfactory is an eight-track bit with a crowd-out profile. This pushes excess sediment away from the central bore and reduces the frequency of blocking. Bits with a crowd-in profile are satisfactory in the more granular sediments, but tend to push too much sediment into the inner barrel and cause frequent blockages.

The drill ship uses a four anchor system laid out at 45°, providing possible coverage of 62 acres. In theory, 16 holes can be drilled from one anchorage when drilling on 330-ft centers. Moving the anchors is accomplished by controlled winching and takes less than 10 minutes (min) to move from one hole to the next. During 4 seasonal programs over the past 2 years, an average of 10 holes per day were drilled. The Becker drill can also operate in a purely rotary mode to produce cores for detailed geological evaluation.

Reverse circulation (RC) drilling in conjunction with down-the-hole hammers (DTH) combines the advantage of DTH penetration speed with rotary chip-sample efficiency. Several companies are marketing RC-DTH hammers and dual-wall rods.[19]

Reverse-Circulation Drills.—In the Entec Sampler system, high-pressure air is split so that one flow operates the 2,000 blows/min hollow piston as the second airflow bypasses the piston and is jetted upward behind the bit face. This causes a powerful suction that collects all the cuttings from the bit face and passes them directly up through the hollow piston and into the dual-wall drill pipe. Some other RC systems pass the cuttings up the outside of the hammer before they are guided via a special crossover sub into the inner drill tube. This can result in significant mineral losses due to smearing against the borehole walls.

Entec Industries reports that, in tests on a gold mining operation in the Western United States, their Samplex hammer gave more than 98% by volume cutting recovery and that just more than 15% of the sample was 0.5 in or larger. This enables the geologist to make a more detailed description of the rock types and helps produce more accurate borehole logs.

Bul Roc (United Kingdom) developed a similar type of RC-DTH hammer and reports that penetration rates of more than 39.4 feet per hour (ft/h) were fast enough to overcome ground water entry and produced dry bulk samples in a hard limestone in northeast England. The use of a 300-pounds-per-square-inch (psi) compression

in holes to 262 ft or less contributed to the restriction in water flow. Water flowed into the hole during rod changes, but if this water was blown clear before rock penetration was resumed, then dry bulk samples were obtained.

Halifax Tool Co. (Halco) introduced its new RC-DTH hammer, which has a stainless steel central sample tube to reduce corrosion problems. This tube can be replaced without dismantling the entire hammer, which is often a major problem on the drill site. Halco gives great importance to the ease of maintaining and servicing its hammer on-site. The Halco dual-wall drill pipe is unique in that it is in integral lengths, has no separate central couplings, and uses no "O" rings. Halco claims that both inner and outer tubes transmit torque.

Core Drill (United Kingdom) Ltd. of Warwick has produced a double-tube swivel core-barrel and bit that cuts a 11.8-in-diameter core by 14.4 in (OD). During field testing, the strata were sufficiently soft to use a special TC core bit, and the double core springs effectively retained the marl and siltstone cores. One of the few problems was in handling the full 3.3- to 16.4-ft core-barrel and in safely transporting cores that weigh 122 pounds per foot (lb/ft).[20]

Drill Systems Premiers EXPLORER 1000 Drill.—The EXPLORER 1000 is designed to operate in environmentally sensitive areas. The drill is mounted on a proven carrier manufactured by Canadian Foremost of Calgary, Alberta. The carrier is four-wheel drive and operates on terra tires, giving the unit a ground pressure of 10.2 psi. This all-terrain vehicle is also equipped with articulating and oscillating frame features that permit drilling in severe off-road conditions with minimal ground surface disturbance. The drill is specially designed for dual-wall reverse circulation drilling for the mineral exploration industry and is equipped with a deck raise that allows the deck of the drill to be leveled on mountain and/or hill sides with the carrier's wheels on the ground surface. Other standard features include a bulldozer blade, sliding angle mast and deck slide, 750 cubic feet per minute (ft^3/min) at 350 psi air compressor, 485 horse power (hp) diesel deck engine, and a top-head rotary head that pivots to horizontal position providing an efficient pipe-handling system. The unit is completely self-sufficient and is capable of carrying a large supply of drill pipe. Under suitable conditions, the drill has a rated depth capacity of 1,000 ft using Drill Systems' 3 3/4-in dual-wall drill pipe.[21]

Rotary Drill Rig.—Ingersoll-Rand (IR) Co.'s rotary-drill division introduced a hydraulic tophead-drive drill rig designed primarily for mineral exploration. This drill uses either a rotary or downhole hammer with conventional or dual-wall drilling methods. The truck-mounted, deck-engine-powered TH75E features a "dump-angle derrick" system designed for angled exploration drilling. This system can position the derrick at any angle between vertical and 45°, then automatically move the derrick structure downward until the base rests firmly on the ground. Once the desired angle is set, an automatic pinning feature secures the deck in place. To make operations easier and more efficient at all angles and to ensure that the operator is always near the hole, the TH75E's control panel is positioned on the derrick and adjusts to a comfortable angle for the operator. The drill-pipe handling systems allow rapid, safe pipe changes in the vertical or angle positions. The TH75E is capable of handling 4 1/2-in by 20-ft dual-wall pipe and can be supplied with a complete dual-wall package. The TH75E also has some unique features that include a two-speed rotary head design (that can be shifted "on the fly"), a remote control clutch between the engine and air compressor, and a remotely retracting hydraulic-powered top-head drive.[22]

All-Hydraulic Core Drill. — The Diamec-232, from Diamond Boart Craelius Inc., is an all-hydraulic core drill with mechanized rod handling. All-hydraulic means one person can perform all drilling and handling operations from the control panel. No tools are required with its mechanized rod handling feature. The machine is especially suitable for coring and drilling grout holes in narrow drifts or galleries. With its light weight and compact size, the Diamec-232 is easy to set up for drilling. This drill offers an advantage of fast moves between sites, without disturbing normal production routines.[23]

Landing Indicator.—Manufactured by Longyear Canada Inc., the landing indicator is a device designed to improve productivity in diamond core-drilling operations. It is a fluid-pressure-activated device that tells the drill operator the inner tube assembly has landed in the core barrel and drilling may be resumed. This avoids unnecessary delays estimating the time required for this operation. The landing indicator also reduces the chance of drilling in a mislatched condition. It is available for several core barrel types, including BQ, NQ, HQ, CHD 76, and CHD 101. The indicator is built into the inner tube assembly of the wireline system of core barrels. The landing indication occurs as an instantaneous fluctuation on the fluid pump gauge. This fluctuation is a result of increased pressure required to push a steel ball through a nylon bushing in the latch body. When the inner tube assembly contacts the landing ring, the waterflow is diverted through the latch body, applying pressure to the ball. Momentary pressure increase of approximately 300 psi forces the ball through the nylon bushing.[24]

Marlow Man-Portable Drill. — The Marlow Mole DD2 man-portable multipurpose drill equipped with a remote portable hydraulic power pack was field-proven from the Arctic to the tropics without modification. Conceived as a state-of-the-art drill suitable for diamond core drilling, auger, DTH hammer, and slim hole RC drilling, a conservative depth rating of 165 ft was claimed by the manufacturer. However, it has now been shown that a 330-ft depth can be achieved using a thin kerf, double tube 1.8-in-diam core barrel taking a 10-ft core on each run and drilling at an angle of 60°. As the Mole DD2 has an integral dual-purpose gearbox (0 to 150 revolutions per minute (r/min) and 0 to 1,250 r/min), it is possible to auger rapidly through overburden and case or to simultaneously drill and case through to bedrock, then withdraw the interior drill string, leaving the casing in bedrock prior to continuing the hole by diamond drilling.[25]

***Ground Surveying.*—GPS Receiver.**—The GPS Nav 1000 Pro is one of the least expensive handheld global positioning system of satellites (GPS) receivers currently available. Cost savings are experienced through the Nav 1000 Pro's ability to replace a surveying team in determining preliminary calculations and positions. The uses of the Nav 1000 Pro include establishing survey control in remote, unmarked areas in the field, plotting coordinates, and storing coordinates. The Nav 1000 Pro is capable of storing up to 200 position fixes in its data buffer. These fixes may then be downloaded through its RS232

port into a data logger or laptop computer. The unit weighs only 30 oz and is shock resistant and waterproof.

Portable X-Ray Analyzer.—The metal Analyzer Probe (MAP) III Portable X-Ray Fluorescence Analyzer, from Scitec, allows the prospector-explorationist to have on-site, real-time analysis performed for assessment work. No sample preparation is required, and each analysis takes an average of 1 minute. MAP III is a hand-held, multielement probe that performs quantitative analysis for silver, base metals, and trace elements, including those elements associated with gold. The in situ analysis can be performed in drill holes up to 250 ft deep.[26]

Laser Mapping.—A new method to map planar geologic features in underground mines—where metal interferes with compass readings—is being patented by the U.S. Bureau of Mines. Based upon extensive testing, time savings of 50% in mapping—using the "geolaser"—are estimated. The geolaser operates on the principle that any beam of light laid horizontally along a planar feature will define its strike. Thus, the laser can project where a planar feature should occur along the back or opposite rib in an underground drift.

Geophysical Surveying.—The development of new geophysical and geochemical techniques and equipment continued during 1990 at a somewhat decreased pace from former years, in part reflecting generally reduced levels of mineral exploration in most parts of the world. There were, however, some notable highlights. Several new sensitive magnetometers for aeromagnetic survey work are in an advanced stage of development in North America. The first triaxial aeromagnetic gradiometer system was built in the Republic of South Africa. In Australia, considerable funding is going into the development of airborne electromagnetic survey systems. The Global Positioning System (GPS) is now being employed by most airborne survey operations and making feasible preliminary field compilation of survey results.[27]

Remote Sensing.—Development of Landsat 6, the next-generation U.S. land remote sensing satellite, is on schedule for launch in late 1991, according to the Earth Observation Satellite Co. (EOSAT). Landsat 6 will orbit the Earth at the same altitude, inclination, and with the same equatorial crossing time as Landsats 4 and 5, both of which are still operational. The Landsat 6 enhanced thematic mapper will provide improved spatial resolution capable of discerning objects smaller than a tennis court. The satellite will have the same multispectral imaging capabilities of Landsats 4 and 5—technology still unrivaled by any other commercial remote sensing platform.[28]

Projects.—Agnico-Eagle Mines Ltd., Asamera Minerals Inc., Comaplex Minerals Corp., Hecla Mining Co., and Lucky Eagle Mines Ltd. jointly announced the results from drilling for gold mineralization on the Meadowbank Project, about 60 mi northwest of Baker Lake in the Northwest Territories, Canada. In 1989, the third year of exploration drilling the Third Portage property, 12 diamond drill holes defined mineralization to a 300-ft depth over a 1,300-ft strike length. A followup program to test the continuity and size of the deposit is budgeted at Can$1.15 million and was scheduled to begin by mid-1990.

In Mexico, Campbell Resources Inc. has gold properties covering 400,000 acres in the State of Sonora. Most notable is the reserve at La Colorado with a reverse-circulation drill program planned for 1990 and a feasibility study for 1991. Also in Mexico, more than 5 million st of gold ore in massive sulfide mineralization has been outlined on the Cerro de Oro property, including a zone containing 0.07 oz/st gold and 1.9 oz/st silver.

Anglo Swiss Mining Corp., formerly Carolin Mines Ltd., recently announced plans for a $1 million exploration of its 1,500-short-ton-per-day (st/d) Ladner Creek gold mine near Hope, British Columbia, Canada. The exploration will be followed by a feasibility study conducted by Wright Engineers Ltd. An independent consultant estimated potential geological reserves of 5 to 6 million st in addition to the 990,000 st of defined gold mineralization, with expected grade on the McMaster zone.[29]

Stroud Resources Ltd. reported that diamond drilling increased reserves of the Creek zone on its Hislop property, near Timmins, Ontario, Canada, to 1.016 million st grading 0.186 oz/st gold. The Main zone, about 1,600 ft southeast along the strike, contains an estimated 102,000 st grading 0.17 oz/st.[30]

High Frontier Resources Ltd. acquired the Washington Dome Project in Washington County, UT. The property consists of approximately 2,880 acres of unpatented placer and lode claims, as well as a royalty interest in an additional 480 acres of unpatented placer and lode claims (about 133 claims). The property is on the axis of the Virgin anticline in Permian and Triassic rock.

Placer Dome (U.S.), Inc., recently completed the second phase of its exploration at Mexican Hat, AZ, spending $1.39 million to date to earn a 60% interest in the property. About 137 holes have been completed, including 54,103 ft of reverse circulation and 8,017 ft of core drilling on the relatively shallow volcanic-hosted target. Fire assays were made on drill holes that were completed in 1990.

Coral Gold Corp., with Amax Gold Inc. as the operator, reported the first drill results from a four-phase, $11.5 million exploration and development program for the Robertson gold property on the Battle Mountain gold trend of northern Nevada. The first deep hole produced gold values from near surface to a depth of about 1,900 ft.[31]

Windarra Minerals Ltd.'s subsidiary, Westward Explorations Ltd., together with its partner and operator, Cameco, and Uranerz Exploration and Mining Ltd. claimed a major new discovery after drilling over the lake section of the Bakos zone of the Preview Lake property in the La Ronge area of Saskatchewan, Canada. Previously reported reserves in the BK1 and BK2 zones are 1.2 million st probable at 0.29 oz/st gold plus 230,000 st possible at 0.31 oz/st gold.[32]

In British Columbia, Canada, attention was directed to the Golden Triangle that connects three new producing precious-metal mines (Golden Bear, Premier, and Skyline) and two advanced exploration areas encompassing about 175,000 square miles (mi^2) near its eastern corner. The three producers struggled to keep their portals open for the same reason five new gold mines opened and closed elsewhere in 1988-89. Golden Bear, Premier, and Skyline all have well-established reserves. However, production costs have far exceeded estimates due to the inaccessibility of the mines and infrastructure problems.[33]

Ghanaian-Australian Goldfields, Ltd. (GAG) finalized a second drilling program within its Iduapriem gold mining lease near Tarkwa in Ghana. The company drilled 48,000 ft of diamond drilling in 178 holes. A resource of almost 17.6 million st containing an average of 0.06 oz/st gold was

delineated, contained within 3.1 mi of sedimentary rocks having a total strike length of 5.6 mi in the mining lease area. The resource includes 2.3 million st of ore averaging 0.08 oz/st gold. The company also located low-grade mineralization in other areas of the property. The sedimentary host rocks were also found in GAG's adjoining prospecting license areas.

Boulder Gold's U.S. subsidiary, Chrome Corp. of America (CCA), reached an agreement with Phelps Dodge Mining Co. on its Stillwater Complex. The property includes two previously operated chromite mines, one of which, the Mountain View Mine, would be reopened for the project.

Ontario's Ministry of Northern Development and Mines announced funding a 4-year Can$2.2 million Geological Reassessment Program for the Elliot Lake region. The project will concentrate on the potential for deposits of base metals, PGM's, and aggregate resources and industrial minerals. Separately, the Ministry will provide Can$50,000 to support the evaluation of prospecting technology developed in the U.S.S.R. A group of researchers led by the Ontario-based geophysical firm Scintrex Ltd. will test a geoelectro-chemical method for prospecting that was developed in the U.S.S.R. over the past 30 years. The method can reportedly detect the presence of ore formation elements at considerable depth, making it potentially valuable for exploration in areas covered with deep overburden. The work will be carried out by Soviet scientists in collaboration with industry, university, and government.[34]

Recent geologic studies in northern Minnesota indicate a greater potential for deposits of gold and silver in the area than had previously been thought, a U.S. Geological Survey scientist told a meeting of mining engineers and geologists in Salt Lake City, UT. "Geologists' mapping and geochemical surveys in northern Minnesota have revealed mineralized shear-zones and bedrock fractures similar to those in known gold- and silver-producing districts, including nearby areas in Canada."[35]

Pegasus Gold Corp. announced two joint ventures: one with Lac Minerals Ltd. in New Mexico and another with Quartz Mountain Gold Corp. in southern Oregon. Spokane, WA-based Pegasus and Toronto-based Lac Minerals will explore and develop the Ortiz gold project in a mining district 25 mi northeast of Albuquerque, NM. Pegasus will be the operator. Several deposits are on the property, but the joint venture will address the Lukas Canyon deposit, which could be in production in less than 2 years. The total geologic resources are estimated to contain 1.4 million (troy) oz of gold.[36]

Homestake Mining Co. announced a 5-year, $23 million underground exploration program to follow up encouraging gold discoveries approximately 3 mi north of its Homestake gold mine near Lead, SD. Deep drilling from the surface intersected the gold mineralization more than 1 mi below the surface. The exploration program will include a drift from existing Homestake underground operations to reach the mineralization.[37]

Inco Ltd., Vior Inc., and Cambior Inc. announced a new gold discovery on the Douay j.v. property 8 mi northeast of Joutel, Quebec, Canada. The j.v. property, which covers approximately 18 mi^2, is owned by Inco Ltd., the operator; Vior; and Cambior. An ongoing diamond drill program intersected 60 ft containing 0.23 oz/st gold and included 16 ft grading 0.35 oz/st and 10 ft grading 0.39 oz/st gold.

Canyon Resources Corp. announced that more than 600,000 oz of gold was discovered at the Briggs deposit in the Panamint Range, CA. In its recent purchase of Addwest Gold, Inc., Canyon acquired 100% ownership of the Briggs property, which includes approximately 24,000 acres of mining leases and claims in the southern Panamint Range.[38]

DEVELOPMENT

A small decline occurred in the total number and value of new mining- and mineral-processing projects worldwide: 318 at a projected capital cost of $59,700 million in 1989 versus 296 at a projected capital cost of $55,700 million in 1990. The data may indicate a trend toward greater stability, with robust markets returning for certain base metals. Projected investment in North American copper production at $1,260 million almost doubled the figure of the previous year. In Asia, projected investments soared to $1,680 million, nearly triple the total of the previous year. Worldwide productive capacity for copper was predicted to increase by as much as 775,000 st between 1990 and 1992.[39]

Alaskan Mines

According to the Department of Natural Resources, lower development spending but a higher level of mineral revenues is attributed to the changing status of two big mineral projects, Greens Creek and Red Dog, from development to production. The final development cost of $144 million for Greens Creek is substantially higher than the $80 million estimated 3 years ago. An environmental benefit at Greens Creek is the relatively small area that will be required for tailings disposal. Approximately 50% of the tailings will be used as backfill underground, and the employment of a mill process that yields dry tailings has reduced the size of the surface tailings disposal area to 34.6 acres—less than one-third that which would be required for a wet-tailings area for a mine of an equivalent size.

Regulatory officials accused Red Dog of fouling the fish-rich Wulik River with zinc and cadmium downstream from the mine. The company must pump contaminated water back upstream into the company's tailings pond, build culverts to divert uncontaminated water into the streams, and submit plans to prevent future ground water seepages. When in full production, the Red Dog open pit is expected to produce 560,000 st/yr of zinc concentrates, 120,000 st/yr of lead concentrate, and 50,000 st/yr of bulk concentrate from 2.1 million st/yr of mined ore.[40]

The National Park Service (NPS) completed an environmental impact study on mining activity in three national parks in Alaska: Denali, Wrangell-St. Elias, and Yukon-Charley Rivers. The study was done in response to a lawsuit brought by several environmental groups. The review evaluated the effects of mining, including cumulative effects, within the three parks. The study recommends that NPS reacquire all lands held under both mining patent and claims in the three parks. NPS will make a final decision after a procedural review of the study and determination by the EPA.[41]

Mining Manganese From the Ocean Floor

In November 1990, the U.S. Department of the Interior and the University of Hawaii's Look Laboratory released the long-awaited final Environmental Impact Statement (EIS) on mining manganese nodules from the ocean floor near Hawaii. The study is the culmination of a 6-year effort by a State-Federal task force. The two-volume report points to the possibility of a new source of cobalt, manganese, and platinum ore for American industry, as

well as new economic opportunities for the State of Hawaii. Ocean floor mining would do little harm to marine life because there is little life under 8,000 ft of water, according to the report. However, bigger environmental problems would occur on land where the nodules would be processed, including air pollution, ground water contamination, noise, landfilling, and the need for large areas of land. The nearest leasable tract is about 200 mi from the main Hawaiian Islands.

Hawaii's Look Laboratory scientists said it is unlikely such a plant would be built in Hawaii because of strict Federal environmental controls. It is estimated that it could take another 10 years to develop the technology to mine the ore. The EIS addresses 10 potential seamount mining sites, estimated to contain 2.9 million st of cobalt, 1.8 million st of nickel, and 89 million st of manganese. Commercial amounts of platinum might be present, but that has yet to be confirmed.

New Nickel Projects

Strong nickel prices during 1988 and the first half of 1989 brought several previously shutdown mines back to life in 1990 and have prompted a spate of investment in new mines. Three underground mines are in the preproduction stage in the Sudbury basin and at least three more, in Botswana, Western Australia, and Indonesia, are at comparable stages of development. Another eight nickel projects are under consideration for development.

The largest of the projects at the feasibility stage is BRGM's proposed $1.03 billion Tiebaghi development in New Caledonia. The project, in the north of the islands, would include a refinery that would incorporate BRGM's hydrometallurgical process.

In Western Australia, the Mount Keith deposit is under consideration for development by a joint venture of Australian Consolidated Minerals (50%) and Outokumpu Mining Oy (50%). Preliminary estimates for development cost are on the order of $330 million. Reserves, which would be mined from an open pit, total 270 million st, grading 0.6% nickel.[42]

Cyprus Reopens Iron Ore Property as Northshore Mining

The taconite mine and plant at Babbitt and Silver Bay, MN, formerly called Reserve Mining Co., was brought back into operation. Cyprus Minerals Co. breathed new life in the property, which was in bankruptcy since 1986. Cyprus planned to produce more than 2.0 million long-ton (lt) pellets in 1990. By 1993, it plans to be producing 4.0 million lt/yr. Cyprus bought the bankrupt mine for $52 million in June 1989 and began a $29.9 million refurbishing program that will continue into 1991. The facility is undergoing renovations aimed primarily at meeting the requirements of its acid-pellet customers by increasing quality control and lowering costs. Northshore had only scheduled production of 1.7 million lt pellets in 1990, but interest from other customers raised that target to about 2.2 million lt in its first year of production.[43]

UNDERGROUND MINING

The Kiruna iron mine in Sweden is using innovative mining technology to increase production. Kiruna installed remotely controlled driverless trains for ore transport on the 775 level in the 1970's. This was a technically sophisticated system that still maintains a high efficiency. With its experience of the driverless trains, Kiruna is now developing a remote control system for LHD's, the so-called SALT Project (System for Automatic Loading and Transport). Filling of the loader bucket is remotely controlled by means of a television monitor and radio control. The rest of the LHD's working cycle is automatic, with the LHD following a cable in the floor of the drift. Using this system, for which production tests started in February 1990, one operator can control up to three LHD machines from a remote control room.[44] This parallels work being done by the U.S. Bureau of Mines on remote control LHD's for narrow underground veins. To more fully use the application of the remote control and automatic system, Kiruna is instituting a large-scale mining method by increasing substantially the distances between sublevels in its caving operations and arranging these sublevel stopes in blocks of nine. The block will be three stopes wide and three stopes deep, and the stopes are mined in sequence. Blast holes are drilled up 79 ft and down 427 ft from the sublevels. This is reportedly twice the distance that any other operation is drilling. The size of the stopes and concentration of operations should not only be more productive, but adaptable to automation.

Computerized 35-st trolley locomotives operating at Molycorp's New Mexico mine increased underground block caving production from 1,250 to 1,900 st/d. Computerized communications, command, control, and monitoring equipment are reportedly producing savings on the order of $500,000 per day.

The use of electric trolley trucks for underground applications continues with the purchase of a Kiruna-type truck and trolley system for haulage at Mount Isa Mines in Queensland, Australia. Wagner also introduced a new four-wheeled electric drive trolley truck for the industry.

A prototype compact underground boring machine for rapid excavation of underground exploration headings was developed by a joint venture and was tested in Canada. It is reported to bore 8-ft-diameter tunnels through hard rock at twice the rate of conventional drill-and-blast methods, with the inherent safety and improved working conditions of boring machines.

Hydrotransformers that drive closed-circuit, water-emulsion systems to operate equipment in the deep mines are now commercially available. The units were first shown to be economically feasible by the Kloop gold mine in the Republic of South Africa. The system operates rock drills, cleaning rods, watering-down and water-jetting guns, prop-setting intensifiers, and scraper winches for rock handling. Currently, one stope at the mine is operated completely by hydropower. Plans are to operate 40% of the mine with hydraulic systems.

An accurate nondestructive evaluation system to locate cracks in mine winder shafts and power-generating turbines is now being used in the South African mining industry. Originally developed to test turbines in nuclear power stations, the new hydropower system, containing 18 ultrasonic transducers mounted in 6 arrays, covers critical areas far more efficiently. Previous techniques used a single transducer placed at one end of a shaft. There are about 900 mine winder shafts in the Republic of South Africa.

Other innovations are the use of a grouting system and timber cribs for underground supports. The system consists of a pump, bag, and a high-yield grout with rapid setting and curing properties. The grout is chemically engineered to have the same comprehensive strength as the timber. It replaces blocking and wedging, a time- and labor-intensive process, and provides a more effective support.

To minimize wear and maintenance on vehicles used in trackless mines, one company developed a system of concrete paving slabs that interlock with a degree of flexibility to counter the less-than-perfect base found in underground mine haulageways. It can be installed with minimal disruption to the mining operation and is reported to result in cost savings for vehicle maintenance and repair.[45]

Drill-Split

Drill-split primary fragmentation, an innovative mechanical excavation method, was developed to supplement or supplant drill-blast methods. The hydraulically powered, radial-axial splitter used by the system breaks rock in a unique action that gives the appearance of pulling a plug of rock from the mass. This fragmentation activity causes the rock to fail in tension, resulting in highly efficient excavation. Because the radial-axial splitter reacts to the forces it generates internally, it is a small device that can be adaptively mounted on lightweight carriers to meet different excavation needs.

After extensive laboratory testing of smaller tools, the U.S. Bureau of Mines developed and built a field-scale drill-split machine that has the ability to excavate one-half st of hard rock per operation. Both the drill and splitter are mounted on an indexing mechanism that provides the handling and feed operations for both tools from a single highly maneuverable boom. The boom is carried on an air-track crawler chassis for complete mobility. Excavation by this system is carried out through repetitions of the basic drill-split process.

Field tests of the mobile drill-split fragmentation system were conducted in an underground limestone mine. During this test, the drill-split fragmentation system produced more than 100 st of ore and produced an average 1 1/4 st per break. The underground field testing demonstrated several desirable characteristics of drill-split fragmentation: (1) compatibility with concurrent operations, as the testing was conducted during the mine's normal day shift with no disruptions, (2) environmentally attractive operations that produce virtually no dust and no dangerous by-products, and (3) inherently safe operations because of the static, nonviolent excavation action. Drill-split is a low-cost primary excavation method with the flexibility to meet the needs of diverse operations.

Decoupling

Decoupling methods once used primarily at surface mines are finding increased underground applications. A good example is the Bureau's tests conducted in the Homestake Mine's Vertical Crater Retreat (VCR) stopes. Hanging wall blastholes were loaded with less than one-half the normal explosive and decoupled. In comparison to control panels using conventional blast designs, ore dilutions as great as 35% were reduced to 3% to 9%.

Concave Bit

The U.S. Bureau of Mines developed a new bit that promises greater productivity and longer life than conventional point-attack bits while using less force and energy. This new bit is called the concave bit because of its concave front surface. Normally the efficiency is better when the concavity is greater. It has a round shank that allows use with standard bit holders and continuous rotation making the entire periphery of the front surface the effect cutting edge. This bit is designed to replace drag bits and can be used on all mechanical excavators such as roadheaders, continuous miners, shearers, and plows.

Camera System on Roadheader

Closed-circuit television equipment specially designed for use in mine development work by Rees Instruments Ltd., United Kingdom, is reported to have successfully completed trials at British Coal's Sherwood Colliery in Nottinghamshire. The system, incorporating an R331.01.000 intrinsically safe camera and R305.00.000 flameproof monitor with integral IS power-supply unit was developed by Rees in order to improve roadheader performance and enhance the operator's safety.

In roadway drivage underground, once the roadheader's boom-mounted cutting head has made sufficient progress, the machine is withdrawn to allow insertion of steel support arches, before advancing again. When it does, the machine must cut out past the last arch set on the blind (left) side. This is normally a two-person job, with one acting as a "spotter" to pass information to the operator.

The camera-television system dispenses with the spotter. The camera is mounted in a stainless steel tube inside an adjustable steel box on the handrail at the left side of the roadheader and transmits black-and-white pictures to a 12-in screen within its flameproof enclosure. The driver can thus accurately position the machine prior to resuming cutting.

Rees engineers found that, in practice, certain on-site modifications were necessary because of the tough mine operating environment, but excellent pictures are now being achieved consistently, and the system is used by all drivers. Modifications have included mounting a diffused headlight on top of the camera enclosure to improve lighting levels. Once actual cutting has started, the television picture is obscured by the reflection of the main lights on the machine on the dust but, by this time, the camera has fulfilled its purpose and accurately positioned the cutting head.[46]

SURFACE MINING

The advent of the microprocessor and its adaptation to the rugged conditions of mobile-equipment operations in the mining industry has caused a radical, but often underestimated, revolution in surface mining. The range of this new technology is all-embracing. It includes geological and survey instrumentation, geotechnical measuring devices, manufacturing design of all types of mobile equipment, and applications in control, operation, and maintenance of all types of surface plants. The variety of microprocessor uses include monitoring drilling performance parameters, providing fault system diagnostics for electric face shovels, measuring ore weights in loaders and trucks, and eliminating torque spikes in large mechanical-drive trucks. The pace of change has been and is rapid. New fields continue to open, and it is not unlikely that the next decade will see such items as the guided automatic haul truck or the automated rock drill.[47]

The number of surface mine closures in 1990 due to depressed markets was small and largely offset by the number of mines opened. Gold remained the most sought-after commodity. Copper continued to stage a remarkable recovery. High commodity prices continued to fuel the strong comeback. Asarco announced plans to spend an additional $80 million at its Ray Mine and Silver Bell unit in Arizona. This will further expand the company's total domestic copper production from 220,000 st to 360,000 st/yr.

Santa Fe Pacific Gold began production at its $77 million Rabbit Creek Mine near

Winnemucca, NV. The 1,600-st/d carbon-in-leach (CIL) plant is expected to produce 100,000 oz/yr in 1993. The company also announced plans to expand the production capacity at the mine and mill to 200,000 oz/yr by 1992 at a cost of $60 million. The direct cost of production for the expanded plan is expected to be $190 per oz. Proven and probable gold reserves at Rabbit Creek is 3.6 million oz. American Barrick is in the midst of a major, $365 million expansion program at its Goldstrike Mine near Elko, NV. When completed, the mine will increase its production from 352,880 oz in 1990 to 900,000 oz by 1993. Pegasus Gold began building the $11.8 million Black Pine open-pit, heap-leach gold mine in Idaho. The mine is expected to produce 40,000 to 80,000 oz/yr.

Atlas plans to spend $80 million to develop the Grassy Mountain Mine in Oregon to produce 100,000 oz/yr of gold and 100,000 oz/yr of silver for 8 years.

The Denton-Rawhide is a joint venture among Kennecott, Kiewit Mining Group, and Plexus. The open-pit, heap-leach operation began operation in 1990. The mine is expected to produce 80,000 oz/yr of gold and 399,000 oz/yr silver for the next 5 years.

Battle Mountain was given the go-ahead to develop its San Luis Project in southern Colorado. Total cost of the carbon-in-pulp (CIP) facility is estimated at $20 million. At full capacity, the San Luis plant will produce 61,000 oz/yr. Cominco brought the Red Dog zinc-lead mine into production at a cost of $415 million. Current reserves at Red Dog are 85 million st at 17% zinc, 5% lead, and 2.4 oz/st silver.

The Escondido Mine came on-stream in northern Chile. This $900 million mine and concentrator is expected to produce 352,000 st/yr copper in concentrates. Geologic reserves amount to 2 million st grading 1.6% copper. Production began at the Bogosu gold project, a joint venture between Billiton BV (62%), Sikaman Gold Resources (14%), IFC (13.5%), and the Government of Ghana (10%). The $86 million open-pit mining operation has reserves of 21 million st grading 0.1 oz/st. Gold production at the (1.2 million st/yr) mine is expected to total 137,000 oz/yr.

The Porgera Mine Project consists of Placer Dome (30%), Highlands Gold (30%), Renison Goldfields (30%), and Papua New Guinea (10%). The $1 billion project is expected to produce 900,000 oz/yr of gold at an average cost of $150/oz. Ore reserves are 56 million st grading 0.22 oz/st gold. The Granny Smith mine (Placer Pacific 60% and Delta Gold NB 40%) began gold production at a rate of 150,000 oz/yr in Western Australia. The $77 million project contains ore reserves of 25 million st, with an average grade of 0.05 oz/st.[48]

Alcoa closed the last operating bauxite mines in the United States at the end of May 1990, after 91 years of operation because ore reserves were exhausted. The mines are in Saline County, AK, adjacent to Alcoa's Arkansas operations. The operations include a bauxite refinery and alumina chemical facilities. The refining operations, which produced 275,000 st/yr of alumina, will also be closed. Chemical production will continue at the site using alumina feedstocks from other Alcoa locations. For most of the history of the plant, alumina was produced to be made into aluminum, but more recently the alumina was used to produce 135 different products from 6 alumina-based chemicals. These chemical products were used in high-performance refractories and cements, ceramics, fire retardants, and in paper and pharmaceuticals. About 200 people either retired or were laid off, reducing staff at the plant to about 700.[49]

Equipment

Perhaps the two most obvious trends in the past few years have occurred in haul trucks. The 240-st-capacity haul trucks appear to be here to stay, as well as the mechanical-drive, 170-st trucks from Caterpillar. One major trend common to both mechanical-drive and electric-drive systems trucks is the rapidly improving electronic control systems. A memory logger can be placed on-board to record the readings of a wide assortment of gauges. When problems occur, they can be played back in the shop, revealing under what conditions the problem appeared, much like a flight recorder. If a failure occurs, the on-board electronics can not only determine which component has failed, but how serious the failure is, whether it requires immediate attention, or whether service can wait until the end of the shift or later in the week.

Haulpak (Komatsu-Dresser) is one of several manufacturers offering its own on-board weighing system. In the Haulpak system, sensors are mounted in strategic places in the frame of the truck and connected to a microprocessor in the payload meter mounted in the driver's cab. While the driver watches the weight, the shovel operator watches the light assembly mounted outside on the deck. The lights flash green, amber, and red, depending on whether the truck is underloaded, loaded between 90% and 105% of rated capacity, or overloaded. Because the system has a microprocessor, it is capable of recording the final weight just before the truck begins its haul. The payload meter has the capacity to store data for 200 haul cycles. A printer is available that typically lists the driver, total number of loads, the weight of each load, the time each haul cycle began, the date, and the total weight moved for that shift.

High quality is another trend. All manufacturers are gaining a solid reputation for reliable machines. Problems inherent with the larger haul trucks have largely been overcome. Haulpak has a multimillion dollar test center where entire truck frames, pulled off the assembly line at random, are tested with bending and twisting loads, simulating years of normal stress in just a few day's time. Any potential problems show up in the laboratory where they are corrected before they have a chance to cause downtime. The result is that their frames have benefited from increased reliability.

Many remarkable trends are found in front-end loaders (FEL's). In addition to their increasing size, they are also benefiting from the electronics revolution. Loaders are also beginning to compete with shovels in some applications. Not only are loaders more mobile than shovels, they can clean up more efficiently.

Many mines have introduced in-pit crushing with mobile crushers, and many more are considering it. Conveyors can move material inexpensively, but need an in-pit crusher to ensure the proper size material. For mobile crushers with mobile connecting belts, FEL's are required to move the material the short distance from the face to the crusher head.

Big loaders in easily diggable material offer shovels more competition. The FEL is more maneuverable than a shovel and requires a lower initial investment. It can be easily moved to get out of the way of blasts. The FEL can also do limited load-and-carry work.

This trend toward using FEL's as short-haul units is causing a change in their design. FEL's are required to haul material further as distances increase between the face and the crusher hopper. Suspensions of FEL's are notorious for having very little shock absorption, causing them to

bounce wildly at increased speeds. Now, Caterpillar has introduced a Ride Control System to allow FEL's to move material longer distances at higher speeds.

Caterpillar has come up with a clever way for a FEL to weigh the material in the bucket—not just while the machine is at rest, but while it is in motion. Knowing how much is in each bucket can greatly aid loading a truck to its proper capacity, not underloading or overloading. By taking the system dynamics and geometry of the loader and knowing where the various loads will be, the FEL's can precisely report the load in the bucket. The scales have an accuracy of 3% when the loader is moving and 1% when stationary. The hardware is the same as for Caterpillar's haul-truck payload monitors, but the software is different, taking into account the fact that the FEL will be moving while the load is being measured. It was under field tests in 1990 and was scheduled to be commercially available in 1991.

According to Caterpillar researchers, the next generation of electronic systems will monitor performance over the life of the machine, allowing performance trends to be easily spotted. This should happen soon because electronic memory is steadily becoming less expensive. Variabilities in performance can be traced to shifts, operators, or other variables. Also, a telemetry system would send operational data to a central point with more detailed software capable of spotting trends common to all trucks. Ultimately, these systems will provide a warning *before* a major failure, not just on an individual-truck basis, but on a fleetwide basis.

There is also a trend toward modular components. For example, in order to decrease downtime, many large units, especially haul trucks, have engines that can be changed out easily and their waiting replacements slipped back into place. The machine is immediately operational, with the shop free to repair or overhaul the engine without the intense pressure of getting the truck back out on the line again immediately.[50]

World's Largest Mechanical-Drive-Wheel Bulldozer.—A machine originally devised early in the past decade for use in the major opencast iron ore mines of Western Australia was further developed and refined for use in ore and coal mining and power station applications. The Tiger 690B, built by Tiger Engineering Proprietary of Perth, West Australia, is reportedly the world's largest mechanical-drive-wheel dozer with an operating weight of almost 90 st. It can be equipped with dozer blades up to 54 cubic yards (yd^3) capacity. Studies in Australia and North America reportedly show that the 690B can doze coal at 750 st/h over a one-way dozing distance of 600 ft. This increases to 1,000 st/h over 300 ft and 2,100 st/h at 100 ft.

A particular benefit of the machine design in bulk coal handling work is the high compaction effect of its large radial tires; this significantly reduces the risk of spontaneous combustion in coal stockpiles. Other tasks for which the machine is well suited are cleaning work around large mining shovels, push-loading scrapers, and selective dozing work in the large open pits.[51]

Largest Mineral-Sand Dredge.—The world's largest mineral-sand dredge, and the largest dredge of any kind in Australia, began work at Cooljarloo in Western Australia in December 1989. Eighty-seven mi north of Perth, Cooljarloo is the world's first integrated project to turn titanium minerals into paint pigment. Partners in the venture, which will generate annual exports worth Aus$200 million, are Minproc Chemicals Pty. Ltd., a subsidiary of Kerr-McGee. The "Cooljarloo I" bucketwheel dredge is the first electric line-shaft-driven dual-wheel excavator. The 900-hp dual-wheel excavator head is 160 inches in diameter and weighs approximately 110 st.[52]

Backhoe-Mounted Dredging Excavator. — Ellicott Machine Corp., Baltimore, MD, developed a hoe-mounted dredging excavator (HMDE) known as the "Hoe Dragon," which makes possible the continuous excavation and pumping of underwater minerals when used in conjunction with a standard model track-mounted backhoe. The combination of backhoe and dredging excavator is said to maximize the capability of the backhoe and provide continuous excavation and material transport from point of loading to disposal without interruption for swinging with boom and bucket manipulation typical of normal backhoe operation. It is in effect a new tool for underwater excavation of both loose and consolidated materials and can extract mineral in both a forward and aft digging mode.

The backhoe can also be walked onto a barge and operated as a swinging ladder-type dredge while discharging to a shore point, into another vessel, or attendant mineral processing system. This type of equipment is well-suited to recovery of small alluvial gold and diamond deposits inaccessible to floating equipment.

The Hoe Dragon offers the combined advantages of a dual-wheel excavator and a wide-bodied pump that transports virtually all excavated material. A flotation option is available in which special devices are fitted to reduce the submerged weight of the module. This feature allows its use in backhoes not normally able to handle the Hoe Dragon because of its weight. Flotation in this manner also allows for extended reach, without impairing the hydraulic or stability limits of the backhoe. Specially designed extendable stick mechanisms are offered for deep digging applications.[53]

Hydraulically Powered Machines Getting Bigger.—At surface mines hydraulic excavators are getting bigger—and are challenging rope shovels in more and more applications. Excavator weights have been climbing, and some of the newer hydraulic shovels on the market have working weights of 400,000 lb and more. One Supersize hydraulic excavator is Demag's H485, which has a gross operating weight of 1.2 million lb. The first units were placed in coal and tar-sand mines. A unit was put into operation in 1990 at Boliden Mineral's Aitik copper mine in northern Sweden. A 920,000-lb, 530- to 1,060-cubic feet (ft^3)-capacity prototype, the SMEC 4500, built by Japan's Kobelco, underwent long-term mine trials at BHP-Utah's Blackwater coal mine in Queensland, Australia.

Despite all this, the rope shovel remains the dominant digging machine in the shovel family. Some of the advantages in design that have been recently incorporated into some of the electrically powered rope shovels include the following: advanced direct current static power conversion, dual planetary propel drives for improving maneuverability and travel speed; electronic programmable logic controllers that replace all the mechanical logic relays previously used for sequencing the electrical system; and solid-state electrical control systems that eliminate moving parts between the high voltage alternating current power coming in and the direct current power for the motion motors.[54]

Controlled Blasting

Surface mines are using controlled blasting techniques to reduce rockfall

hazards and improve blast casting by maintaining a uniform and predictable burden. Since the bulk of the material is cast by the front row of blastholes, this burden dimension is critical to the success of the entire cast. Many mines are adapting presplit techniques to reduce rockfall hazards. The economic aspect of transitory highwalls encourage methods such as the popular air deck prosplit, low-density explosives, and decoupling techniques. The U.S. Bureau of Mines demonstrated several techniques that deal with a broad range of conditions where air decks and decoupling may be used.

REMOTE MINING

Borehole Mining

The frozen placers in Alaska contain vast deposits of columbium, gold, platinum, and tin. In the past, dredging has most often been the choice for mining these deposits. Now that most of the shallow, dredge-type deposits have been mined out, the use of conventional surface and underground methods to mine the remaining deposits would not be economical.

The U.S. Bureau of Mines-developed borehole mining system has been successfully tested in coal, oil sands, phosphate, and uranium ore. This system can remotely extract a mineral deposit through a borehole. A tool consisting of a water-jet nozzle and slurry eductor is lowered into the deposit, and the water jet erodes a cavity in the mineralized ore, which it slurrifies and pumps to the surface. The values are extracted from the slurry through settling ponds or other means, and the waste material is then returned underground by operating a similar tool in reverse.

In addition, borehole mining research is continuing in the U.S.S.R. To date, gold ore, iron, and titanium have been mined successfully using the borehole mining system.

In Situ Leach Mining

The U.S. Bureau of Mines is conducting research to develop in situ leach mining technology for oxidized copper deposits and oxidized manganese deposits. In situ leach mining offers the potential to significantly reduce production costs that would allow the economic recovery of minerals from small-, deep-, and/or low-grade mineralized deposits. In addition, the method requires significantly less surface disturbance when compared to conventional mining methods.

Preparations for an in situ copper leach mining field test are underway at the Santa Cruz site near Casa Grande, AZ. A five-spot well pattern was constructed, and a salt tracer test was conducted to obtain hydrologic leaching tests. Geologic characterization studies of the ore were also conducted. These data were used to prepare the field test design plan, and the environmental permit applications required before the in situ mining test with dilute sulfuric acid can begin.

Two manganese deposits in the Cuyuna Range of north-central Minnesota are being evaluated for in situ leach mining in the future. One core hole was drilled into each deposit to provide additional information on site geology and to provide samples for geologic characterization studies and laboratory leaching. Laboratory leaching tests with a sulfur dioxide leach manganese from the metal-bearing solution are being developed. These data will provide a basis to evaluate the technical, economic, and environmental feasibility for in situ mining these deposits.

Hot Spots Show Coal-Rock Interface

Development began on a new coal interface detection (CID) system by the U.S. Bureau of Mines. The system employs a highly sensitive, passive infrared (IR) capable of measuring the temperature changes that occur when mining machines contact different types of geological materials, such as coal, sandstone, and limestone. In a passive IR system, naturally generated, thermal IR radiation can be detected—no active IR illumination source is required. With the recent advances in sensor technology and computer-processing capabilities, researchers have been seeking an instrument to sense precisely the interface between coal and the other strata. Such an instrument would become indispensable in longwall and continuous mining, boosting productivity, reducing amounts of rock and minerals that must be removed from coal, and providing additional technology for underground automation.[55]

Automated Hoisting

One area of many underground mines that has already become automated is the shaft. Because of a hoisting accident 2 years ago, Placer Dome was forced to replace the skips, chairs, and dump in its No. 8 shaft in the Timmins Mine. Placer Dome also decided to enhance the automated ore-hoisting process.

Programmable "logic controllers" (PLC's), installed on the mine's underground water pumps in 1985, worked so well that they were also used to automate the loading pocket operation. During a 3-year, fault-free operating period, the number of 14-st skips hoisted during an 8-hour shift jumped to 152 from 127. After shaft rehabilitation during 1988, the mine now hoists 160 16-st skips per shift.[56]

Automated Train Haulage

An automated ore-handling system exists at the Golden Giant Mine in Hemlo, Ontario, Canada. Ore from the mine's ore pass system is fed through chutes into 22-st-capacity, bottom-dump ore cars on the 4335 level. The (unstaffed) PLC-equipped locomotive is controlled remotely during the loading cycle by an operator in the surface control room using video monitors. The locomotive is then placed on automatic control and hauls cars to a coarse ore bin that feeds into the underground crusher on the 4295 level and returns for another load. PLC's also monitor the ore feeder, crusher, discharge conveyor, and levels in the fine ore bin. The 4235-level loading pocket below the crusher is fully automated as is the production hoist. Having achieved a hoisting record of 6,600 st in a 24-h period, the company is now looking seriously at increasing the speed at which the 17.6-st skips are hoisted along the 3,756-ft distance to the surface.[57]

BENEFICIATION

Effect of Grinding

Effect of grinding and electrochemical interactions on the flotation of minerals was studied extensively in 1990. For example, it was found that the grinding media and environment can affect the surface properties of sulfide minerals, thus causing either improvement or deterioration in their floatability.[58]

Flotation

Froth flotation continued to be the most widely used separation process in mineral processing. In the past year, research continued to focus on the hydrodynamics within the flotation cells and the description of the bubbles in the pulp and froth

phases. Kinetic models of bubble and particle collisions were refined to more accurately portray real-world results.[59]

Rapid Flotation

The U.S. Bureau of Mines is developing a rapid flotation system. The speed of flotation is governed by the rate of bubble-particle attachment and bubble-pulp separation. In most conventional flotation cells, attaching the bubble to the fine particles is the slowest step in the flotation process, often requiring 5 to 15 minutes for completion. Intense mixing of the air bubbles and ore pulp speeds up this process, but the higher levels of agitation also disturb the relatively quiescent surface of the cell where the froth concentrates the hydrophobic minerals. The disturbance usually lowers recovery by detaching particles from the bubbles and lowers grade by allowing suspended gangue to overflow into the concentrate. In a conventional flotation cell, interaction between the agitation for rapid bubble-particle attachment and the pulp quiescence required for selective recovery of the froth make it virtually impossible to optimize one of the processes without sacrificing the effectiveness of the other. In 1990, the Bureau devised a revolutionary flotation system using discrete unit operations for bubble-particle attachment and bubble-pulp separation. The conditioned ore is pumped to the bubble-particle attachment unit where intense agitation with another stream of externally generated bubbles quickly attaches the hydrophobic particles to the bubbles. After passing through the bubble-particle attachment unit, the mixture enters a shallow tank where the mixture spreads horizontally near the top of the tank. The bubbles quickly rise to the top and overflow at the outer edge of the tank. The relatively quiet flow in the tank cleanly recovers the bubbles from the pulp, and the shallow depth of the tank allows the bubbles to separate quickly from the pulp. Using a phosphate-bearing sample, the rapid flotation system recovered 76% of the phosphate at a speed 20 times faster than a conventional flotation system using the same sample. In addition, the conventional flotation system process only recovered 65% of the phosphate. Similar test work on coal and porphyry copper ore samples demonstrated rapid flotation with acceptable product grades and recoveries. The rapid flotation circuits will be many times smaller than the current conventional flotation circuits and should cost less to construct. In addition, present facilities with limited space will be able to expand their capabilities with the rapid flotation system without enlarging their buildings.

New Phosphate Resource Produced From Waste Ponds

New reclamation techniques have yielded large quantities of dried mining waste containing high amounts of phosphate from impoundment ponds in Florida. But these wastes also contain significant amounts of undesirable contaminants such as aluminum, iron, and small amounts of radium.

The U.S. Bureau of Mines developed a way to remove most of these contaminants so that this "new" phosphate resource can be used. The Bureau's technology involves leaching phosphate values from the clay wastes using sulfuric acid as the leaching agent and methane as the solvent. Research showed that about 85% of the phosphate can be recovered in the form of a phosphoric acid suitable for fertilizer manufacture. A new flotation technique, also developed by the Bureau, enables the leach tailings to be separated efficiently from the methane-phosphoric acid product.[60]

Procedure Demonstrated to Take Valuable Metals From Sulfide Ores

The U.S. Bureau of Mines developed a procedure, based on oxidation under pressure, to recover valuable metals from sulfide ores. Cobalt, copper, nickel, and zinc, commonly found in the United States in massive sulfide ores, cannot be effectively upgraded by physical separation. They must be processed by chemical methods. These ores also contain gold and silver; however, these precious metals cannot be extracted by standard cyanide processes.

The Bureau successfully demonstrated a laboratory process to recover cobalt, copper, gold, silver, and zinc from an Oregon massive-sulfide ore. The ore is pulverized and placed in a medium-pressure vessel. With the addition of water and oxygen, the ore is heated to 392° F. The cobalt, copper, and zinc are dissolved and recovered from the solution, and the ore residue is altered so that the gold and silver can be easily extracted by cyanide solution. The use of pressure oxidation is being used by a few operations to recover gold.[61]

New Bio-Oxidation Technology

U.S. Gold Corp. produced its first gold-utilizing bacterial oxidation. The company has been a pioneer in commercializing this new technology over the past 2 years. The bio-oxidation process developed at the Tonkin Springs Mine in Nevada uses naturally occurring bacterium *Thiobacillus ferrooxidans* and pretreats refractory gold ore. The process breaks down the iron and sulfur compounds within the ore releasing the gold, which is then recovered using conventional milling methods.

Because bio-oxidation allows for development of this important class of gold deposits, it could be the technology of the nineties for the gold industry. The process should provide a lower cost in processing sulfide refractory ore and has important environmental benefits. For example, byproducts of bio-oxidation can neutralize residual cyanide in mill tailings, rendering the cyanide harmless.

The newly constructed $31 million Tonkin Springs mill has a design capacity of 1,500 st/d with a designed 90% recovery rate that should produce 50,000 oz of gold annually. This initial gold pour represents a major milestone for the company demonstrating the technical feasibility of bio-oxidation. However, the mill must still demonstrate commercial and economic viability, which is dependent on operations reaching full-scale production.[62]

Wet Milling

Minimizing a worker's exposure to asbestos fiber remains a top priority in 1990 for operators of mills that treat asbestos ore. Current Canadian regulations permit two fibers of asbestos per milliliter (ml) of air, while other countries have lowered the limit to 0.5 fibers per ml. Baie Verte Mines, a 100%-held subsidiary of Cliff Resources Corp., which operates an asbestos mine in north-central Newfoundland, Canada, thinks it has found a solution to airborne fiber—a solution that could keep the operation going for another 18 years. To recover more fiber from its ore, the company spent $18 million to construct a wet mill that in March began recovering more asbestos from the tailings stream of the existing dry mill. When that dry mill is decommissioned 3 years from now, the new mill will continue to treat asbestos tailings that have been stockpiled for the past 36 years. At a rate of 55,100 st per year, that would suffice for about 15 years of operation.

Experience in a prototype mill constructed at the Woods Reef Mine in New South Wales, Australia, in 1981 showed that occupational exposure to asbestos fiber could be maintained at less than 0.08 fibers per ml. The process was developed in a research project that began in 1977.[63]

Carbon-in-Leach With Oxygen (CILO) Cost Study

Minproc Engineers (United States) prepared a cost study to compare carbon-in-leach with oxygen (CILO) and conventional CIL circuits designed for equivalent extraction of gold. The key assumption is that CILO can reduce the retention time by a factor of four compared to CIL—something that can reportedly be demonstrated in laboratory tests for a specific ore.

The study provides capital and operating cost comparisons for the leach-absorption section of CILO and CIL circuits of 1,100, 3,310, and 5,510 st/d throughput. Costs for an open design in moderate climate conditions and for an enclosed design for more inclement weather are included for each case. Capital savings range from about $900,000 for the 1,100-st open plant to about $3.2 million for the enclosed design. The savings become increasingly significant as the capacity increases and may suggest some new options for large-tonnage, low-grade projects that are currently being considered only for heap leaching.

Operational savings are based on reduced power requirements and reduced cyanide consumption, with an allowance for oxygen costs. Projects savings are said to range from about $70,000 per year for the 1,100 st circuit to about $315,000 per year for the 5,510 st circuit.

Kamyr Inc., from whom the patented CILO process can be licensed for commercial production, suggests that the capital and operating cost savings are also compelling reasons to consider CILO for any new project. The company can provide a variety of services to process users ranging from technical assistance in process application to a complete mill.[64]

Real-Time Ore Analysis

The new model 200, offered by Outokumpu Electronics of Finland and widely used in the minerals extraction industries, was introduced to the range of Beltcon on-line analyzers. The novel feature of the model 200 is its measurement principle: the Beltcon uses X-ray fluorescence (XRF) to measure simultaneously the concentrations of any two elements from potassium to uranium.

The analyzer is able to operate on both fine and course bulk materials directly from the moving conveyor belt and is thus well suited to mineral processing and metallurgical applications. A typical use is in analysis of calcium and iron in limestone. The noncontact system is easy to install on operating conveyors without the conveyor being modified. The analyzer is above the belt; there is no contact with the moving ore stream, and no physical sampling is required.

Analysis is reportedly very rapid at 300 measurements per minute and, as each assay is based on several thousand measurements, the results obtained are described as highly reliable and accurate. A personal computer can be interfaced to the analyzer for versatile data processing. The results are available on a serial output to either a terminal and/or printer for stand-alone operation or to a personal computer for more versatile data processing. The data are also available as 4 to 20 milliamperes current outputs for recorders, controllers, etc. The control and alarm outputs allow the system to be used for direct-process control. Benefits are said to include lower production costs through improved selective loading, as well as increased efficiency and higher product quality through process stabilization.

The personal computer calculates and displays measured average analyses over the measurement period; it stores the 6,000 latest measurements, 200 shift levels, and 350 latest daily levels. These measurements are also available for statistical processing. The display shows continuously the results of the latest assays as well as cumulative shift and daily averages, indicating any trends.

The Beltcon 200 requires little maintenance as there are no moving parts, and, under normal operating conditions, no user intervention is necessary.[65]

Magnetic Separators

In 1990, Boxmag-Rapid Ltd., the Birmington, United Kingdom-based magnetic mineral separation specialist, launched a new range of high-intensity magnetic separators utilizing powerful rare-earth permanent magnets.

Designated the Magnaroll, the new separator was designed to remove weakly paramagnetic minerals or fine iron scale from nonmagnetic feed material. The feed passes over a head pulley, and nonmagnetics are thrown from the roll by centrifugal force while the magnetic particles adhere to the belt and are discharged into a separate chute. Separation flexibility is introduced by providing an adjustable splitter plate to separate the nonmagnetic-magnetic fractions and by varying the rotational speed of the Magnaroll. The head pulley is manufactured from powerful neodymium-boron-iron rare-earth magnets. The choice of two different roll diameters, 3 in for fine particle and 4 in for course materials, allows an optimum magnetic circuit to be designed for each individual mineral.

The magnetic field strength produced by the Magnaroll on the feed belt surface is usually between 9,000 and 10,000 gauss, and the exceptionally high field gradients achieved by the magnetic circuit design gives excellent separation performance, reportedly comparable to traditional induced roll magnetic separators.

Typical applications for the Magnaroll include purification of silica sand and feldspar, andalusite upgrading, and removal of iron scale from spray-dried ceramic granules. Capacities for the MR1.1000 Magnaroll, which has a feed belt width of 39 in, range from 2.2 to 11 st/h, depending on the mineral application and particle size of feed.

The Magnaroll can effectively process a wide size range of feed materials, from 1.5 in down to 1.77×10^{-3} in. This compares very favorably with the feed range to an induced roll (less than 0.1 in down to 1.77×10^{-3} in). The extra flexibility is said to have opened up new uses for high-intensity, dry magnetic separation; for example, coarse magnesite-serpentine separation.[66]

New Rare-Earth Metal Refining Method

A new method to refine rare-earth metals by means of laser purification and selective ionization was developed by researchers at the National Research Institute for Metals of the Science and Technology Agency and Nippon Steel Corp.

The process, while not new in concept, is reported as the world's first demonstration and proof of the purification concept. The new technology involves vaporizing a rare-earth metal with a beam of electrons and then directing a laser into the metal vapor to separate impure elements. The technology could enable purification of any

type of rare-earth metal simply by altering the wavelength of the laser.

In the experiment, however, efforts were directed at the metal neodymium and praseodymium was removed, considered to be the most difficult element to separate from neodymium. The experiment succeeded in reducing the amount of praseodymium in neodymium metal from 1.5% to 0.09%. Previously, a purity of 99.9% was considered the limit of refining for rare-earth metals, but the new process should permit even purer final products.[67]

HEALTH AND SAFETY

Safety Data

Preliminary injury and employment statistics compiled by the Mine Safety and Health Administration (MSHA) for 1990 showed that there were 56 mine fatalities in the Nation's metal and industrial mineral mines, eight more than in 1989. The same data showed that the average number of employees increased by only 0.5%, much less than the 4.0% average increase in 1989 and the 5.6% increase in 1988. From the MSHA data, employee-hours were shown to decrease by an early estimate of 6.6%, in contrast to 1989's increase of 2.7%. Total reported injuries decreased following an increase for 4 consecutive years, dropping to about 7.2 per 200,000 employee-hours, down from a 8.0 rate for 1989 and 7.9 in 1988. The rate of nonfatal injuries requiring lost work time was essentially the same as those in 1989 and 1988. Approximately 4.3 of such injuries occurred per 200,000 employee-hours in 1990, 4.4 in 1989 and 4.3 in 1988. All figures include independent contractors.

Legislation

The Occupational Safety and Health Administration (OSHA) revised its 1986 asbestos standard by banning smoking by workers in all areas where there is occupational exposure to asbestos; requiring employers to provide workers with literature on smoking cessation programs; issuing new requirements for respirator use; and modifying its hazard-communication program on training, labeling, and posting of warning signs. The agency also proposed reducing the permissible 8-hour time-weighted average limit to 0.1 fiber per cubic centimeter (f/cm^3); introducing work practice standards for certain occupations; requiring notification of OSHA prior to asbestos removal, demolition, or renovation; modifying hazard communication standards and project monitoring requirements; and dealing with requirements for negative-pressure enclosures.

OSHA extended a partial stay on the ruling that established exposure limits for the nonasbestiform varieties of actinolite, anthophyllite, and tremolite through November 30, 1990, while it continued to evaluate the economic impact on the mining and construction industries and whether to regulate nonasbestiform amphiboles under the standard for asbestos.

MSHA continued a review of its proposed revision to its existing asbestos standard. The proposed permissible 8-hour time-weighted average exposure limit will be reduced from 2.0 f/cm^3 to 0.2 f/cm^3 if the proposed standard is enacted.

In February 1990, OSHA proposed to reduce the Permissible Exposure Limit (PEL) for airborne cadmium to either 1 or 5 micrograms cadmium per cubic meter of air (μg/m^3). The current PEL is 100 μg/m^3 PEL for cadmium fumes and 200 μg/m^3 for cadmium dust.

OSHA held two public hearings, one in Washington, DC, in June, the other in Denver, CO, in July. These hearings were held to obtain further information on the feasibility of meeting a 1 or 5 μg/m^3 PEL for cadmium using engineering controls and/or administrative controls. The Agency was expected to reach a final decision by the second quarter of 1991.

MSHA continued to review a proposed revision to its existing talc exposure standard and proposed introducing an exposure standard for soapstone. The proposed permissible 8-hour time-weighted average exposure limit is 2.5 milligrams per cubic meter (mg/m^3) for talc (containing no asbestos), 3 mg/m^3 for respirable soapstone dust, and 6 mg/m^3 for total soapstone dust.

Human Factors

The use of extended workdays, shift lengths longer than 8 hours, received increasing attention in 1990 by the mining industry in the United States and Canada.

Despite the attractive features of these alternative work schedules, questions remain about possible safety and health risk factors associated with extended workdays in mining.

Increased fatigue, decrements in behavioral performance, increased errors, and longer exposure to airborne contaminants and environmental hazards are factors that must be considered in a 10- to 12-hour day. To address these, the Bureau initiated a human factors field research study of extended workdays in underground mining. Cooperators are an underground metal mine in western Canada and the British Columbia provincial government. The first phase of the study was completed in May 1990, while mine workers participating in the study still were on a rotating 8-hour shift schedule. The second phase of the study is scheduled for May 1991, 10 months after the workers in question changed to 12-hour shifts. The same measures will be repeated on the same subjects.[68]

Research

Ground Control, Roof Support.—The U.S. Bureau of Mines is developing improved waveform processing and tomographic image capabilities to assist in the interpretation of subsurface geologic and hydrologic features. The crosshole systems are used with advanced tomographic imaging. They permit visually opaque earth structures to be viewed by acoustic (sound-seismic) waves in a manner similar to the way computer-assisted tomography (CAT) scans view parts of the body.

The first known application of fiberglass dowels, or forepoles, in a room-and-pillar continuous mining development section was completed at the South Field Mine in Utah by the Bureau. The forepoles were installed ahead of the working face into the mine roof for distances of up to 20 ft and were held in place by a resin-type grout. Air was injected into the face and overlying strata to evaluate the tightness of the fractured rock strata before and after forepole installation. This demonstration of the use of forepoles provided access to previously inaccessible coal reserves. It also verified theoretical models that indicated that forepoling maintained the integrity of roof strata after mining.

An automated, minewide monitoring system was successfully deployed by the Bureau at the Foidel Creek Mine, Cyprus Yampa Valley Coal Corp. This system is obtaining ground and shield pressure data from 100 instruments and continuously transmitting the information to a central site. Three-dimensional computer programs

were developed to graphically display the data and permit detailed examination of stress buildup and load transfer trends as mining progresses. The system has predicted ground pressures ahead of the face for distances of up to several hundred feet. It will form the foundation for developing an effective tool for mining engineers and management to evaluate and control the ground conditions in real time.

Bureau field testing of a short-pulse radar system in a West Virginia coal mine successfully located cased and uncased boreholes 50 ft inside a block of coal. Radar penetrations of 200 ft were achieved with minimal attenuation. Experience showed that the best radar configuration from operational and analysis viewpoints involved transmitting from one side of the panel (headgate) to the other side of the panel (tailgate).

The analysis of longwall pillar stability (ALPS) method was used to size pillars in operating mines that are essential to protect critical gate entries that provide access to the face. In using the Bureau-developed ALPS method, the candidate mines have improved the safety of miners by reducing the possibility of rock falls in the gate entries. The ALPS method was formatted for personal computers and is now being distributed throughout the coal industry.

Acid Mine Drainage.—Research studies continued to evaluate the performance of constructed wetlands to accomplish passive treatment of acid mine drainage (AMD). Generally, data collected by regulatory agencies and mining companies about the performance of constructed wetlands consist of influent and effluent water chemistry. In the absence of valid flow rate measurements, it is difficult to separate the effect of the wetland from that of the dilution by fresh water. As some wetlands received inflows of surface water during storm events, dilution may be an important component of wetland performance at these sites, possibly complicating the analysis of water chemistry data.

The Bureau developed a method that allows adjustment of water chemistry data so that dilution is no longer an analytical concern. It is based on the following observations:

- Concentrations of calcium, magnesium, and sodium are commonly quite high for AMD versus fresh water; and
- These cations are not affected by wetland processes.

By calculating a dilution factor from changes in the ions, iron and magnesium concentration can be adjusted, resulting in a better evaluation of wetland performance.[69]

Rock Reinforcing Cables.—Researchers at the U.S. Bureau of Mines found that steel cables grouted into drill holes offer a safe and effective method to support the roof prior to cut-and-fill (overhand) mining. Steel cable supports recently gained popularity in conventional mining practices as a means to reinforce rock before mining it.

As each slice of ore is blasted and removed, the rock above it remains in place because it is supported by the cables. Bureau engineers found that presupporting the rock increases miners' safety and improves ore production primarily by allowing mining to take place in rock that may be difficult to support after blasting. The steel cables offer unique advantages as a support system. They are strong, able to carry about 58,000 lb of load, and since they are flexible, they are useful in even confined areas.[70]

Smart Roof-Bolt Drill.—Researchers at the Bureau developed a system that provides data needed by miners to evaluate roof conditions in a mine. Even though about 25% of the production budget of a typical coal mine is used for ground control, roof falls still occur because of the difficulty involved in detecting hazardous geological conditions.

The Bureau's system is mounted on a roof-bolt drill. This smart drill system provides the operator with real-time displays of the specific energy of drilling and drill bit position. Through the use of a microcomputer, critical drilling parameters can be instantaneously interpreted and analyzed. The operator can be informed of hazardous roof conditions about which he or she may be unaware, such as voids, inclusions, or changes in strata. Mine workers can use this information to help them decide when to install longer bolts, change spacing between bolts, or use a different bolt system.

The Bureau plans to improve the capability of the existing system by incorporating a means to automatically control drilling efficiency. As a result, equipment maintenance and downtime will be reduced, and the useful life of drilling components will be extended. Other plans include the development of computer software that can be used to achieve better drill control and that will provide additional data on rock structure. Through judicious use of sensor technology, an expert system could determine imminent failure of roof strata.[71]

Dust Control.—Airborne dust in mineral processing facilities poses health risks for plant workers. The U.S. Bureau of Mines successfully lowered the dust exposure of workers by approximately 70% during the bag-stacking process at processing plants by developing a dust-control system specifically for pallet loading. The system not only lowers dust levels, it makes bag stacking much easier for workers, thereby reducing back fatigue and injuries in this job function. The system employs a hydraulic lift table to ensure the pallet height remains constant throughout the entire bag-stacking cycle. A number of operations are presently pursuing implementing this technique at their facilities.

The system uses a push-pull ventilation technique to capture dust generated during bag stacking. A low-volume, high-velocity blower system blows a stream of air over the top layer of bags on a pallet and traps the dust. The exhaust air can then be dumped into a baghouse ventilation system or filtered before being discharged outside the mill. The system has been tested successfully at two mineral processing plants.

Reducing Worker Exposure to Silica Dust.—The health effects of exposure to respirable silica dust continued to be a major concern to the U.S. mining industry in 1990.

The Bureau investigated optimizing total mill ventilation systems. By properly designing ventilation flow patterns to sweep major contaminants, dust levels inside these facilities can be substantially lowered in a cost-effective manner. A Bureau-designed total mill ventilation system was installed at a clay operation in New York and lowered respirable dust concentrations throughout the facility by approximately 40%. This system provided 10 air changes per hour, and the total cost to purchase and install this system was less than $10,000. A second total mill ventilation system was evaluated at a silica sand operation in central Texas where the system provided approximately 30 air changes per hour. Reduction in respirable dust levels up to 80% was measured in a number of locations throughout the facility.

Diesel Breakthrough.—A breakthrough in diesel particulate control was achieved by the U.S. Bureau of Mines through the development of disposable filters used after water scrubbers. Two evaluations in operating mine sections showed a 98% reduction in diesel particulate loading in the return airway.

Also in the diesel area, field validation of the dichotomous nature of diesel particulate in mineral dust in underground coal mines progressed. Analysis of the data collected to date confirmed that the aerosol is less than 0.8 micrometer (μm) in diameter, while the diameters of mineral dust tend to be greater than 1 μm (≈1/25,000 in).

During these studies, the research version of the Bureau's personal diesel aerosol sampler (PDAS) performed effectively. It accurately separated the two particulates to determine the respective mass fractions. The success of the work is attracting attention in the United States and abroad, specifically in Australia, Canada, and the United Kingdom. Because of excessive manufacturing costs of the PDAS research version, the Bureau designed and tested prototypes of a less expensive version that could be commercially manufactured for about $10.[72]

Catalytic Diesel Purifier.—A new high-performance catalytic purifier—the Englehard PTX-Ultra exhaust purifier—claims to reduce poisonous and noxious emissions from diesel-powered mining and tunneling equipment. In addition to converting hydrocarbons and carbon monoxide (CO) to water and carbon dioxide (CO_2), it is said to achieve significant reductions in sulfate and sooty fume emissions (which include soluble organic fractions or SOF's) commonly associated with diesel engines. The purifier can also be rapidly retrofitted on-site to diesel-powered equipment, such as personnel carriers, dump trucks, and front-end loaders, with engine capacities up to 1,281 in^3.

Soot and heavy hydrocarbons produced by the incomplete combustion of diesel fuel and lubricating oils, besides being a severe respiratory irritant, can also cause headaches, nausea, and dizziness which, in turn, can lead to accidents. The PTX-Ultra reportedly reduces SOF's by about 60% compared to conventional purifiers and also retards formation of sulfates, which existing systems can accelerate by as much as 10%, as well as converting gaseous hydrocarbons and CO. The purifier unit was specially designed to achieve maximum emission reduction without loss in engine efficiency and to withstand any rough handling in the tough mining and/or tunneling environment.[73]

Reducing Exposure to Diesel Exhaust Emissions.—To reduce worker exposure to diesel exhaust emissions, the U.S. Bureau of Mines successfully developed and tested several new control technologies. These developments enable the mining industry to comply with increasingly stringent health and safety standards.

Diesel engines emit both gaseous and particulate pollutants into the atmosphere, and control of these emissions is necessary to ensure a healthful work environment. Diesel particulate matter is the greatest concern because it is almost entirely respirable in size.

The Bureau, with industrial cooperators, successfully developed a disposable diesel exhaust particulate filter system. Tests in an underground coal mine showed diesel soot reductions of 95%. The filter element is similar to intake air filters used on large diesel engines. The filter material can be made of various types of treated natural or synthetic materials.

The DDEF system consists of adapters, a water trap, the filter, and canister. These components are downstream of the water scrubbers used on part 36 permissible coal mining equipment. Installation at this location takes advantage of the cool exhaust exiting the water scrubber.

A week-long study determined the effects of the disposable filter on air quality in an underground coal mine. Analysis of measurements taken in the mine indicate that diesel-generated soot was reduced by 95%. The filters have a useful service life of about 10 to 12 hours and cost about $40 each.

Sheathed Explosive.—Setting off unconfined explosive charges in gassy or dusty underground mines is prohibited by law because their detonation could cause catastrophic mine explosions or fires. However, there are advantages in using unconfined charges underground. These explosive charges can be used effectively to break up large boulders, rocks, and slabs when cleaning up roof falls. They can also be used to dislodge dangerous overhangs.

The U.S. Bureau of Mines developed a nonincendive explosive charge that will not ignite gassy or dusty atmospheres, even methane-laden air. The explosive charge effectively breaks rock in underground coal mines and can be safely fired without the use of blastholes and stemming. Firing the charge can be performed safely because the explosive is encased in a sheath of salt that disperses into a fine cloud upon firing. As the salt scatters, it acts as a flame retardant. The shock from the explosive detonation breaks the rock.

The Department of Labor's MSHA approved the device as "permissible" or legal for use in underground coal mines. An explosives manufacturer, Austin Powder Co., began marketing the commercial version of the charge in spring 1990 under the name "Sheathed Rockbuster."

Shock-Resistant Emulsion Explosive.—The U.S. Bureau of Mines, in 1990, designed a safer emulsion explosive. Emulsions are preferred in many applications because they are more powerful than traditional explosives, offer a reduced risk of being accidentally detonated, and are easy to handle. Emulsions do have some undesirable characteristics, however. When used in a delay blasting pattern in underground mines, shock waves from neighboring explosive-loaded boreholes can damage emulsion explosives to the point that they will, at best, not detonate properly, or at worst, not detonate at all. Reports from the field suggest similar events may be occurring during blasting at surface mining operations. The Bureau's new safer emulsion explosive solves this problem. The safer emulsion is resistant to shock waves and detonates properly because it contains an improved, pressure-resistant emulsion composition. In addition, the safer emulsion retains the favorable characteristics of conventional emulsion-type explosives.

The Bureau applied for a patent on this novel shock-resistant explosive and is seeking a commercial manufacturer.[74]

Rock Movement Forecasting.—A computer technique developed by the aircraft industry is being used by U.S. Bureau of Mines mining engineers and geologists to evaluate and optimize shaft designs for deep mines. The technique, called "finite-element modeling" (FEM), was adapted by Bureau scientists specifically for the mining industry. Using the FEM technique, Bureau researchers can forecast how rock in a deep mine shaft will behave. To evaluate the stability of a shaft pillar, for example, a finite-element model would be developed by entering information about three critical factors: mining geometry, premining stress state, and material properties of the rock

mass. Using this information, different shaft designs can be analyzed for safety and stability. The Bureau successfully used the FEM program to forecast the stability of a mine shaft at the Homestead Mine in Lead, SD.

Computers and Blasting.—The use of computers for scheduling, inventory control, and mine planning in 1990 expanded rapidly. Computers also saw increasing use in machine-mounted instrumentation to monitor various operating parameters onboard blasthole drills and rock-loading equipment. Related work involves using expert systems to interpret data and advise on machine maintenance timing and troubleshooting procedures.

The application of explosive casting technology to surface mining continued to grow. Two companies reported that, even in geologically disturbed overburden, modified drilling patterns and presplitting resulted in reduced operating costs with dramatic improvements in highway stability and safety.[75]

Computer-Aided Fire Detection.—Based on a Bureau-developed, patent-pending process algorithm, a unique computer program was prepared during 1990 to quickly determine the location of a fire in a complex network of mine workings. The computer program utilizes real-time data from a network of in-mine fire detection devices, along with the output from a mine ventilation simulator, to calculate the probable location of a fire. In-mine tests of the complete system are planned to validate the process.

Mine Fire Modeling.—A Bureau-developed computer simulation program called "MFIRE," originally released in 1988, underwent various upgrades to improve performance and ease of use in 1990. The program is an enhanced ventilation network simulator that enables quantitative evaluation of complex interactions between mine fires and mine ventilation systems. The program is unique among ventilation simulators in that it calculates natural ventilation forces, due both to natural strata heat and fires; identifies reversals and recirculation paths; tracks the production and time-dependent spread of combustion products; and permits analysis of multiple, overlapping transient events involving the ventilation system and mine fires. Upgrades completed during 1990 include increasing the range of conditions that the program can simulate and increasing the accuracy of the predictions of the program.

New Communication System Enhances Mine Safety.—The system developed and patterned on novel Bureau-developed technology is hailed as a breakthrough in underground mine communications in that it can transmit messages through the Earth, from surface to locations underground without cables and without radio aerial networks. Known as PED (Personal Emergency Device), in its most basic form this innovative system consists of four elements: a personal computer, a transmitter, a single-surface aerial, and a portable receiving unit.

To send messages, they are typed into the personal computer—each message can be up to 32 characters long. Once created, the message is sent by transmitter in the form of low-frequency electromagnetic waves. By linking additional personal computers into the system, messages can be sent from numerous mine locations—both above and below ground. Messages can be directed to an individual, to a group (e.g., blasting crew or longwall face crew), or simultaneously to all personnel.

The PED receiving unit is integrated with the miner's battery pack—already carried for his or her cap lamp. When a message is received, the cap lamp flashes over 10 seconds; the miner can then read the message from a liquid crystal display on top of the battery pack.

PED is reportedly suitable for both coal (it is intrinsically safe) and hard-rock mines and is very durable, having been designed for long-term use in physically arduous environments.[76]

Safety at Surface Mining Dump Points.—A specialized computer simulation program that models surface mine dump points was completed and released during 1990. The software, "INSLOPE3," is unique in that it accounts for the dynamic loads imparted by haulage trucks operating near the dump point slope under the surcharge loading of the truck. Distribution of the program is pending completion of a user manual, which is scheduled for release in 1991.

Human Factors Research to Prevent Groundfall Accidents.—In most years, roof falls are the leading cause of fatal accidents in the underground coal mining industry. During the 5-year period 1985-89, 92 coal miners were killed by falls and more than 4,000 miners were injured. According to MSHA's accident investigation reports, 47% of the 92 victims of fatal roof fall accidents were in an area of unsupported roof at the time they were killed. One cause of these accidents relates to the problem of properly positioning roof bolting machines prior to installing new rows of bolts. An employee at a mine in eastern Ohio suggested welding flexible wire antennas onto one of the support pads of the bolter's temporary roof support system. These antennas serve as a convenient gauge to determine if the next row of bolts will be spaced the appropriate distance from the rib and from the last row of bolts bordering the area of unsupported roof.

Portable Alarm.—A new handheld, three-gas portable alarm designed for combustible gas, oxygen, and toxic gas monitoring was made available from Mine Safety Appliances Co. (MSA). The MiniGard III Portable Alarm is battery-operated, can be handheld or worn on a belt, and is designed to detect combustible gas, oxygen, and either hydrogen sulfide or carbon monoxide. It uses a microcomputer and state-of-the-art electronics to provide full-function capabilities, according to MSA. Its compact size (7 by 3.5 by 1.7 in) makes it suitable for confined space applications. The alarm features three diffusion-type sensors with concentrations of gases and vapors shown individually on an easy-to-read liquid crystal display. The display can scroll through the three channels or be locked on one, but all three gases are monitored simultaneously regardless of display setting. An earphone or optional remote alarm module is available for use in high-noise environments. A common audible and visual alarm alerts the user of dangerous gas and oxygen concentrations. When in the alarm mode, a descriptor activates in the display to indicate the type of alarm. Combustible gas calibrations are either general-purpose 0 to 100% Lower Explosive Limit pentane-in-air, or 0 to 5% methane (CH_4) in a methane-air mixture for mining applications. For toxic gas, the alarm can be selected with either a 0 to 50 parts per million (ppm) hydrogen sulfide sensor or with a 0 to 500 ppm carbon monoxide sensor. All alarms indicate 0% to 25% oxygen.[77]

Contractor Training

Dependence on using contractor personnel to perform a variety of production, extraction, and support services throughout the mining industry is increasing.

Analysis of accident and/or injury statistics for the past 8 years indicated several trends among independent contractors in the mining industry. The most alarming one is the fatality incident rate (calculated from fatality figures and normalized on the basis of 200,000 hours worked). This rate is significantly higher for contractors than for operators in both coal and metal-nonmetal mining. The fatality incident rate for contractors at coal mines averages almost twice that for operators, and the rate for contractors at metal-nonmetal mines is almost five times as great. Further analysis shows that four major accident types account for 70% of these fatalities. They include powered haulage, machinery, slips and/or falls, and electrical.

The fatal injury trend has compelled regulatory and company personnel to look at existing standards to deal with health and safety training. Policymakers and safety practitioners agree that current 30 CFR training regulations designed for mining company employees are not appropriate for the myriad of contractors and agents hired by operators to perform various services on-site.

MSHA Crackdown on Mine Fatalities

MSHA developed a program to identify high-hazard metal mines so necessary safety corrections can be made. As a part of its spotlight on safety, MSHA worked at improving accountability and strengthening the investigations unit.

A decision was made to expand the upgrading of MSHA's enforcement capability to the metal and nonmetal sector after evaluating an internal review of the Agency's performance preceding a coal mine explosion in 1989 that killed 10 Kentucky miners. The review listed several "shortcomings" of MSHA personnel, including weak enforcement at the mine where the explosion occurred.

Hoping to prevent similar disasters, MSHA called for closer monitoring of mines in the United States. "It's our intention to have a parallel program for metal and nonmetal mines," MSHA confirmed. Based on MSHA statistics, there is room for safety improvements in the metal industry.[78] Both the number of coal and noncoal mining facilities and the rate of fatalities per total hours worked increased in the first half of 1990 compared to the same period last year.

Twenty-eight metal and nonmetal (noncoal) miners died in accidents in the first 6 months of 1990 compared with 25 for the same period in 1989. The rate of fatal injuries in metal and nonmetal mining through June 1990 was 0.03 per 200,000 employee-hours compared with 0.02 for 1989.

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TABLE 1

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

(Million short tons)

Type and year	Surface			Underground			All mines[1]		
	Crude ore	Waste	Total[1]	Crude ore	Waste	Total[1]	Crude ore	Waste	Total[1]
Metals:									
1985	411	499	911	48	9	57	459	508	968
1986	418	615	1,030	52	7	59	470	622	1,090
1987	489	825	1,310	43	6	49	532	831	1,360
1988	r637	951	r1,590	31	6	37	r668	957	r1,620
1989	799	1,110	1,910	50	5	55	849	1,120	1,970
Industrial minerals:									
1985[2]	1,260	450	1,710	54	2	56	1,320	452	1,770
1986[3]	1,130	380	1,510	34	1	35	1,160	380	1,540
1987[2]	1,430	452	1,880	77	1	78	1,510	453	1,960
1988[3]	1,210	366	1,580	34	([4])	34	1,250	366	1,610
1989[2]	1,550	774	2,330	63	2	65	1,620	776	2,390
Total metals and industrial minerals:[1]									
1985	1,670	950	2,620	102	11	113	1,770	961	2,740
1986	1,550	995	2,540	86	7	93	1,630	1,000	2,630
1987	1,920	1,280	3,200	120	7	126	2,040	1,280	3,320
1988	1,990	1,320	3,310	65	6	72	2,050	1,320	3,380
1989	2,350	1,890	4,240	113	8	120	2,470	1,890	4,360

rRevised.

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

[2]Includes industrial sand and gravel. Construction sand and gravel data were not available for 1985, 1987, and 1989 because of biennial canvassing.

[3]Crushed and broken and dimension stone data were not available for 1986 and 1988 because of biennial canvassing.

[4]Less than 1/2 unit.

TABLE 2[1]

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES[2] IN THE UNITED STATES IN 1989, BY COMMODITY AND STATE

(Thousand short tons)

Commodity	Surface			Underground			All mines[3]		
	Crude ore	Waste	Total[3]	Crude ore	Waste	Total[3]	Crude ore	Waste	Total[3]
METALS									
Bauxite	951	W	951	—	—	—	951	W	951
Copper	300,000	334,000	634,000	4,730	146	4,880	305,000	334,000	639,000
Gold:									
Lode	214,000	566,000	780,000	13,400	3,180	16,500	227,000	569,000	796,000
Placer	13,800	26,800	40,500	—	—	—	13,800	26,800	40,500
Iron ore	206,000	108,000	31,400	W	W	W	206,000	108,000	314,000
Lead	W	W	W	8,550	W	8,550	8,550	W	8,550
Silver	12,900	35,600	48,400	3,430	781	4,210	16,300	36,300	52,700
Titanium	7,900	W	7,900	—	—	—	7,900	W	7,900
Zinc	—	—	—	5,530	W	5,530	5,530	W	5,530
Other[4]	44,400	40,900	85,300	14,000	1,190	15,200	58,400	42,100	101,000
Total metals[3]	799,000	1,110,000	1,910,000	49,600	5,300	54,900	849,000	1,120,000	1,970,000
INDUSTRIAL MINERALS									
Abrasives[5]	87	W	87	W	—	W	87	W	87
Barite	320	—	320	—	—	—	320	—	320
Clays	85,400	50,800	109,000	270	4	274	58,700	50,800	109,000
Diatomite	731	W	731	—	—	—	731	W	731
Feldspar	721	—	721	—	—	—	721	W	721
Gypsum	16,600	W	16,600	1,670	W	1,670	18,200	W	18,200
Iron oxide pigments (crude)	31	—	31	—	—	—	31	—	31
Mica (scrap)	208	109	317	—	—	—	208	109	317
Perlite	842	W	842	W	—	W	842	W	842
Phosphate rock	167,000	412,000	579,000	W	W	W	167,000	412,000	579,000
Potash	W	—	W	969	—	969	969	—	969
Pumice[6]	561	56	617	—	—	—	561	56	617
Salt	4,330	—	4,330	12,800	—	12,800	17,200	—	17,200
Sand and gravel	33,000	273	33,300	—	—	—	33,000	273	33,300
Soda ash	—	—	—	16,300	W	16,300	16,300	W	16,300
Stone:									
Crushed and broken	1,190,000	97,500	1,290,000	30,300	212	30,500	1,220,000	97,700	1,320,000
Dimension	3,470	1,430	4,900	W	—	W	3,470	1,430	4,900
Talc, soapstone, and pyrophyllite	1,360	W	1,360	W	W	W	1,360	W	1,360
Vermiculite	307	W	307	—	—	—	307	W	307
Other[7]	76,800	212,000	288,000	650	2,340	2,890	77,400	214,000	291,000
Total industrial minerals[3]	1,550,000	774,000	2,330,000	62,900	2,450	65,400	1,620,000	776,000	2,390,000
Grand total[3]	2,350,000	1,890,000	4,240,000	113,000	7,750	120,000	2,470,000	1,890,000	4,360,000
STATE									
Alabama	35,100	4,550	39,700	W	W	W	35,100	4,550	36,700
Alaska	11,500	20,700	32,200	W	W	W	11,500	20,700	32,200
Arizona	203,000	189,000	392,000	190	110	301	203,000	189,000	392,000
Arkansas	23,000	6,980	29,900	—	—	—	23,000	6,980	29,900
California	89,900	73,400	163,000	375	21	395	90,300	73,500	164,000
Colorado	7,800	1,900	9,700	10,600	175	10,700	18,400	2,080	20,400
Connectcut	11,900	1,060	12,900	—	—	—	11,900	1,060	12,900
Florida	239,000	376,000	616,000	—	—	—	239,000	376,000	616,000
Georgia	62,400	13,800	76,200	W	—	W	62,400	13,800	76,200

See footnotes at end of table.

TABLE 2[1]—Continued

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES[2] IN THE UNITED STATES IN 1989, BY COMMODITY AND STATE

(Thousand short tons)

Commodity	Surface			Underground			All mines[3]		
	Crude ore	Waste	Total[3]	Crude ore	Waste	Total[3]	Crude ore	Waste	Total[3]
				STATE—Continued					
Hawaii	6,210	523	6,740	—	—	—	6,210	523	6,740
Idaho	11,800	18,700	30,500	1,240	744	1,980	13,100	19,400	32,500
Illinois	66,000	6,040	72,100	995	21	1,020	67,000	6,060	73,100
Indiana	38,800	4,060	42,800	728	—	728	39,500	4,060	43,600
Iowa	30,300	4,240	34,500	993	7	1,000	31,300	4,250	35,500
Kansas	18,100	1,860	20,000	1,690	W	1,690	19,800	1,860	21,700
Kentucky	37,300	3,860	41,100	12,200	85	12,200	49,400	3,940	53,400
Louisiana	6,010	487	6,500	4,550	—	4,550	10,600	487	11,100
Maine	1,650	179	1,830	—	—	—	1,650	179	1,830
Maryland	27,700	2,600	30,300	W	W	W	27,700	2,600	30,300
Massachusetts	12,100	1,100	13,200	—	—	—	12,100	1,100	13,200
Michigan	97,200	64,200	161,000	5,220	W	5,220	102,000	64,200	167,000
Minnesota	164,000	51,800	216,000	—	—	—	164,000	51,800	216,000
Mississippi	2,480	1,310	3,790	—	—	—	2,480	1,310	3,790
Missouri	52,500	5,700	58,200	11,100	310	11,400	63,600	6,010	69,600
Montana	49,500	47,300	96,800	13,300	396	13,700	62,800	47,700	111,000
Nebraska	3,280	460	3,710	W	W	W	3,250	460	3,710
Nevada	185,000	469,000	653,000	345	628	973	185,000	469,000	654,000
New Hampshire	911	144	1,050	—	—	—	911	144	1,050
New Jersey	22,300	1,790	24,100	—	—	—	22,300	1,790	24,100
New Mexico	60,600	103,000	163,000	2,680	232	2,910	63,300	103,000	166,000
New York	40,800	4,060	44,800	4,610	W	4,610	45,400	4,060	49,400
North Carolina	68,700	45,100	114,000	—	—	—	68,700	45,100	114,000
Ohio	52,800	7,200	60,000	3,630	W	3,630	56,400	7,200	63,600
Oklahoma	30,400	7,940	38,300	—	—	—	30,400	7,940	38,300
Oregon	19,000	2,470	21,400	40	7	47	19,000	2,480	21,500
Pennsylvania	93,500	8,590	102,000	2,170	15	2,180	95,700	8,600	104,000
Rhode Island	1,280	100	1,380	—	—	—	1,280	100	1,380
South Carolina	35,400	8,520	43,900	—	—	—	35,400	8,520	43,900
South Dakota	9,180	12,800	22,000	1,840	2,430	4,260	11,000	15,200	26,200
Tennessee	58,500	12,000	70,500	10,400	250	10,700	68,900	12,300	81,200
Texas	83,400	13,800	97,200	666	W	666	84,100	13,800	97,900
Utah	53,900	67,700	122,000	133	W	133	54,000	67,700	122,000
Vermont	3,600	365	3,960	W	—	W	3,600	365	3,960
Virginia	66,100	6,240	72,400	W	W	W	66,100	6,240	72,400
Washington	14,000	1,310	15,300	W	W	W	14,000	1,310	15,300
West Virginia	10,100	1,070	12,000	W	W	W	10,900	1,070	12,000
Wisconsin	28,100	2,220	30,300	—	—	—	28,100	2,220	30,300
Wyoming	22,100	17,700	39,800	16,300	W	16,300	38,400	17,700	56,100
Undistributed[8]	83,500	191,000	274,000	6,650	2,320	8,970	90,200	193,000	283,000
Grand total[3]	2,350,000	1,890,000	4,240,000	113,000	7,750	120,000	2,470,000	1,890,000	4,360,000

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

[1]This table is a compilation of previous Minerals Yearbook tables 2 and 3. Data have been compiled and reorganized.

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

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

[4]Includes beryllium, magnesium, mercury, molybdenum, platinum-group metals, tin, tungsten, uranium, zinc, zirconium, and metal items indicated by symbol W.

[5]Includes abrasive stone and millstones.

[6]Excludes volcanic cinder and scoria.

[7]Includes aplite, asbestos, boron minerals, fluorspar, graphite (natural), kyanite, magnesite, marl (greensand), olivine, soda ash, and industrial minerals indicated by symbol W.

[8]Includes Delaware, North Dakota, and States items indicated by symbol W.

TABLE 3[1]

VALUE OF PRINCIPAL MINERAL PRODUCTS AND BYPRODUCTS OF SURFACE AND UNDERGROUND ORES MINED IN THE UNITED STATES IN 1989

(Value per ton)

Ore	Surface			Underground			All mines		
	Principal mineral product	By-product	Total	Principal mineral product	By-product	Total	Principal mineral product	By-product	Total
METALS									
Bauxite	$13.52	W	$13.52	—	—	—	$13.52	W	$13.52
Copper	11.70	$1.72	13.42	$46.46	$1.66	$48.12	12.27	$1.72	13.99
Gold:									
Lode	15.43	1.15	16.58	9.51	1.94	11.45	14.90	1.22	16.12
Placer	5.08	—	5.09	—	—	—	5.08	—	5.09
Iron ore	8.03	—	8.03	W	W	W	8.03	—	8.03
Lead	—	—	—	32.15	38.04	70.18	32.15	38.04	70.18
Silver	4.71	7.44	12.15	25.18	18.01	43.19	9.33	9.82	19.16
Titanium	5.99	W	12.97	—	—	—	5.99	W	12.97
Zinc	—	—	—	48.04	.99	49.03	48.04	.99	49.03
Average, metals[2]	10.88	1.12	11.99	24.32	8.30	32.63	11.77	1.59	13.36
INDUSTRIAL MINERALS									
Abrasives[3]	20.57	—	20.57	W	—	W	20.57	—	20.57
Barite	39.45	—	39.45	—	—	—	39.45	—	39.45
Clays	27.85	5.09	32.94	W	W	W	27.85	5.09	32.94
Diatomite	101.06	—	101.06	—	—	—	101.06	—	101.06
Feldspar	31.43	W	35.12	—	—	—	31.43	W	35.12
Gypsum	6.97	W	6.97	7.29	—	7.29	7.00	W	7.00
Iron oxide pigments (crude)	91.09	—	91.09	—	—	—	91.09	—	91.09
Mica (scrap)	19.85	—	19.85	—	—	—	19.85	—	19.85
Perlite	12.35	—	12.35	W	—	W	12.35	—	12.35
Phosphate rock	5.09	—	5.09	W	W	W	5.09	—	5.09
Potash	W	—	W	153.50	—	153.50	153.50	—	153.50
Pumice[4]	17.51	—	17.51	—	—	—	17.51	—	17.51
Salt	10.45	W	10.45	16.49	W	16.49	14.97	W	14.97
Sand and gravel	12.45	.43	12.88	—	—	—	12.45	.43	12.88
Soda ash	—	—	—	41.43	—	41.43	41.43	—	41.43
Stone:									
Crushed and broken	4.36	.02	4.38	5.39	—	5.39	4.39	.02	4.40
Dimension	56.76	1.12	57.88	W	—	W	56.76	1.12	57.88
Talc, soapstone, and pyrophyllite	18.56	W	18.56	W	W	W	18.56	W	18.56
Vermiculite	105.93	W	105.93	—	—	—	105.93	W	105.93
Average, industrial minerals[2]	6.12	.35	6.47	22.94	4.69	27.63	6.78	.52	7.30
Average, industrial minerals (excluding sand and gravel and stone)[2]	11.82	1.65	13.47	39.07	9.06	48.13	14.50	2.38	16.87
Average, metals and industrial minerals[2]	7.69	.60	8.29	23.57	6.35	29.92	8.46	.88	9.34
Average, metals and industrial minerals (excluding sand and gravel and stone)[2]	11.15	1.27	12.41	29.92	8.59	38.51	12.57	1.82	14.39

W Withheld to avoid disclosing company proprietary data.
[1]This table had been table 4 in previous issues of the Minerals Yearbook.
[2]Includes unpublished data.
[3]Includes abrasive stone and millstones.
[4]Excludes volcanic cinder and scoria.

TABLE 4[1]

CRUDE ORE AND TOTAL MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1989, BY COMMODITY AND STATE

(Percent)

Commodity	Crude ore		Total material	
	Surface	Underground	Surface	Underground
METALS				
Bauxite	100.0	—	100.0	—
Copper	98.4	1.6	99.2	0.8
Gold:				
Lode	94.1	5.9	97.9	2.1
Placer	100.0	—	100.0	—
Iron ore	[2]100.0	W	[2]100.0	W
Lead	W	[3]100.0	W	[3]100.0
Silver	79.0	21.0	92.0	8.0
Titanium	100.0	—	100.0	—
Zinc	—	100.0	—	100.0
Average, metals[4]	94.2	5.8	87.2	12.8
INDUSTRIAL MINERALS				
Abrasives[5]	[2]100.0	W	[2]100.0	W
Barite	100.0	—	100.0	—
Clays	99.5	.5	99.7	.3
Diatomite	100.0	—	100.0	—
Feldspar	100.0	—	100.0	—
Gypsum	90.9	9.1	94.2	5.8
Iron oxide pigments (crude)	100.0	—	100.0	—
Mica (scrap)	100.0	—	100.0	—
Perlite	[2]100.0	W	[2]100.0	W
Phosphate rock	[2]100.0	W	[2]100.0	W
Potash	W	[3]100.0	W	[3]100.0
Pumice[6]	100.0	—	100.0	—
Salt	25.2	74.8	25.2	74.8
Sand and gravel	100.0	—	100.0	—
Soda ash	—	100.0	—	100.0
Stone:				
Crushed and broken	97.5	2.5	97.7	2.3
Dimension	[2]100.0	W	[2]100.0	W
Talc, soapstone, and pyrophyllite	[2]100.0	W	[2]100.0	W
Vermiculite	100.0	—	100.0	—
Average, industrial minerals[4]	96.1	3.9	97.3	2.7
Average, metals and industrial minerals[4]	95.4	4.6	97.2	2.8
STATE				
Alabama	[2]100.0	W	[2]100.0	W
Alaska	[2]100.0	W	[2]100.0	W
Arizona	99.9	.1	99.9	.1
Arkansas	100.0	—	100.0	—
California	99.6	.4	99.8	.2
Colorado	42.5	57.5	47.5	52.5
Connectcut	100.0	—	100.0	—
Florida	100.0	—	100.0	—
Georgia	[2]100.0	W	[2]100.0	W

See footnotes at end of table.

TABLE 4[1]—Continued

CRUDE ORE AND TOTAL MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1989, BY COMMODITY AND STATE

(Percent)

Commodity	Crude ore		Total material	
	Surface	Underground	Surface	Underground
STATE—Continued				
Hawaii	100.0	—	100.0	—
Idaho	90.5	9.5	93.9	6.1
Illinois	98.5	1.5	98.6	1.4
Indiana	98.2	1.8	98.3	1.7
Iowa	96.8	3.2	97.2	2.8
Kansas	91.5	8.5	92.2	7.8
Kentucky	75.4	24.6	77.1	22.9
Louisiana	56.9	43.1	58.8	41.2
Maine	100.0	—	100.0	—
Maryland	[2]100.0	W	[2]100.0	W
Massachusetts	100.0	—	100.0	—
Michigan	[2]100.0	W	[2]100.0	W
Minnesota	100.0	—	100.0	—
Mississippi	100.0	—	100.0	—
Missouri	82.5	17.5	83.6	16.4
Montana	78.8	21.2	87.6	12.4
Nebraska	[2]100.0	W	[2]100.0	W
Nevada	99.8	.2	99.9	.1
New Hampshire	100.0	—	100.0	—
New Jersey	100.0	—	100.0	—
New Mexico	95.8	4.2	98.2	1.8
New York	[2]100.0	W	[2]100.0	W
North Carolina	100.0	—	100.0	—
North Dakota	W	[3]100.0	W	[3]100.0
Ohio	[2]100.0	W	[2]100.0	W
Oklahoma	100.0	—	100.0	—
Oregon	99.8	.2	99.8	.2
Pennsylvania	97.7	2.3	97.9	2.1
Rhode Island	100.0	—	100.0	—
South Carolina	100.0	—	100.0	—
South Dakota	83.3	16.7	83.7	16.3
Tennessee	84.8	15.2	86.8	13.2
Texas	[2]100.0	W	[2]100.0	W
Utah	99.8	.2	99.9	.1
Vermont	[2]100.0	W	[2]100.0	W
Virginia	[2]100.0	W	[2]100.0	W
Washington	[2]100.0	W	[2]100.0	W
West Virginia	[2]100.0	W	[2]100.0	W
Wisconsin	100.0	—	100.0	—
Wyoming	[2]100.0	W	[2]100.0	W
Average, States[4]	95.4	4.6	97.2	2.8

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

[1]This table is a compilation of previous Minerals Yearbook tables 5 and 6. Data have been compiled and reorganized.

[2]Includes underground; the Bureau of Mines is not at liberty to publish separately.

[3]Includes surface; the Bureau of Mines is not at liberty to publish separately.

[4]Includes unpublished data.

[5]Includes abrasive stone and millstones.

[6]Excludes volcanic cinder and scoria.

TABLE 5[1]

NUMBER OF DOMESTIC METAL AND INDUSTRIAL MINERAL MINES[2] IN THE UNITED STATES IN 1989, 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							
Bauxite	4	—	—	2	2	—	—
Copper	24	—	2	2	2	6	12
Gold:							
Lode	117	4	9	17	38	46	3
Placer	26	5	4	9	5	3	—
Iron ore	23	1	1	6	6	2	7
Lead	13	—	1	1	8	3	—
Silver	13	—	1	2	5	5	—
Titanium	4	—	—	1	2	1	—
Zinc	9	—	—	1	6	2	—
Others[3]	38	15	6	6	5	4	2
Total metals	271	25	24	47	79	72	24
INDUSTRIAL MINERALS							
Abrasives[4]	6	2	—	4	—	—	—
Barite	17	1	6	5	5	—	—
Clays	737	35	142	411	146	3	—
Diatomite	11	—	2	7	2	—	—
Feldspar	14	—	1	11	2	—	—
Gypsum	65	1	6	13	44	1	—
Iron oxide pigments (crude)	3	1	1	1	—	—	—
Mica (scrap)	12	—	8	3	1	—	—
Perlite	9	—	2	4	3	—	—
Phosphate rock	23	—	—	—	5	13	5
Potash	6	—	—	2	4	—	—
Pumice[5]	18	—	5	6	7	—	—
Salt	28	—	1	5	16	6	—
Sand and gravel	160	2	9	67	79	3	—
Soda ash	5	—	—	—	—	5	—
Stone:							
Crushed and broken	4,065	236	463	1,406	1,679	280	1
Dimension	487	282	123	79	3	—	—
Talc, soapstone, pyrophyllite	28	2	4	16	6	—	—
Vermiculite	6	—	—	5	1	—	—
Others[6]	181	11	126	51	-10	2	1
Total industrial minerals	5,881	573	899	2,096	1,993	313	7
Grand total	6,152	598	923	2,143	2,072	385	31
STATE							
Alabama	105	—	18	26	48	13	—
Alaska	34	2	7	12	10	3	—
Arizona	73	3	10	31	15	6	8
Arkansas	74	3	11	23	32	5	—
California	318	47	66	109	70	26	—
Colorado	89	3	22	41	20	3	—
Connecticut	26	1	1	10	10	4	—
Florida	152	1	2	37	71	37	4
Georgia	214	2	29	79	85	19	—

See footnotes at end of table.

TABLE 5[1]—Continued

NUMBER OF DOMESTIC METAL AND INDUSTRIAL MINERAL MINES[2] IN THE UNITED STATES IN 1989, BY COMMODITY AND STATE

Commodity	Total number of mines	Less than 1,000 tons	1,000 to 10,000 tons	10,000 to 100,000 tons	100,000 to 1,000,000 tons	1,000,000 to 10,000,000 tons	More than 10,000,000 tons
				STATE—Continued			
Hawaii	24	—	4	8	11	1	—
Idaho	73	1	12	35	21	4	—
Illinois	247	57	16	75	85	14	—
Indiana	117	3	10	25	72	7	—
Iowa	336	5	63	185	80	3	—
Kansas	161	10	26	73	52	—	—
Kentucky	107	—	2	25	72	7	1
Louisiana	25	—	1	8	14	2	—
Maine	15	—	3	7	5	—	—
Maryland	46	2	6	13	14	11	—
Massachusetts	36	—	5	6	22	3	—
Michigan	70	2	6	14	32	14	2
Minnesota	68	2	11	25	23	2	5
Mississippi	31	—	3	22	6	—	—
Missouri	401	2	98	175	112	14	—
Montana	74	16	12	15	16	13	2
Nebraska	21	4	3	8	5	1	—
Nevada	109	5	11	29	36	25	3
New Hampshire	14	—	3	8	3	—	—
New Jersey	38	—	5	10	17	6	—
New Mexico	90	22	19	28	18	1	2
New York	126	11	13	23	71	8	—
North Carolina	166	4	26	49	70	16	1
Ohio	192	6	22	50	100	14	—
Oklahoma	92	4	10	19	57	2	—
Oregon	231	27	35	136	32	1	—
Pennsylvania	252	10	20	58	148	16	—
Rhode Island	6	—	—	3	3	—	—
South Carolina	59	1	17	3	29	9	—
South Dakota	184	153	7	10	10	4	—
Tennessee	164	3	8	36	101	16	—
Texas	336	25	39	129	126	17	—
Utah	49	1	6	23	13	5	1
Vermont	43	5	11	14	13	—	—
Virginia	135	3	5	28	80	19	—
Washington	221	80	25	76	40	—	—
West Virginia	49	—	4	19	24	2	—
Wisconsin	313	9	79	171	50	4	—
Wyoming	256	62	103	74	10	6	1
Undistributed[7]	90	1	8	60	18	2	1
Total, States	6,152	598	923	2,173	2,072	385	31

[1]This table had been table 7 in previous issues of the Minerals Yearbook. In addition, a breakout of data by State is included.
[2]Excludes wells, ponds, or pumping operations.
[3]Includes beryllium, magnesium metal, mercury, molybdenum, platinum-group metals, tin, tungsten, uranium, and zirconium.
[4]Includes abrasive stone and millstones.
[5]Excludes volcanic cinder and scoria.
[6]Includes aplite, asbestos, boron, fluorspar, graphite, kyanite, magnesite, merl (greensand), olivine, pyrite, and wollastonite.
[7]Includes Delaware, North Dakota, and undistributed data.

TABLE 6[1]

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL[2] MINES IN THE UNITED STATES IN 1989, IN ORDER OF OUTPUT OF CRUDE ORE

Mine	State	Operator	Commodity	Mining method
		METALS		
Smokey Valley Common Operation	Nevada	Round Mountain Gold Corp.	Lode gold	Open pit.
Carlin Mines Complex	do.	Newmont Gold Co.	do.	Do.
Mintac	Minnesota	USX Corp.	Iron ore	Do.
Morenci	Arizona	Phelps Dodge Corp.	Copper	Do.
Bingham Canyon	Utah	Kennecot, Utah Copper Corp.	do.	Do.
Tyrone	New Mexico	Phelps Dodge Corp. and Burro Chief Copper Co.	do.	Do.
Sierrita	Arizona	Cyprus Sierrita Corp.	do.	Do.
Hibbing	Minnesota	Hibbing Taconite Co.	Iron ore	Do.
Empire	Michigan	Empire Iron Mining Partnership	do.	Do.
Erie	Minnesota	LTV Steel Mining Co.	do.	Do.
Bagdad	Arizona	Cyprus Bagdad Copper Co.	Copper	Do.
Pinto Valley	do.	Pinto Valley Copper Corp.	do.	Do.
Inspiration	do.	Cyprus Miami Mining Corp.	do.	Do.
Tilden	Michigan	Tilden Magnetite Partnership	Iron ore	Do.
East Berkeley Pit	Montana	Montana Resources Inc.	Molybdenum	Do.
National Steel Pellet Complex Project—Itasca	Minnesota	National Steel Pellet Co.	Iron ore	Do.
Continental	Montana	Montana Resources Inc.	Copper	Do.
San Manuel	Arizona	Magma Copper Co.	do.	Do.
Chino	New Mexico	Phelps Dodge Corp.	do.	Do.
Thunderbird	Minnesota	Eveleth Mines	Iron ore	Do.
Ray	Arizona	ASARCO Incorporated	Copper	Do.
Sleeper	Nevada	Amax Gold Inc.	Lode gold	Do.
Zortman-Landusky	Montana	Pegasus Gold Inc.	do.	Do.
Eisenhower	Arizona	ASARCO Incorporated	Molybdenum	Do.
Mission Complex	do.	do.	Copper	Do.
		INDUSTRIAL MINERALS[3]		
Grand Rivers	Kentucky	Reed Crushed Stones Co., Inc.	Stone	Open quarry.
Calcite	Michigan	Michigan Mineral Associates	do.	Do.
Cook	Illinois	General Dynamics Corp.	do.	Do.
Stoneport	Michigan	Presque Isle Corp.	do.	Do.
McCook	Illinois	Vulcan Materials Co.	do.	Do.
FEC Hialea	Florida	Rinker Materials Corp.	do.	Do.
Pennsuco	do.	Tarmac America Inc.	do.	Dredging.
Beckman	Texas	Redland Stone Products	do.	Open quarry.
Suwanne	Florida	Occidental Chemical Agricultural Products, Inc.	Phosphate rock	Open pit.
Lee Creek	North Carolina	Texasgulf Chemical Co.	do.	Dredging.
Fort Green	Florida	Agrico Chemical Co.	do.	Open pit.
White Rock	do.	Vecellio and Grogan Inc.	Stone	Open quarry.
Georgetown	Texas	Texas Crushed Stone Co.	do.	Do.
Nichols	Florida	Mobil Oil Corp.	Phosphate rock	Open pit.
St. Genevieve	Missouri	Tower Rock Stone Co.	Stone	Open quarry.
New Braunfels	Texas	Parker Bros and Co	do.	Do.
Payne Creek	Florida	Agrico Chemical Co.	Phosphate rock	Open pit.
Oro Grande	California	Riverside Cement Co.	Stone	Open quarry.
Cape Sandy	Indiana	Mulzer Crushed Stone Co., Inc.	do.	Do.
Ravena	New York	Blue Circle Atlantic Inc.	do.	Do.
Mount Hope	New Jersey	Mount Hope Rock Products Inc.	do.	Do.
Frederick	Maryland	Genstar Stone Products Co.	do.	Do.
Granite	South Carolina	Bad Creek Constructors	do.	Do.
Manassas	Virginia	Vulcan Materials Co.	do.	Do.
Permanen	California	Hanson Industries	do.	Do.

[1]This table had been table 8 in previous issues of the Minerals Yearbook.
[2]Excludes brines and materials from wells.
[3]Includes industrial sand and gravel. Construction sand and gravel were not available for 1989 because of biennial canvassing.

TABLE 7[1]

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL[2] MINES IN THE UNITED STATES IN 1989, IN ORDER OF OUTPUT OF TOTAL MATERIALS HANDLED

Mine	State	Operator	Commodity	Mining method
		METALS		
Carlin Mines Complex	Nevada	Newmont Gold Co.	Lode gold	Open pit.
Chino	New Mexico	Phelps Dodge Corp.	Copper	Do.
Goldstrike	Nevada	Barrick Goldstrike Mines Inc.	Lode gold	Do.
Morenci	Arizona	Phelps Dodge Corp.	Copper	Do.
Bingham Canyon	Utah	Kennecot, Utah Copper Corp.	do.	Do.
Smokey Valley Common Operation	Nevada	Round Mountain Gold Corp.	Lode gold	Do.
Tyrone	New Mexico	Phelps Dodge Corp. and Burro Chief Copper Co.	Copper	Do.
Empire	Michigan	Empire Iron Mining Partnership	Iron ore	Do.
Sierrita	Arizona	Cypris Sierrita Corp.	Copper	Do.
Pinto Valley	do.	Pinto Valley Copper Corp.	do.	Do.
Jerritt Canyon (Enfield Bell)	Nevada	Freeport-McMoRan Gold Co.	Lode gold	Do.
Hibbing	Minnesota	Hibbing Taconite Co.	Iron ore	Do.
Erie	do.	LTV Steel Mining Co.	do.	Do.
Mintac	do.	USX Corp.	do.	Do.
Ray	Arizona	ASARCO Incorporated	Copper	Do.
Inspiration	do.	Cyrpus Miami Mining Corp.	do.	Do.
McCoy and Cove	Nevada	Echo Bay Mining Co.	Lode gold	Do.
Tilden	Michigan	Tilden Magnetite Partnership	Iron ore	Do.
Continental	Montana	Montana Resources Inc.	Copper	Do.
Twin Buttes	Arizona	Cyprus Sierrita Corp.	do.	Do.
Sleeper	Nevada	Amax Gold Inc.	Lode gold	Do.
Mission Complex	Arizona	ASARCO Incorporated	Copper	Do.
Mesquite	California	Goldfields Mining Co.	Lode gold	Do.
Candelaria	Nevada	NERCO Metals Inc.	Silver	Do.
Bagdad	Arizona	Cyprus Bagdad Copper Co.	Copper	Do.
		INDUSTRIAL MINERALS[3]		
Lee Creek	North Carolina	Texasgulf Chemical Co.	Phosphate rock	Dredging.
Suwanne	Florida	Occidental Chemical Agricultural Products, Inc.	do.	Open pit
Fort Green	do.	Agrico Chemical Co.	do.	Do.
Fort Meade	do.	Cargill Fertilizer Inc.	do.	Do.
Nichols	do.	Mobil Oil Corp.	do.	Do.
Fort Meade	do.	do.	do.	Do.
Grand Rivers	Kentucky	Reed Crushed Stones Co., Inc.	Stone	Open quarry.
Silver City	Florida	Estech Inc.	Phosphate rock	Open pit.
Hookers	do.	W.R. Grace & Co.	do.	Do.
Calcite	Michigan	Michigan Mineral Associates	Stone	Open quarry.
Swift Creek	Florida	Occidental Chemical Agricultural Products, Inc.	Phosphate rock	Open pit.
Cook	Illinois	General Dynamics Corp.	Stone	Open quarry.
Stoneport	Michigan	Presque Isle Corp.	do.	Do.
McCook	Illinois	Vulcan Materials Co.	do.	Do.
FEC Hialea	Florida	Rinker Materials Corp.	do.	Do.
Pennsuco	do.	Tarmac America Inc.	do.	Dredging.
Beckman	Texas	Redland Stone Products	do.	Open quarry.
White Rock	Florida	Vecellio and Grogan Inc.	do.	Do.
Vernal	Utah	Cheveron Chemical Co.	Phosphate rock	Open pit.
Georgetown	Texas	Texas Crushed Stone Co.	Stone	Open quarry.
St. Genevieve	Missouri	Tower Rock Stone Co.	do.	Do.
New Braunfels	Texas	Parker Bros and Co	do.	Do.
Payne Creek	Florida	Agrico Chemical Co.	Phosphate rock	Open pit.
Oro Grande	California	Riverside Cement Co.	Stone	Open quarry.
Cape Sandy	Indiana	Mulzer Crushed Stone Co., Inc.	do.	do.

[1]This table had been table 9 in previous issues of the Minerals Yearbook.
[2]Excludes brines and materials from wells.
[3]Includes industrial sand and gravel. Construction sand and gravel were not available for 1989 because of biennial canvassing.

TABLE 8[1]

ORE TREATED OR SOLD PER UNIT OF MARKETABLE PRODUCT AT SURFACE AND UNDERGROUND MINES[2] IN THE UNITED STATES IN 1989, BY COMMODITY

Commodity		Surface			Underground			Total[3]		
		Ore treated (thousand short tons)	Marketable product (units)	Ratio of units of ore to units of marketable product	Ore treated (thousand short tons)	Marketable product (units)	Ratio of units of ore to units of marketable product	Ore treated (thousand short tons)	Marketable product (units)	Ratio of units of ore to units of marketable product
METALS										
Bauxite	thousand long tons	951	673	1.4:1	—	—	—	951	673	1.4:1
Copper	thousand short tons	286,000	1,520	188.8:1	4,770	85	56.4:1	291,000	1,600	181.8:1
Gold:										
Lode	thousand troy ounces	169,000	6,820	24.8:1	16,600	412	40.2:1	186,000	7,230	25.7:1
Placer	do.	13,800	190	72.5:1	—	—	—	13,800	190	72.5:1
Iron ore	thousand long tons	224,000	56,300	4.0:1	W	W	—	224,000	56,300	4.0:1
Lead	thousand short tons	W	W	—	8,590	269	31.9:1	8,590	269	31.9:1
Silver	do.	12,900	11,300	1.1:1	3,770	17,300	.2:1	16,700	28,600	.6:1
Zinc	do.	—	—	—	5,490	174	31.5:1	5,490	174	31.5:1
INDUSTRIAL MINERALS										
Abrasives[4]	thousand short tons	87	87	1.0:1	W	W	—	87	87	1.0:1
Barite	do.	320	320	1.0:1	—	—	—	320	320	1.0:1
Clays	do.	58,400	45,600	1.3:1	270	240	1.1:1	58,700	45,800	1.3:1
Diatomite	do.	1,290	641	2.0:1	—	—	—	1,290	641	2.0:1
Feldspar	do.	721	695	1.0:1	—	—	—	721	695	1.0:1
Gypsum	do.	16,400	15,600	1.1:1	1,670	1,670	1.0:1	18,100	17,300	1.0:1
Iron oxide pigments (crude)	do.	35	34	1.0:1	—	—	—	35	34	1.0:1
Mica (scrap)	do.	219	99	2.2:1	—	—	—	219	99	2.2:1
Perlite	do.	1,310	597	2.2:1	W	W	—	1,310	597	2.2:1
Phosphate rock	do.	210,000	51,800	4.0:1	W	W	—	210,000	51,800	4.0:1
Potash	do.	W	W	—	969,000	969,000	1.0:1	969,000	969,000	1.0:1
Pumice[5]	do.	469	467	1.0:1	—	—	—	469	467	1.0:1
Salt	do.	4,320	830	5.2:1	12,800	12,600	1.0:1	17,100	13,400	1.3:1
Sand and gravel	do.	33,000	29,200	1.1:1	—	—	—	33,000	29,200	1.1:1
Soda ash	do.	—	—	—	16,300	8,980	1.8:1	16,300	8,980	1.8:1
Stone:										
Crushed and broken	do.	1,190,000	1,190,000	1.0:1	30,300	30,300	1.0:1	1,220,000	1,220,000	1.0:1
Dimension	do.	3,470	1,170	3.0:1	W	W	—	3,470	1,170	3.0:1
Talc, soapstone, and pyrophyllite	do.	1,420	1,170	1.2:1	W	W	—	1,420	1,170	1.2:1
Vermiculite	do.	307	293	1.0:1	—	—	—	307	293	1.0:1

W Withheld to avoid disclosing company proprietary data.
[1]This table had been table 10 in previous issues of the Minerals Yearbook.
[2]Excludes wells, ponds, and pumping operations.
[3]Data may not add to totals shown because of independent rounding.
[4]Includes abrasive stone and millstones.
[5]Excludes volcanic cinder and scoria.

TABLE 9[1]

MATERIAL HANDLED PER UNIT OF MARKETABLE PRODUCT AT SURFACE AND UNDERGROUND MINES[2] IN THE UNITED STATES IN 1989, BY COMMODITY

Commodity		Surface			Underground			Total[3]		
		Total material handled[4] (thousand short tons)	Marketable product (units)	Ratio of units of material handled to units of marketable product[5]	Total material handled[4] (thousand short tons)	Marketable product (units)	Ratio of units of material handled to units of marketable product[5]	Total material handled[4] (thousand short tons)	Marketable product (units)	Ratio of units of material handled to units of marketable product[5]
METALS										
Bauxite	thousand long tons	5,360	673	8.0:1	—	—	—	5,360	673	8.0:1
Copper	thousand short tons	634,000	1,520	418.1:1	4,880	85	57.7:1	639,000	1,600	399.1:1
Gold:										
Lode	thousand troy ounces	780,000	6,820	114.4:1	15,600	412	40.1:1	796,000	7,230	110.2:1
Placer	do.	40,500	190	212.8:1	—	—	—	40,500	190	212.8:1
Iron ore	thousand long tons	314,000	56,300	5.6:1	W	W	—	314,000	56,300	5.6:1
Lead	thousand short tons	W	W	—	8,860	269	32.9:1	8,860	269	32.9:1
Silver	do.	48,400	12,300	4.3:1	4,210	17,300	2:1	52,700	28,600	1.8:1
Zinc	do.	—	—	—	5,740	174	32.9:1	5,740	174	32.9:1
INDUSTRIAL MINERALS										
Abrasives[6]	thousand short tons	203	87	2.3:1	W	W	—	203	87	2.3:1
Barite	do.	320	320	1.0:1	—	—	—	320	320	1.0:1
Clays	do.	109,000	45,600	2.4:1	274	240	1.1:1	109,000	45,800	2.4:1
Diatomite	do.	736	641	1.1:1	—	—	—	736	641	1.1:1
Feldspar	do.	721	695	1.0:1	—	—	—	721	695	1.0:1
Gypsum	do.	27,400	15,600	1.8:1	1,680	1,670	1.0:1	29,100	17,300	1.7:1
Iron oxide pigments (crude)	do.	31	359:1	—	—	—	31	359:1		
Mica (scrap)	do.	317	99	3.2:1	—	—	—	317	99	3.2:1
Perlite	do.	1,040	597	1.7:1	W	W	—	1,040	597	1.7:1
Phosphate rock	do.	579,000	51,800	11.2:1	W	W	—	579,000	51,800	11.2:1
Potash	do.	W	W	—	969	969	1.0:1	969	969	1.0:1
Pumice[7]	do.	617	467	1.3:1	—	—	—	617	467	1.3:1
Salt	do.	4,330	830	5.2:1	12,800	12,600	1.0:1	17,200	13,400	1.3:1
Sand and gravel	do.	33,300	29,200	1.1:1	—	—	—	33,300	29,200	1.1:1
Soda ash	do.	—	—	—	18,500	8,980	2.1:1	18,500	8,980	2.1:1
Stone:										
Crushed and broken	do.	1,290,000	1,190,000	1.1:1	30,500	30,300	1.0:1	1,320,000	1,220,000	1.1:1
Dimension	do.	4,900	1,170	4.2:1	W	W	—	4,900	1,170	4.2:1
Talc, soapstone, and pyrophyllite	do.	6,200	1,170	5.3:1	W	W	—	6,200	1,170	5.3:1
Vermiculite	do.	W	W	—	—	—	—	W	W	—

W Withheld to avoid disclosing company proprietary data.
[1]This table had been table 11 in previous issues of the Minerals Yearbook.
[2]Excludes wells, ponds, and pumping operations.
[3]Data may not add to totals shown because of independent rounding.
[4]Includes material from exploration and development activities.
[5]Material from development and exploration activities is excluded from the ratio calculation.
[6]Includes abrasive stone and milltones.
[7]Excludes volcanic cinder and scoria.

TABLE 10[1]

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

(Percent)

Commodity	Total material handled	
	Preceded by drilling and blasting	Not preceded by drilling and blasting[2]
METALS		
Bauxite	100	—
Beryllium	—	100
Copper	96	4
Gold:		
Lode	98	2
Placer	—	100
Iron ore	97	3
Magnesium	100	—
Mercury	100	—
Molybdenum	100	—
Silver	100	—
Tin	—	100
Titanium (ilmenite)	—	100
Tungsten	—	100
INDUSTRIAL MINERALS		
Abrasives[3]	57	43
Aplite	100	—
Asbestos	100	—
Barite	100	—
Boron	100	—
Clays	100	—
Diatomite	99	1
Feldspar	100	—
Graphite	100	—
Gypsum	92	8
Iron oxide pigments (crude)	100	—
Kyanite	100	—
Magnesite	100	—
Marl (greensand)	100	—
Mica (scrap)	28	72
Olivine	100	—
Perlite	70	30
Phosphate rock	3	97
Potash	—	100
Pumice[4]	87	13
Pyrite	100	—
Salt	—	100
Sand and gravel	11	89
Stone:		
Crushed and broken	99	1
Dimension	—	100
Talc, soapstone, and pyrophyllite	100	—
Vermiculite	100	—
Average[5]	89	11

[1]This table had been table 12 in previous issues of the Minerals Yearbook.
[2]Includes drilling or cutting without blasting, dredging, or mechanical excavation and nonfloat washing, and other surface mining methods.
[3]Includes abrasive stone and millstones.
[4]Excludes volcanic cinder and scoria.
[5]Includes unpublished data.

TABLE 11[1]

EXPLORATION AND DEVELOPMENT ACTIVITY IN THE UNITED STATES IN 1989, BY METHOD, COMMODITY, AND STATE

(Feet)

Commodity	Exploration							Development				
	Churn drilling	Diamond drilling	Percussion drilling	Rotary drilling	Other drilling	Trenching	Total[2]	Drifting, cross-cutting, or tunneling	Raising	Shaft and winze sinking	Solution mining	Total[2]
METALS												
Copper	—	63,300	66,000	W	—	—	129,000	8,730	158	2	—	8,890
Gold:												
Lode	W	554,000	626,000	2,040,000	266,000	50,600	3,540,000	702,000	12,700	1,120	—	716,000
Placer	—	—	—	W	50,300	115	50,400	—	—	—	—	—
Iron ore	W	23,500	—	—	—	—	23,500	W	—	—	—	—
Lead	W	W	W	30	13,100	—	13,100	16,500	1,610	—	—	18,100
Platinum-group metals	—	50,900	—	—	—	—	50,900	W	W	—	—	—
Silver	—	63,200	W	W	12	—	63,200	27,100	4,240	176	—	31,500
Titanium concentrates	—	1,500	3,000	—	—	—	4,500	—	—	—	—	—
Other[3]	82,800	62,400	454,000	138,000	38,800	—	777,000	84,100	7,780	—	—	91,900
Metals total[2]	82,800	819,000	1,150,000	2,180,000	368,000	50,700	4,650,000	839,000	26,500	1,300	—	867,000
Percent of metals total[4]	1.8	17.6	24.7	46.9	7.9	1.1	100.0	96.8	3.1	.2	—	100.0
INDUSTRIAL MINERALS												
Diatomite	—	660	—	W	—	—	660	—	—	—	—	—
Gypsum	—	1,720	—	W	—	—	1,720	—	—	—	—	—
Perlite	—	1,260	—	W	—	500	1,760	—	—	—	—	—
Phosphate rock	—	W	—	76,300	—	—	76,300	W	W	—	—	—
Pumice[5]	—	20	—	2,900	—	—	2,920	—	—	—	—	—
Stone (crushed and broken)	—	943	—	—	—	—	943	—	—	—	—	—
Talc, soapstone, and pyrophyllite	—	—	—	—	511	—	511	—	—	—	—	—
Other[6]	644	76,300	32,600	223,000	52,300	305	385,000	168,000	1,530	—	—	169,000
Industrial minerals total[2]	644	80,900	32,600	302,000	52,800	805	470,000	168,000	1,530	—	—	169,000
Percent of industrial minerals total[4]	.1	17.2	6.9	64.3	11.2	.2	100.0	99.1	.9	—	—	100.0
Grand total[2]	83,500	900,000	1,180,000	2,480,000	420,000	51,500	5,120,000	1,010,000	28,000	1,300	—	1,040,000
Percent of grand total[4]	1.6	17.6	23.1	48.5	8.2	1.0	100.0	97.2	2.7	.1	—	100.0
STATE												
Alaska	—	W	3,000	W	32,200	40,100	75,300	W	—	—	—	—
Arizona	—	W	—	W	—	—	0	4,350	882	—	—	5,230
Arkansas	—	1,930	—	3,210	—	—	5,140	—	—	—	—	—
California	—	5,640	26,400	120,000	W	4,360	156,000	2,680	W	600	—	3,280
Colorado	W	140,000	W	102,000	200	W	242,000	29,300	4,460	3	—	33,700
Florida	—	—	—	36,700	—	—	36,700	—	—	—	—	—
Idaho	—	W	150	W	15,100	—	15,200	24,400	3,470	W	—	27,800
Minnesota	W	22,700	—	—	—	—	22,700	—	—	—	—	—
Montana	—	88,700	110,000	82,200	W	W	281,000	33,500	4,390	—	—	37,900
Nevada	W	199,000	557,000	1,610,000	221,000	5,250	2,590,000	168,000	W	90	—	169,000
New Mexico	W	2,160	11,400	4,440	36,800	—	54,800	W	W	—	—	—
Oregon	—	31,900	19,000	W	—	—	50,900	1,520	158	20	—	1,690

See footnotes at end of table.

TABLE 11[1]—Continued

EXPLORATION AND DEVELOPMENT ACTIVITY IN THE UNITED STATES IN 1989, BY METHOD, COMMODITY, AND STATE

(Feet)

Commodity	Exploration							Development				
	Churn drilling	Diamond drilling	Percussion drilling	Rotary drilling	Other drilling	Trenching	Total[2]	Drifting, cross-cutting, or tunneling	Raising	Shaft and winze sinking	Solution mining	Total[2]
STATE—Continued												
South Dakota	—	60,000	11,000	75,000	7,280	—	153,000	524,000	5,800	—	—	529,000
Utah	—	4,960	W	42,200	13,900	1,300	62,400	W	W	—	—	—
Undistributed[7]	83,500	343,000	445,000	409,000	94,100	515	1,370,000	219,000	8,880	588	—	228,000
Total all States[2]	83,500	900,000	1,180,000	2,480,000	420,000	51,500	5,120,000	1,010,000	28,000	1,300	—	1,040,000
Percent of all States[4]	1.6	17.6	23.1	48.5	8.2	1.0	100.0	97.2	2.7	.1	—	100.0

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]This table has been table 13 in the previous issue of the Minerals Yearbook.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes antimony, beryllium, molybdenum, rare-earth concentrates, zinc, and metals items indicated by symbol W.
[4]Based on unrounded footage.
[5]Excludes volcanic cinder and scoria.
[6]Includes abrasives, boron minerals, fluorspar, gypsum, lime, soda ash, stone (dimension), and mineral items indicated by symbol W.
[7]Includes Illinois, Michigan, Missouri New York, Oklahoma, South Carolina, Virginia, Washington, Wyoming, and State items indicated by symbol W.

TABLE 12[1]

TOTAL MATERIAL (ORE AND WASTE) PRODUCED BY MINE DEVELOPMENT IN THE UNITED STATES IN 1989, BY COMMODITY AND STATE

(Thousand short tons)

	Drifting, crosscutting, or tunneling	Raising	Shaft and winze sinking	Stripping	Total[2]
METALS					
Copper	145	(3)	(3)	2	148
Gold:					
Lode	3,020	82	10	75,600	78,700
Placer	—	—	—	12,500	12,500
Lead	286	16	—	—	302
Silver	429	213	2	—	645
Others[4]	554	20	—	8,940	9,510
Metals total[2]	4,430	332	13	97,000	102,000
INDUSTRIAL MINERALS					
Abrasives[5]	—	—	—	34	34
Others[6]	2,190	(3)	—	11,900	14,100
Industrial minerals total[2]	2,190	(3)	—	11,900	14,100
Grand total[2]	6,620	332	13	109,000	116,000
STATE					
Alaska	W	—	—	10,100	10,100
Arizona	78	3	—	4	86
California	8	W	1	2,890	2,900
Colorado	139	16	(3)	—	155
Idaho	413	210	W	203	826
Montana	112	22	—	—	134
Nevada	593	W	1	70,300	70,900
New Mexico	W	W	—	30	30
Oregon	6	(3)	(3)	W	7
South Dakota	2,400	22	—	—	2,430
Utah	W	W	—	8,400	8,400
Undistributed[7]	2,870	58	10	17,100	20,000
Total[2]	6,620	332	13	109,000	116,000

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

[1]This table had been table 14 in the previous issue of the Minerals Yearbook.

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

[3]Less than 1/2 unit.

[4]Includes iron ore, molybdenum, platinum-group metals, and zinc.

[5]Includes abrasive stone and millstones.

[6]Includes fluorspar, gypsum, phosphate, pumice, soda ash, and talc and pyrophyllite.

[7]Includes Illinois, Michigan, Minnesota, Missouri, New York, Oklahoma, Tennessee, Washington, Wyoming, and State items indicated by symbol W.

TABLE 13[1]

INDUSTRIAL EXPLOSIVES AND BLASTING AGENTS SOLD FOR CONSUMPTION IN THE UNITED STATES, BY CLASS AND USE

(Thousand pounds)

Year	Coal mining	Metal mining	Quarrying and nonmetal mining	Total mineral industry	Construction work	All other purposes	Total industrial[2]
TOTAL, BY USE							
1985	2,241,303	382,410	510,500	3,134,213	247,451	418,690	3,800,354
1986	2,566,337	319,844	585,220	3,471,401	258,651	192,784	3,922,836
1987	3,220,762	340,283	482,911	4,043,956	308,912	145,389	4,498,257
1988[e]	3,137,000	440,000	595,250	4,172,250	320,200	245,000	4,737,440
1989[e]	3,175,000	480,000	630,210	4,285,210	330,170	190,000	4,805,380
BY CLASS AND USE							
PERMISSIBLES							
1985	[3]34,563	[3]117	[3]481	35,161	[3]836	[4]71	36,068
1986	34,971	7	[3]155	35,133	245	[4]61	35,439
1987	33,391	—	248	33,639	214	—	33,853
1988[e]	27,000	—	250	27,250	200	—	27,450
1989[e]	22,000	—	210	22,210	170	—	22,380
OTHER HIGH EXPLOSIVES							
1985[5]	[3]21,705	[3]9,466	[3]55,470	86,641	[3]35,460	[4]13,775	135,876
1986	18,004	7,027	[3]63,249	88,280	37,403	[4]6,106	131,789
1987	23,171	9,013	62,250	94,434	43,355	5,458	143,247
1988[e]	20,000	10,000	65,000	95,000	45,000	10,000	150,000
1989[e]	19,000	9,000	61,000	89,000	42,000	9,000	140,000
WATER GELS AND SLURRIES							
1985[5]	[3]133,858	[3]66,653	[3]80,283	280,794	[3]27,487	[4]16,245	324,526
1986	180,201	57,153	[3]128,854	366,208	38,582	[4]15,300	420,090
1987	195,737	63,125	160,412	419,274	55,758	6,326	481,358
1988[e]	240,000	100,000	220,000	560,000	80,000	20,000	660,000
1989[e]	234,000	98,000	215,000	547,000	78,000	20,000	645,000
AMMONIUM NITRATE: FUEL OIL BLASTING AGENTS AND UNPROCESSED							
1985[6]	[3]2,051,177	[3]306,174	[3]374,266	2,731,617	[3]183,668	[4]388,599	3,303,884
1986	2,333,161	255,657	[3]392,962	2,981,780	182,421	[4]171,317	3,335,518
1987	2,968,463	268,145	260,001	3,496,609	209,585	133,605	3,839,799
1988[e]	2,850,000	330,000	310,000	3,490,000	195,000	215,000	3,899,990
1989[e]	2,900,000	373,000	354,000	3,627,000	210,000	161,000	3,998,000

[e]Estimated.

[1]This table had been table 15 in the previous issue of the Minerals Yearbook.

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

[3]Some quantities of this use are included with "All other purposes" to avoid disclosing company proprietary data.

[4]Includes some quantities from "Coal mining," "Metal mining," "Quarrying and nonmetal mining," and "Construction work."

[5]Some quantities of this use are included with "Ammonium nitrate: Fuel oil blasting agents and unprocessed" to avoid disclosing company proprietary data.

[6]Includes some quantities from "Other high explosives," and "Water gels and slurries."

ABRASIVE MATERIALS

By Gordon T. Austin

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

The combined value of production of natural abrasives, which include tripoli, special silica stone, garnet, staurolite, and emery, increased about 4% in 1990. The increase in the value of tripoli production was the result of an increase in the unit value. Emery increased owing to an increase in the volume of the material produced and an increase in the unit value. Special silica stone experienced a decrease in unit value and an increase in the quantity produced. Garnet showed a 10% increase in quantity and a 73% increase in unit value. Staurolite decreased about 8% in the quantity produced, and the value of production decreased about 10%.

The fused aluminum oxide industry showed a 5% decline in the quantity produced and in the value of production. The silicon carbide industry saw a 10% decrease in the quantity produced and a 9% decrease in the value of production. Production for both industries decreased 7% in quantity and value compared with those of 1989.

The quantity of metallic abrasives sold and shipped was essentially the same as for 1989, and the value increased slightly. This was the second stable year after 4 consecutive years of increases in both quantity and value. The industry includes the primary producers of steel, chilled and annealed iron, cut wire shot and grit, and shot and grit reclaimed by primary producers. Shipments in 1990 were about 13% below the industry's high of 239,619 metric tons[1] in 1979.

The United States continued as the largest single manufacturer, exporter, importer, and consumer of synthetic industrial diamond in the world. The estimated apparent U.S. consumption of industrial diamond stones continued its rebound from the 48-year low in 1987 with an increase of 52% to 9.3 million carats in 1990.

DOMESTIC DATA COVERAGE

Domestic production data for abrasive

TABLE 1

SALIENT U.S. ABRASIVES STATISTICS

		1986	1987	1988	1989	1990
Natural abrasives production by producers:						
Tripoli (crude)	metric tons	106,298	104,259	99,928	105,230	94,390
Value	thousands	$918	$975	$864	$2,537	$3,194
Special silica stone[1]	metric tons	973	1,378	1,892	898	454
Value	thousands	$501	$489	$566	$147	$230
Garnet[2]	metric tons	24,298	38,353	42,506	42,605	47,009
Value	thousands	$2,603	$4,350	$4,707	$4,408	$6,939
Emery	metric tons	2,611	1,764	869	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	438,043	r462,773	r544,899	r535,213	514,869
Value[4]	thousands	$173,858	r$167,593	r$209,998	$227,761	$218,207
Foreign trade (natural and artificial abrasives):						
Exports (value)[5]	do.	$207,624	$238,522	$281,633	$260,363	$270,928
Reexports (value)[5]	do.	$27,011	$21,192	$19,302	$33,771	$24,545
Imports for consumption (value)[5]	do.	$406,572	$424,640	$501,707	r$419,084	$469,781

rRevised. W Withheld to avoid disclosing company proprietary data.
[1]Includes grindstones, oilstones, whetstones, and deburring media. Excludes grinding pebbles and tube-mill liners.
[2]Primary garnet; denotes first marketable product. Includes crude concentrates.
[3]Includes Canadian production of crude silicon carbide and fused aluminum oxide and shipments of metallic abrasives by producers.
[4]Excludes United States and Canadian production and value of aluminum-zirconium oxide.
[5]Bureau of the Census.

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, 14, 15, and 16.

FOREIGN TRADE

The total value of abrasive materials, exports plus reexports, was $295.5 million, a very slight increase compared with the 1989 value.

The total value of abrasive materials imported was $469.8 million, an increase of 12% compared with the 1989 value. The average total value for the past 10 years was $382.3 million per year, with the high in 1988 of $501.7 million and the low of $245.0 million in 1982. Abrasive material imports had, until the 1989 decrease, increased at a compounded rate of slightly less than 13% per year for the past 6 years. The 1990 increase put the level of imports back on trend.

The United States has shown a trade deficit in abrasive materials for every year of the past 10 years. In 1990, the deficit increased 40% compared with 1989's 38% decrease from 1988's record high of $200.8 million.

TRIPOLI

The category of tripoli includes not only tripoli, but other fine-grained, porous silica materials that have similar properties and end uses. It does not include fine-grained or porous silica materials included in other Mineral Annual Report chapters, such as pumice.

Production

In 1990, the quantity of crude tripoli produced decreased 10% after 1989's increase, which followed 5 consecutive years of decline. The value of 1990's production increased 27% compared with that of 1989. The average production for the past 10 years was 103,229 tons per year, with a high of 112,928 tons in 1984 and a low of 94,389 tons in 1990. Six firms produced tripoli in four States. Malvern Minerals Co., Garland County, AR, produced crude and finished material. American Tripoli Co. produced crude material in Ottawa County, OK, and finished material in Newton County, MO. Illinois Minerals Co. and Tammsco Inc., both in Alexander County, IL, produced crude and finished amorphous (microcrystalline) silica. 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.

Consumption and Uses

Processed tripoli, sold or used, decreased 6% in quantity, but increased 17% in value; the increase in value was the result of an increase of 25% in the average value per ton. Because tripoli grains lack distinct edges and corners, it has unique abrasive uses. It is the mild abrasive 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 largest use of the mineral was as a filler and extender in paint, plastic, rubber, and enamel. The use of tripoli as an abrasive decreased about 8% in

TABLE 2

U.S. EXPORTS OF ABRASIVE MATERIALS, BY KIND

(Thousands)

Kind		1989		1990	
		Quantity	Value	Quantity	Value
NATURAL					
Industrial diamond, natural or synthetic, powder or dust	carats	73,168	$113,446	68,716	$104,153
Industrial diamond, natural or synthetic, other	do.	1,521	13,645	448	5,420
Natural abrasives, crude	kilograms	3,339	4,270	2,258	1,973
Natural abrasives, other	do.	9,027	12,836	10,856	12,430
MANUFACTURED					
Artificial corundum (fused aluminum oxide)	do.	17,207	19,192	13,675	17,746
Silicon carbide, crude or in grains	do.	8,452	9,954	8,179	10,379
Other refined abrasives	do.	5,672	2,788	NA	NA
Grinding and polishing wheels and stones:					
Diamond	number of items	761	9,896	759	13,693
Polishing stones, whetstones, oilstones, hones, similar stone	do.	3,311	6,235	2,778	10,199
Wheels and stones, n.e.c	do.	777	1,075	904	2,042
Abrasive paper and cloth, coated with natural or artificial abrasive materials	kilograms	11,451	60,729	13,327	79,995
Metallic abrasives:					
Grit and shot, including wire pellets	do.	8,646	6,297	25,559	12,898
Total		XX	260,363	XX	270,928

NA Not available. XX Not applicable.

Source: Bureau of the Census.

TABLE 3

U.S. REEXPORTS OF ABRASIVE MATERIALS, BY KIND

(Thousands)

Kind		1989		1990	
		Quantity	Value	Quantity	Value
NATURAL					
Industrial diamond, natural or synthetic, powder or dust	carats	5,067	$10,734	2,325	$5,347
Industrial diamond, natural or synthetic, other	do.	1,234	19,603	1,250	14,700
Emery, natural corundum, pumice in blocks	kilograms	59	111	27	590
MANUFACTURED					
Artificial corundum (fused aluminum oxide)	do.	1,803	1,598	659	1,373
Silicon carbide, crude or in grains	do.	90	102	17	75
Grinding and polishing wheels and stones:					
Diamond	carats	9	299	18	376
Polishing stones, whetstones, oilstones, hones, similar stone	number	45	150	63	159
Abrasive paper and cloth, coated with natural or artificial abrasive materials	kilograms	584	1,174	592	1,879
Metallic abrasives:					
Shot grit, pellets, etc.	do.	XX	XX	90	46
Total		XX	33,771	XX	24,545

XX Not applicable.

Source: Bureau of the Census.

TABLE 4

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

(Thousands)

Kind		1989		1990	
		Quantity	Value	Quantity	Value
Silicon carbide, crude	metric tons	80	$45,439	66	$38,342
Aluminum oxide, crude	do.	78	34,529	83	38,623
Other crude artificial abrasives	do.	9	1,339	NA	NA
Abrasives, ground grains, pulverized or refined:					
Silicon carbide	do.	12	18,056	9	14,232
Aluminum oxide	do.	20	28,589	19	28,078
Emery, corundum, flint, garnet, other, including artificial abrasives	do.	4	4,078	17	6,207
Papers, cloths, other materials wholly or partly coated with natural or artificial abrasives	do.	20	105,414	21	118,618
Hones, whetstones, oilstones, polishing stones	number	2,300	1,786	1,956	2,296
Abrasive wheels and millstones:					
Burrstones manufactured or bound up into millstones	do.	701	4,597	1,132	4,309
Solid natural stone wheels	do.	1,404	2,592	482	1,428
Diamond	do.	508	13,143	702	16,395
Abrasive wheels bonded with resins	do.	6,076	25,880	6,406	28,159
Other		(2)	24,919	(2)	30,505
Grit and shot, including wire pellets	metric tons	4,168	3,428	7,346	4,982
Diamond, natural and synthetic:					
Natural industrial diamond stones	carats	6,232	34,610	8,568	40,426
Miners' diamond	do.	2,558	26,426	2,471	32,059
Powder and dust, synthetic	do.	49,466	36,637	73,150	51,976
Powder and dust, natural	do.	12,087	7,622	12,201	13,146
Total		XX	419,084	XX	469,781

NA Not available. XX Not applicable.

[1]Customs values.

[2]Quantity not reported.

Source: Bureau of the Census.

TABLE 5

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

Use		1986	1987	1988	1989	1990
Abrasives	metric tons	33,188	26,637	26,360	26,192	24,090
Value	thousands	$3,590	$3,089	$3,151	$3,172	$3,083
Filler	metric tons	67,048	71,160	68,618	63,080	56,468
Value	thousands	$8,588	$9,855	$9,876	$9,185	$11,041
Other	metric tons	W	W	W	W	W
Value	thousands	W	W	W	W	W
Total	metric tons	100,237	97,796	94,978	89,272	80,558
Total value	thousands	$12,178	$12,944	$13,027	$12,357	$14,124

W Withheld to avoid disclosing company proprietary data.
[1]Includes amorphous silica and Pennsylvania rottenstone.

1990 to a 10-year low of 24,089 tons; 1990 was the sixth consecutive year of decline. During the 6-year period, consumption declined about 35%. The average annual consumption of abrasive tripoli for the past 10 years was 30,810 tons, with a high of 37,024 tons in 1984 and a low of 24,089 tons in 1990. The 1990 consumption was the lowest since 1953, when only 22,680 tons was sold or used.

After 5 consecutive years of growth, from 1982 to 1987, the amount of tripoli used as a filler declined for the third consecutive year. The 10% decline in 1990 followed 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 60,953 tons per year, with a high of 71,160 tons in 1987 and a low of 50,180 tons in 1982. U.S. Bureau of Mines data show that tripoli use in the United States is greater as a filler than as an abrasive.

Prices

The average reported value of abrasive tripoli, sold or used, in the United States was $173.10 per ton. The average annual value reported for abrasive tripoli for the past 10 years was $103.44 per ton, with the high value in 1990 of $127.98 and the low in 1981 of $70.50. 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 the present was significantly lower than the annual rate of increase from 1981 through 1984.

The average reported value of filler tripoli, sold or used, in the United States was $195.53 per ton. The average annual value for the past 10 years was $125.06 per ton, with a high of $195.53 per ton in 1990 and a low of $85.06 per ton in 1981. The value increased at an annual compounded rate of 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. Manufacture of these products was from novaculite, quartzite, or other microcrystalline quartz rock.

Production

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

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

The production of oilstones, hones, whetstones, files, and grindstones increased about 19% in quantity from the 10-year low of 1989 to 450 tons and 13% in value to $6.2 million. The average annual production of the products for the past 10 years was 509 tons, with a high of 647 tons in 1982 and a low of 378 tons in 1989. The average value of annual production for the past 9 years was $5.8 million, with a high of $7.4 million in 1987 and a low of $3.8 million in 1983. In the past 10 years, two distinct and different trends in the value of production appeared. One was from 1980 through 1984, when the average value of production was $4.1 million per year. The other was 1985 through 1990, when the value of production was 68% greater at an average value of $6.9 million per year. During 1985-90, the average annual quantity of production was less than the 10-year average, 467 tons versus 509 tons. During the same period, the average annual value of production was 19% greater than the 10-year average. The change in average annual value was the result of a significant increase in the value per ton of manufactured products, starting in 1985.

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

Arkansas accounted for 99% of the value and 97% of the total quantity of special silica stone products reported as sold or used by U.S. producers.

TABLE 6

SPECIAL SILICA STONE FINISHED PRODUCTS SOLD OR USED BY PRODUCERS IN THE UNITED STATES[1]

Year	Quantity (metric tons)	Value (thousands)
1986	463	$6,520
1987	598	7,367
1988	371	5,415
1989	377	5,459
1990	450	6,328

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

TABLE 7

PRODUCERS OF SPECIAL SILICA STONE PRODUCTS IN 1990

Company and location	Type of operation	Product
Arkansas Abrasives Co.: Hot Springs, AR	Stone cutting and finishing	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
Buffalo Stone Corp.: Hot Springs, AR	Tumbling and sizing novaculite	Metal finishing media and deburring media.
Cleveland Quarries Co.: Amherst, OH	Stone cutting and finishing	Grindstones.
Do.	Quarry	Crude silica stone.
Dans Whetstone Cutting Co., Inc.: Royal, AR	Stone cutting and finishing	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
(Gomance) Operations: Parrin, AR	do.	Do.
Halls Arkansas Oilstones, Inc.: Pearcy, AR	Stone cutting and finishing	Whetstones and oilstones.
Hiram A. Smith Whetstone Co., Inc.: Hot Springs, AR	do.	Do.
Do.	Quarry	Crude novaculite.
Ed Kramer & Sons: Plain, WI (inactive)	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.: Hot Springs, AR	do.	Do.
Taylor Made Crafts, Inc.: Lake Hamilton, AR	do.	Do.
Wallis Whetstone: Malvern, AR	Quarry	Crude novaculite.

TABLE 8

TYPES OF ARKANSAS STONES

Trade name	Use
Black Hard Arkansas Stone	Polishing the most perfect edge possible.
Hard Arkansas Stone	Polishing blade to a very fine edge.
Soft Arkansas Stone	General purpose.
Washita Stone	Rapid sharpening.

Consumption and Uses

The domestic consumption of special silica stone products resulted from a mixture 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 wood carving, gun engraving, jewelry making, and other engraving work. The estimated value of U.S. apparent consumption was $1.3 million.

Prices

The value of crude novaculite suitable for cutting into finished products varied from a low of $0.33 per kilogram to as much as $2.75 per kilogram. 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 $39 per ton to more than $300 per ton. The average value in 1990 of oilstones, hones, whetstones, and grindstones, sold or used by U.S. producers, was $13,861 per ton or about $13.86 per kilogram. The average annual value of the same items for the past 9 years was $11,367 per ton, with a high of $14,443 per ton in 1989 and a low of $6,411 per ton in 1984. In the past 9 years, the unit value of special silica stone products followed two distinct negative trends with a significant increase in 1989 and 1990 indicating what may be the start of another negative trend. The first trend, a gradual decrease, occurred during the period 1980–84. The value per ton averaged $7,227, with a high of $8,284 and a low of $6,411. The lowest value occurred 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. 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. Because the special silica stone products industry is not high technology, new products can be duplicated by competitors. This very quickly results in short-term price pressures.

Foreign Trade

The value of exported special silica stone products was $6.2 million, an increase of 148% compared with that of 1988. The average annual value of exports for the past 10 years was $2.7 million, with a 10-year high of $6.2 million in 1989 and a low of $2.0 million in 1987. The annual value of exports during the past 10 years did not appear to have established a trend. Instead, the value drifted between $2.0 million and $2.6 million with as many increases as decreases until the significant increase in 1989.

The value of imported products was $1.8 million, an increase of 13% compared with that of 1988, but essentially the same compared with those of 1985

and 1986. The average annual value of imports for the past 10 years was $1.2 million, with a high of $1.8 million in 1985 and 1989 and a low of $0.3 million in 1980. 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 1989, the trade surplus in special silica stone products was $4.4 million, an increase of about 389%. During the past 10 years, the United States has enjoyed an average trade surplus of $1.5 million per year, with a high of $4.4 million in 1989 and a low of $0.4 million in 1985. The trend for the past 10 years has been one of declining surpluses until the significant increase in 1989. The average annual surplus for the previous 4 years had been only $0.6 million or about 40% of the 10-year average.

GARNET

High-quality U.S. industrial garnet is a mixture of almandite and pyrope that, when under pressure, breaks into sharp chisel-edged plates. Industry uses this garnet as an abrasive powder and to manufacture coated abrasives. Low-quality industrial garnet found uses primarily as airblasting or hydroblasting media and as filtration media.

Background

Definitions, Grades, and Specifications.—Garnet is a general name for a family of complex silicate minerals having similar physical properties and crystal form, the most common being the magnesium-aluminum silicate (pyrope) and the iron-aluminum silicate (almandite). Almandite is the most important type of industrial garnet. It ordinarily has a hardness of 7.5, an average specific gravity of 4, and a melting point of 1,315° C. It has a color of various shades of red, a chemical composition of $Fe_3Al_2(SiO_4)_3$, and a cubic crystal structure.

Each domestic producer has distinctive products. The Barton Mines Corp. 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. The NYCO and International Garnet Abrasive garnet is a mixture of andradite and grossularite, and the crude garnet concentrate may contain diopside-hedenbergite ($Ca[MgFe]Si_2O_6$). The Idaho garnet is an alluvial material with rounded small-to-medium grains.

Consumers purchase crushed, ground, and graded-to-size material depending on the intended end use. The sale of garnet for sandblasting and water filtration is by screen size. Some popular mesh sizes are minus 7 plus 12, minus 7 plus 20, minus 20 plus 40, minus 30 plus 50, minus 50 plus 94, and minus 120 plus 230.

Descriptions of testing methods for materials to be used in coated abrasives manufacture are in American National Standards Institute (ANSI) Specification B74.18-1977[2] and other sources.[3] Data on other graded sizes are in ANSI Specification B74.12-1976.[4]

Industry Structure.—Currently, four firms produce garnet from five plants in three States. Barton Mines Corp., Warren County, NY, produced garnet for use in coated abrasives, glass grinding and polishing, and metal lapping. The NYCO Div. of Processed Minerals Inc., Essex County, NY, recovered garnet as a by-product 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 Inc., Clinton County, NY, produced garnet for use as blasting and filtration media. Emerald Creek Garnet Milling Co. continued to operate six mining operations, two jigging plants, and a single mill in Benewah County, ID. Blasting and filtration media were the primary uses of the garnet. International Garnet Abrasives also operated its garnet reclaiming plant in Jefferson Parish, LA. The petroleum industry used the garnet as blasting media. 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.[5] 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.[6]

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

Geology-Resources.— Members of the garnet group are common accessory minerals in a large variety of rocks, including granites, gneisses, schists, marbles, serpentine, and peridotite. The geographical areas in which it may be found are enormous both in extent and in number. Commercially attractive industrial garnet occurrences are not common. Many garnets that occur in deposits of economic size degrade during processing because of internal stresses. These stresses developed in the garnet crystal during formation and cooling. Stress relieving is not economical; therefore, these deposits have no commercial value as a high-grade abrasive material source.

The best abrasive garnets are of the almandite variety, but andradite, grossularite, and pyrope also are used. All varieties of garnet have been mined for gem stones.

The garnet occurrence near Rangeley, ME, is very unusual. Some classify the host rock as metamorphic, but others, as igneous. The ore exhibits characteristics of both classifications. Because it has a very high garnet content, 50% to 80%, some geologists argue that the ore is a garnet granofel of metamorphic origin. Others contend that the ore is igneous in origin because of the lack of foliation and other textural considerations. In any case, the rock is similar to granite, an igneous rock, except that garnet crystals replace the quartz crystals, a major constituent of granite.

New York and Maine have the only known high-quality garnet reserves in the United States. 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. Other similar deposits occur in the area. The estimate of reserves in the igneous rock deposit near Rangeley, ME, are more than 1.8 million tons of garnet. 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 Milling Co. deposits.

There can be little doubt that tremendous reserves of garnet similar to the lower priced materials can be located as needed.[7] Also, the production of byproduct garnet from many current mining operations is possible if demand improved.

Reserves are significant in Australia, India, and the U.S.S.R., but accurate data are not available. Huge inferred and undiscovered resources are likely to exist throughout the world.[8]

***Technology.*—Mining.**—At the Barton Mine in New York, garnet occurs in a metamorphosed igneous rock. The Ruby Mountain ore body covers approximately 4.1 hectares, which is nearly the entire mountain. The estimated total depth of the deposit is 50 to 60 meters. The ore benches in the mine are about 9 meters high. A drop ball breaks the large pieces, and power shovels load trucks to haul the ore to the crusher at the mill, about 0.4 kilometer away.

At Emerald Creek and Carpenter Creek, Benewah County, ID, stripping from 1 to 2 meters of overburden exposes the garnetiferous gravel. Mining is accomplished with a dragline dredge.

Wollastonite mining at Willsboro, NY, produces a byproduct concentrate containing garnet, diopside-hedenbergite, and minor amounts of wollastonite. The ore at the NYCO mine contains 60% wollastonite, 30% garnet, and 10% diopside. After blasting and loading, the ore is transported 22 kilometers to the plant for separation of the wollastonite from the garnet-diopside.

Beneficiation.—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.[9]

At Barton Mines Corp., separation of garnet from other minerals is by combinations of crushing and grinding, screening, tabling, flotation, magnetic separation, water sedimentation, drying, heat treating, and air separation. Sometimes the same process will do both sizing and removal of gangue minerals, but usually it requires consecutive processes. Particle size control is difficult.

At Emerald Creek, sizing of the garnetiferous gravel is by trommeling and then treatment with jigs and concentrating tables. The garnet concentrate is dried, crushed, and screened. The maximum product grain size is 46 millimeters.

At NYCO, the processing and beneficiation of the wollastonite-garnet ore involves two stages. The first stage includes drying, crushing, screening, and recrushing the feed to minus 16 mesh. In the second stage, the minus 16-mesh raw material passes over a battery of screens to attain minus 16-, minus 20-, minus 40-, and minus 60-mesh splits. Then a battery of magnetic separators removes the garnet fraction from these splits. The final product includes four sizes bagged for shipment.

Annual Review

***Production.*—**The United States continued to be the largest garnet producer and consumer, accounting for about 45% of the world's production. Four domestic producers operated five plants, three in New York and one each in Idaho and Louisiana.

In 1990, the quantity and value of crude garnet concentrates produced were 47,009 tons worth $8.3 million, a 10% increase in quantity and a 89% increase in value. The average annual production for the past 10 years was 33,485 tons, with a high of 47,009 in 1990 and a low of 23,089 in 1981. During the past 10 years, production increased about 104%, or at an annual compounded rate of about 8.5% per year. The production trend for the past 10 years has been one of continued long-term growth with occasional downward adjustments.

***Consumption and Uses.*—**In 1990, the quantity of garnet sold or used by producers was 45,934 tons, an increase of 11%, and the value increased about 19% to $11.7 million. The average annual quantity of garnet sold or used for the past 10 years was 32,158 tons, with a record high of 45,934 tons in 1990 and a low of 23,150 tons in 1981. The trend for the past 10 years was one of steady annual growth, except for 4% decreases in both 1981 and 1984. The growth rate averaged about 8% compounded annually.

Much of the growth in the use of garnet was the result of new regulations. These regulations established new limits on leachable minerals and free silica content in hydroblasting and airblasting media. These changes made garnet the preferred blasting media in some work environments.

The major industrial use for high-quality, high-value garnet since before 1880 has been as material for free-abrasive machining in such applications 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. Demand for this use 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

TABLE 9

GARNET SOLD OR USED BY PRODUCERS IN THE UNITED STATES

Year	Quantity (metric tons)	Value (thousands)
1986	28,899	$6,748
1987	35,812	7,744
1988	41,896	11,144
1989	41,320	9,768
1990	45,935	11,759

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 $178, a 73% increase compared with the 1989 average. The average value for the past 10 years was $105 per ton, with a high of $178 in 1990 and a low of $88 per ton in 1986. During the past 10 years, the trend for the value of crude concentrates was one of general increase with decreases in some years. The 1990 value was 100% of the 1981 value.

In 1990, the average value per ton of garnet sold or used was $255, an increase of 8% from that of 1989. The average value for the past 10 years was $232 per ton, with a high of $266 in 1988 and a low of $216 per ton in 1987. The price trend of garnet sold or used during the past 10 years has been one of stable prices with very minor changes, except the 23% increase from 1987 to 1988.

Foreign Trade.—Garnet exports, as reported to the U.S. Bureau of Mines, by producers were about 10,000 tons, essentially the same as those for 1989. 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 3 years. Before 1987, the U.S. Bureau of Mines estimated garnet exports. Trend analysis beyond the past 4 years would be of limited value because of the large number of estimates included with the data. According to reports by producers, exports increased significantly during the past 10 years.

Mineral brokers and other garnet importers reported to the U.S. Bureau of Mines about 5,000 tons of imported garnet, unchanged from that of 1989. 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 4 years, showed a significant increase in garnet imports each year. The United States was a net exporter of garnet in 1990; exports exceeded imports by 200%.

World Review.—The United States was the dominant world producer and consumer of garnet, accounting for approximately 47% of the estimated world output and nearly 40% of estimated world consumption. Target Mines Ltd. continued to produce at near capacity from its Australian garnet sand operation. During 1989, Target sold a 50% interest in the operation to Barton Mines, a U.S. garnet producer. The Chinese mines continued to increase production of garnet for the export market. Yet, to date the quality of the garnet routinely has not met requirements for the U.S. market. Two mineral-sand mining operations in India continued to produce garnet as a byproduct of mineral sands production. Samples of the garnet were tested for applications in the United States, but to date the major market for the Indian garnet has been Japan. Norway, Turkey, and the 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. Currently, the industry is operating at or near capacity. If capacity can be added, production and consumption will increase to approximately 60,000 tons per year by 1996. If garnet were not available, other abrasives could be used in its place, but in many cases with some sacrifices in work volume, quality of work, or cost.

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

TABLE 10

WORLD GARNET ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990[1]

(Metric tons)

Country	Capacity
North America:	
United States	63,503
Europe:	
Norway	7,257
Turkey	635
U.S.S.R.	907
Total	8,800
Asia:	
China	18,144
India	27,216
Sri Lanka	91
Total	45,450
Oceania:	
Australia	14,515
Others	907
World total	133,175

[1]Includes capacity at operating plants as well as plants on standby basis.

EMERY

Emery is an impure corundum containing magnesium-aluminum silicates. Its uses include use 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 1990. The U.S. production of emery increased about 100% in quantity and value compared with those of 1989. Production from the historical emery producer near Peekskill in Westchester County, NY, stopped in 1988. The emery mine was sold to a firm that converted the mine into a crushed stone quarry.

Consumption

The Bureau estimated that the United States consumed approximately 10,000 tons of emery in 1990. 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 1990, nor has it exported emery 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 exports and reexports in mineral group categories; thus, exact data on emery are not available. The Bureau of the Census also reports emery imports in a mineral group category; therefore, data on emery imports are not available.

World Review

Turkey was the world's largest producer of emery. The second largest producer was Greece.

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 8% in quantity and 10% in value compared with those of 1989.

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 1990, shipments of staurolite increased 16% in tonnage and 13% in value compared with those of 1989. 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 gem stone 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. Or it may be a synthetic diamond that is tailormade for industrial applications.

Background

Definitions, Grades, and Specifications.—Natural industrial diamond is diamond that, because of color, structure, size, or shape, is unsuitable for use as gem stones. 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.[10]

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,[11] ANSI Specification B74-20-1981,[12] and by a proposed standard developed by the Industrial Diamond Association[13] for sub-sieve 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 manufacturer of diamond at its Schenectady, NY, laboratories. Commercial production started in 1957 at its plant in Detroit, MI. In 1969, production moved to Worthington, OH. In 1959, De Beers Consolidated Mines Ltd. announced the manufacture of industrial diamond at its laboratory in Johannesburg, Republic of South Africa. Since these two announcements, the production of synthetic diamond by General Electric, De Beers, and others continued to increase. Today it exceeds the production of natural diamond worldwide about five times.

Geology.—The major source of in-place diamond is kimberlite, an altered, 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 assume a dikelike habit. The diamond may contain inclusions of many minerals, and many of these minerals have inclusions of diamond. These accessory minerals include olivine, garnet, diopside, ilmenite, magnetite, rutile, and phlogopite. Every mine has some diamond that is typical of it, but most diamond is indistinguishable from that of other mines.

Currently, approximately 40% of diamond is from alluvial deposits. These may be alluvial placers, recent or elevated marine beach placers, or glacial deposits. Often the distance of transport has been great. In many areas, the diamond-bearing, alluvial placers were deposited in former drainage systems unrelated to any present system.[14]

***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[15] 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.[16]

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.[17] 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 is 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.[18]

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.[19]

Annual Review

Government Programs.—The National Defense Stockpile (NDS) for industrial diamonds, as of December 31, 1990, had a goal of zero carats and an inventory of 19.0 million carats for crushing bort. The goal for industrial stones was 7.7 million carats, and the inventory was 7.78 million carats. There was 2.98 million carats of sales of crushed and crushing bort diamonds from the stockpile during 1990. There is currently legislative authority for disposal of 5,000,000 carats of bort and 2,400,000 carats of industrial stones, but there were no disposals of stones during the year. The inventory of small diamond dies was 25,473 pieces compared with a goal of 60,000 pieces; but, no purchase authorization was issued.

Production.—The United States was the largest producer of synthetic industrial diamond. This has made the United States independent of foreign sources for crushing bort or similar diamond except the grit sizes larger than about 20 mesh. Having no production of natural diamond, it was dependent on other countries for its natural diamond supply.

Three domestic firms produced synthetic industrial diamond in the United States: Du Pont Industrial Diamond Div., Gibbstown, NJ; General Electric Co., GE Superabrasives, Worthington, OH; and Megadiamond Industries Inc., a subsidiary of Smith International Inc., Provo, UT. A fourth company, U.S. Synthetics Corp., Orem, UT, manufactured polycrystalline diamond from purchased synthetic diamond grit. U.S. Synthetics had the capability to manufacture synthetic industrial diamond grit, but chose not to for economic reasons. Publishing production data would disclose company proprietary data. Domestic production did increase significantly. The United States continued to be the largest single producer of synthetic industrial diamond, a role it has enjoyed since 1957. During the past 10 years, production increased at an average rate of 9% compounded annually.

U.S. secondary production of industrial diamond was from six firms. They were 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 6.4 million carats from used drill bits, diamond tools, and wet and dry diamond-containing waste, an increase of 78% compared with that of 1989.

Consumption and Uses.—The United States continued to be the largest single consumer of industrial diamond. The U.S. Bureau of Mines estimate of apparent consumption of industrial diamond was approximately 86 million carats, an increase of about 19% compared with 1987 consumption. Average annual consumption for the past 10 years was about 55.7 million carats. During this period, two different trends for consumption occurred. The average annual consumption for 1979–83 was about 37.5 million carats, whereas that for 1984–88 was 97% greater or about 73.9 million carats. The second trend was the result of the strong movement to industrial diamond in the U.S. manufacturing sectors. This was because of the economic advantages in removing material and finishing surfaces using industrial diamond and diamond tools and wheels. Additionally, the continued economic growth of the U.S. industrial sector affected demand.

Diamond is far harder than any other natural or artificial abrasive material. So it was essential for some uses and much more efficient than other abrasives for many others. The primary uses for industrial diamond stones were in drilling bits and reaming shells, single- or multiple-point tools, saws, and wiredrawing dies. Miscellaneous uses for stones include engraving points, glasscutters, bearings, surgical instruments, hardness testers, radiation counters, and other instruments and special tools.

Mineral, oil, and gas exploration were the primary uses of drilling bits and shells. Foundation testing for dams, buildings, and other construction also used diamond bits and shells, as did masonry drilling in buildings for conduits and access and testing of concrete in various structures and other similar applications. The primary uses of diamond tools were for dressing and trueing grinding wheels and for cutting, machining, boring, and finishing. Beveling glass automobile windows also was a use. Cutting dimension stone, ceramics, and concrete in highway reconditioning were the major uses of diamond saws. The forming of refractory shapes for furnace linings also uses diamond saws. Diamond wire dies were essential for high-speed drawing of fine wire, especially from hard, high-strength metals and alloys.

Diamond grit, powders, and fragmented bort go into diamond grinding wheels, saws, impregnated bits and tools, and loose abrasives compounds for lapping and polishing.

Three major types of grinding wheels were made—resinoid, metal, and vitrified bonds—in many shapes and sizes designed for specific applications. The sizes range up to 1 meter in diameter for very large industrial wheels. Sharpening and shaping of carbide machine tool tips, grinding of dies, edging of plate glass, and optical grinding were among the primary applications of diamond grinding wheels. The cutting of concrete, stone, ceramics, and composite materials were uses of saws made with diamond grit. Very fine saws sliced wafers from brittle metals and crystals for use in electronic and electric devices.

Finishing optical surfaces, jewel bearings, gem stones, 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.

Changes in technology and conventional wisdom resulted in an increased use of synthetic industrial diamonds and polycrystalline diamond shapes (PDS) and compacts (PDC) for many of the uses listed above. In the past 3 years, the use of PDS, PDC, and matrix set synthetic diamond grit increased in drilling bits and reaming shells. The manufacture of single- and multiple-point tools use PDS and PDC. Many manufacturers of diamond wire-drawing dies use PDC. Diamond saws, diamond wheels, and diamond abrasive grit and powder still are made almost exclusively from synthetic diamond.

Prices.—The U.S. Bureau of Mines does not collect price data on industrial diamonds. The Bureau did track the average import value of various classifications of industrial diamonds. The average value of U.S. imports of natural grit and powder, synthetic grit and powder, and industrial stones was $0.63 per carat, $0.74 per carat, and $6.94, respectively. The average annual value of imported natural grit and powder for the past 10 years was $1.64 per carat. The high value was $2.86 in 1980 and the low was $0.82 in 1988.

The average value of natural grit and powder, in current dollars, declined every year since 1980. The 1980 average value was 425% greater than that of 1988.

The average annual value of imported synthetic grit and powder for the past 10 years was $1.49 per carat. The high value was $1.86 per carat in 1981 and the low was $1.08 in 1988. The average value of imported synthetic grit and powder decreased every year since 1981. The 1988 value declined 72% compared with 1981, while the decline from 1987 to 1988 was only about 7%. During the past 10 years, a major change occurred in the relationship of the average value of natural grit and powder to the average value of synthetic grit and powder. In 1979, natural grit and powder average value was 49% greater than the average value for the synthetics. In 1988, the average value for the synthetics was 32% greater than that for natural material. Natural grit and powder declined in value at a much greater rate than did synthetic grit and powder. This made the synthetic material more valuable.

The average annual value of imported industrial diamond stones for the past 10 years was $10.26 per carat, with a high value of $13.93 in 1981 and a low of $7.24 in 1986. The trend for the value of industrial stones was mixed for the past 10 years. There was a small, 7%, decrease in the average value. The period started with 3 years of increasing values, followed by 3 years of decreasing values. Values the final 4 years were alternating decreases and increases. The 1988 average value was 4% less than the 1987 value, 50% less than the 1981 high, and 12% less than the 1979 value.

Foreign Trade.—The United States was the largest exporter of industrial diamond grit and powder in the world. The United States exported and reexported a record 74.5 million carats of natural and synthetic grit and powder. The material was worth a record $115.4 million. Additionally, the U.S. exported and reexported approximately 3.0 million carats of industrial stones, valued at $29.3 million.

Six countries received approximately 76% of the total U.S. exports of synthetic grit and powder. The countries and the percentage of exports they received were as follows: Japan, 27%; Federal Republic of Germany, 21%; Ireland, 8%; Italy, 7%; Belgium, 7%; and Republic of Korea, 6%. Six countries received about 74% of the total U.S. exports of industrial stones. The countries and the percentage of exports they received were as follows: Belgium, 24%; Ireland, 21%; Canada, 10%; Japan, 9%; France, 8%; and Federal Republic of Germany, 6%.

The average annual exports plus reexports of natural and synthetic grit and powder for the past 10 years was 44.0 million carats, with an average value of $81.3 million. The highest level of exports plus reexports during the past 10 years was 74.5 million carats valued at $115.4 million in 1988. The lowest was 27.8 million carats valued at $72.8 million in 1979. The trend of exports plus reexports for the past 10 years was one of continued growth. There was an increase of 168% during the period or an annual average compounded growth rate of 11.2%. The increase from 1987 to 1988 was about 31%, showing very strong growth at approximately three times the 10-year average.

The average annual exports plus reexports of industrial stones for the past 10 years were 2.9 million carats per year, and the average value was $33.3 million. The high was 3.6 million carats in 1986, and the low was 1.9 million carats in 1982. There was not a distinct trend for the past 10 years. Exports plus reexports of about 3.0 million carats were 18% greater than in 1987, but only about 9% higher than those in 1979. The 1987 exports plus reexports were 28% less in quantity than the 10-year high in 1986.

The average annual imports of natural diamond grit and powder was 7.3 million carats per year for the past 10 years. The high was 13.0 million in 1988, and the low was 3.3 million in 1982. Imports as measured in carats were about 7% less than those in 1988 and 235% greater than those in 1980. The trend for the quantity of natural grit and powder imported during the past 10 years was one of significant increases. Yet, during this period, the quantity of natural grit and powder decreased from 23% to 20% of total grit and powder imports. During 1989, four countries supplied 85% of U.S. imports of natural grit and powder: Ireland, 37%; U.S.S.R., 25%; Japan, 15%; and the United Kingdom, 8%. Only the U.S.S.R. was a producer of natural diamonds.

The average annual imports of synthetic diamond grit and powder was 26.8 million carats per year for the past 10 years. The high was 50.7 million carats in 1988, and the low was 10.9 million carats in 1981. Imports in 1989 were about 3% less than those in 1988 and 311% greater than those in 1980. The trend of synthetic grit and powder imports during the past 10 years was one of an early decline of about 8% over 2 years followed by continued strong growth until the slight decline in 1989. The average annual compounded growth rate for the 10 years was about 17%; but, the average annual compounded rate of growth from the low in 1981 through 1989 was about 21%. The level of imports in 1988 and 1989 indicated that the growth trend has begun to increase at even a greater rate. Three countries furnished 89% of the synthetic diamond grit and powder imported into the United States in 1988: Ireland, 74%; Japan, 11%; and Federal Republic of Germany, 4%.

The 10-year average for imports of industrial diamond stones was 6.9 million carats per year, with a high of 9.4 million in 1985 and a low of 3.9 million in 1987. Imports of industrial diamonds lacked a distinct trend during the period; the quantity imported in 1989 was about 42% greater than the quantity imported in 1980. The 1989 imports were about 27% greater than 1988 imports, but 1988 imports were less than the 10-year average. Four countries accounted for about 81% of the diamond stones imported into the United States during 1988: Zaire, 40%; United Kingdom, 22%; Belgium, 10%; and Ireland, 9%.

The United States was a net exporter of diamond grit and powder and a net importer of industrial diamond stones. The United States was a net exporter of

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF INDUSTRIAL DIAMOND (EXCLUDING DIAMOND DIES)

(Thousand carats and thousand dollars)

Year	Quantity	Value
1986	45,991	110,648
1987	48,877	95,559
1988	71,147	130,300
1989	70,342	105,295
1990	96,483	137,607

Source: Bureau of the Census.

TABLE 12

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)[1 2]				Miners' diamond, natural and synthetic (7102.21.1010 and .1020)[1 3]				Diamond powder and dust, synthetic (7105.10.0020; 0.0030 and 0.0050)[1 4]				Diamond powder and dust, natural (7105.1011 and 0.0015)[1 5]			
	1989		1990		1989		1990		1989		1990		1989		1990	
	Quantity	Value[6]	Quantity	Value[6]	Quantity	Value[6]	Quantity	Value[6]	Quantity	Value[6]	Quantity	Value[6]	Quantity	Value[6]	Quantity	Value[6]
Australia	7	108	17	23	56	98	(7)	3	29	33	6	30	—	—	11	15
Belgium-Luxembourg	123	1,927	104	2,728	35	1,111	13	290	950	682	947	2,265	231	183	1,145	2,485
Canada	3	12	1	1	(7)	4	1	7	127	81	385	251	85	33	8	20
China	2	2	48	46	1	8	—	—	634	308	620	432	—	—	91	14
France	3	474	—	—	6	18	(7)	34	2	4	—	—	—	—	—	—
Germany, Federal Republic of	17	119	1	48	2	2	51	628	1,173	581	2,502	511	260	229	440	873
Ghana	246	3,221	708	6,789	104	918	7	349	1	2	22	23	4	5	145	1,283
Greece	—	—	—	—	—	—	—	—	164	924	92	30	—	—	—	—
Hong Kong	(7)	215	13	100	10	281	—	—	55	59	685	236	15	23	—	—
Ireland	901	3,219	—	—	1,749	5,488	1,932	5,067	29,010	26,273	51,856	39,500	5,965	3,008	6,111	4,417
Israel	5	425	10	23	(7)	53	2	48	—	—	152	46	—	—	100	32
Italy	4	13	274	55	7	2	86	1,438	2,116	924	1,099	390	29	74	191	157
Japan	3	201	122	62	19	881	16	655	5,093	3,107	3,226	1,985	735	219	—	—
Mexico	—	—	5	397	2	14	2	12	—	—	—	—	—	—	—	—
Netherlands	6	1,039	26	1,723	15	1,406	35	1,332	—	—	15	3	5	4	—	—
South Africa, Republic of	28	546	—	—	—	—	—	—	—	—	—	—	—	—	1	3
Switzerland	(7)	46	25	258	6	678	1	42	2,015	1,135	1,519	1,488	867	715	362	349
U.S.S.R.	20	68	—	—	—	—	—	—	3,794	1,192	6,781	2,174	1,380	496	1,846	508
United Kingdom	949	9,648	1,319	14,039	322	11,431	223	16,303	1,349	879	974	1,141	1,566	1,470	1,141	2,238
Zaire	3,425	8,512	5,695	8,520	192	3,331	102	5,459	(7)	4	106	195	795	1,096	698	681
Other	490	4,815	200	5,614	22	702	2	392	2,954	449	2,163	1,276	149	67	2	71
Total	6,232	34,610	8,568	40,426	2,558	26,426	2,473	32,059	49,466	36,637	73,150	51,976	12,086	7,622	12,292	13,146

[1]HTS codes.
[2]Formerly TSUSA No. 520.2900.
[3]Formerly TSUSA Nos. 529.1900 and 520.2340.
[4]Formerly TSUSA No. 520.2800.
[5]Formerly TSUSA Nos. 520.2000; 520.2020; 520.2040; 520.2060 and 520.2100.
[6]Customs value.
[7]Less than 1/2 unit.

Source: Bureau of the Census.

industrial diamond based on the total quantity and total gross value. The excess trade balance in industrial diamonds was about 6.4 million carats and $14.4 million.

World Review.—Botswana and the Republic of South Africa were the largest producers of good-quality industrial diamond stones. Australia and Zaire were the world's largest producers of natural industrial diamond and were the primary sources of natural crushing bort as well as substantial producers of industrial stones. Estimates suggest that the U.S.S.R. was the third largest producer of natural industrial diamond, but reliable data were lacking.[20] 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.[21] Total world output of natural industrial diamond in 1989 was approximately 51.8 million carats, a slight increase over that of 1988.

Angola.—Endiama, the state diamond company, signed a two-part agreement with De Beers' Central Selling Organization that reestablished a trading relationship that was ended in 1985. The first part of the agreement calls for De Beers to provide a $50 million loan to Endiama to be used to increase the production from the Cuango area. De Beers will market all of the production from the Cuango area, which accounts for about 80% of Angola's production.

The second part of the agreement calls for De Beers to spend $50 million over 5 years on the evaluation of the Camutue kimberlite in northeastern Angola and looking for additional kimberlite sources of diamonds. Any sources found will be jointly developed by De Beers and Endiama, according to the terms of the agreement.

TABLE 13

WORLD INDUSTRIAL DIAMOND ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990, RATED CAPACITY[1]

(Carats)

Country	Capacity	
	Natural	Synthetic
North America:		
United States	—	100,000,000
South America:		
Brazil	1,250,000	—
Guyana	10,000	—
Venezuela	600,000	—
Total	1,860,000	—
Africa:		
Angola	200,000	—
Botswana	5,000,000	—
Central African Republic	200,000	—
Ghana	750,000	—
Guinea	25,000	—
Liberia	200,000	—
Namibia	100,000	—
Sierra Leone	100,000	10,000
South Africa, Republic of	8,000,000	60,000,000
Tanzania	100,000	—
Zaire	30,000,000	—
Total	44,675,000	60,010,000
Europe:		
Czechoslovakia	—	5,000,000
France	—	4,000,000
Greece	—	1,000,000
Ireland	—	90,000,000
Romania	—	5,000,000
Sweden	—	25,000,000
U.S.S.R.	8,000,000	70,000,000
Yugoslavia	—	5,000,000
Total	8,000,000	205,000,000
Asia:		
China	800,000	60,000,000
India	5,000	—
Indonesia	30,000	—
Japan	—	3,000,000
Total	835,000	63,000,000
Australia	25,000,000	—
World total	80,370,000	428,010,000

[1]Includes capacity at operating plants as well as plants on standby basis. Rated capacity based on 340-day-per-year effective operation.

Endiama also signed an agreement with Steinmetz Evens Diamonds for the sale of diamonds produced in the Andrada and Lucapa areas. The alluvial deposits of these areas are nearly depleted and are of little interest to De Beers.[22]

Australia.—Diamond production in Australia decreased slightly because of a decrease in the production from Argyle. Argyle produced 33.8 million carats compared with a 1989 production of 34.4 million, a decrease of about 2%. Estimates of 1990 Bow River production are about 900,000 carats.

More than 90 companies are involved in diamond projects in Australia, with another 23 companies exploring for diamonds on offshore projects. The success of the Argyle mine and reassessment of the old information has led to the latest rush concentrated in New South Wales, with some companies in northern New South Wales claiming to have discovered pipes larger than that at Argyle.

Botswana.—Corona Corp. agreed to acquire control of Repadre Capital Corp., and the new firm will be named Corona Diamonds International Corp. Repadre had agreed to a joint venture with Ampal (Pty.) Ltd. to develop Ampal's diamond licenses in Botswana. Ampal holds multiple prospecting licenses covering about 20,700 square kilometers upon which a number of kimberlites have been identified. Exploration drilling is scheduled to start on 30 to 50 of these targets. Corona Diamonds could earn a 40% interest in the properties by spending about $1.75 million before December 31, 1991.

Canada.—Uranerz Exploration and Mining of Canada reported finding two diamonds, one 2 millimeters and the other 4 millimeters, near Melfort in the area of Fort a la Corne. These diamonds are significantly larger than the microdiamonds found in the past. Microdiamonds have been found in the area by other companies, including Claud Resources and Monopros Ltd., a subsidiary of De Beers. None of the companies exploring in the area has yet to discover a commercial deposit of diamonds, but these larger stones increase the interest of the companies exploring the area. Uranerz plans to spend $2 million on exploration in the area in the next 2 years.

China.—The Mineral Resources Bureau reports that geologists discovered 13 diamond deposits along the Tanlu Fault Zone, which stretches across several Provinces in the eastern part of the country. The Bureau claims to have found more than 100 kimberlites and 4 diamond placers in Shandong Province, and in Liaoning Province, it has found

3 large primary deposits and 3 smaller placer deposits.

Guinea.—Currently, at least four companies are either exploring for or mining diamonds in Guinea. Aredor, the company with the longest history in diamond operations in the country, is experiencing a decline in production and in profits. The decline in production is because of decreasing ore grades. The decreasing profit is because of a combination of lower diamond production and a lower sales price for diamonds. The 1990 average sales price for Aredor's diamonds was down 19% to $245 per carat.

Star Diamonds has a prospection license 30 kilometers to the south and east of the Aredor lease. The alluvial deposits that are of the most interest are those on the flats near Bouro and those at the headwaters of the Bouloumba.

Sidam-Minorex is exploring in an area for diamonds near Forecariah, east of Conakry, and Hydro Mineral Exploration is exploring for diamonds near Bounoudou.

Brigade Aurifere de Guinee has a concession to mine gold in an area north of the Aredor lease in which diamonds may be also found.

Indonesia.—Development of the Danau Seran diamond project in southeast Kalimantan began in late 1990. Dry mining and a conventional diamond recovery plant will be used in place of a dredge. This approach is cheaper and easier to finance. The Danau Seran contains about 2.9 million cubic meters of diamondiferous gravel with a grade of greater than 0.1 carat per cubic meter. The deposit will be mined during the next 3 years at a production rate of 72,000 cubic meters per month. The group that put up the $2 million in financing will control a 25% equity interest. The interests of Indonesian Diamond Corp. (formerly Acorn Securities) and Keymead have been reduced to 44.7% and 10.3%, respectively, with PT Aneka Tambang (Indonesian Government) holding the remaining interest.[23]

Sierra Leone.—The Government of Sierra Leone granted a 20-year concession to Sunshine Mining Co. of the United States to mine and market diamonds from the Kono kimberlite deposit. Exploration and development work to date indicates the deposit contains about 2.4 million carats of recoverable gem-quality diamonds. Sunshine estimated the project capital costs at about $54 million.

The Government of Sierra Leone granted a lease to Intertrade Prospecting, a Swedish firm, to mine diamonds in an area north of Freetown. The firm announced plans to spend about $3 million dollars on deposits that reported to be of marginal viability.

Wildcat Holdings PLC, a wholly owned subsidiary of Pioneer Resources, entered into an agreement with Xerxes Ltd. to explore for diamonds in the Baoma district. The area is believed to contain both alluvial and kimberlite diamond deposits.

South Africa, Republic of—The De Beers Mine, the smallest of the four mines De Beers Consolidated Mines Ltd. operates in Kimberley, is scheduled to close in October 1990. Treatment of surfaces stockpile ore at the mine will continue well into 1991. The mine was discovered in 1871 and operated as an open pit mine until 1885, at which time underground operations were started. The mine closed in 1908 and remained closed until opening once more in 1960 and operating until 1990.[24]

Tanzania.—The Government of Tanzania and Tanex Ltd., a company associated with De Beers Centerary AG, concluded an agreement to explore for diamonds over a large area south of Lake Victoria and to the south and west of the Williamson Mine. Exploration in the past has discovered several kimberlites that contained diamonds, but none were economical to mine.

U.S.S.R.—Reportedly, the U.S.S.R. is considering a joint venture with unnamed Western concerns to open a new diamond mine and cutting factory. The mine would be on a deposit about 100 kilometers north of Archangel. Reports indicate that the deposit contains 50% gem-quality diamonds.

Zimbabwe.—De Beers was unable to reach agreement with the Government of Zimbabwe on the development of the River Ranch kimberlite deposit near the southern border at Beitbridge. The deposit was originally discovered in 1975. The Government of Zimbabwe was unwilling to grant De Beers' Central Selling Organization an exclusive marketing agreement. The Government wanted to market the production through its Minerals Marketing Corp., which would also retain a portion of the production for domestic processing. The Government has initiated procedures for the forfeiture of the River Ranch claims held by De Beers.

Outlook

Diamond grit and powder should experience substantial increases in domestic demand for every end use during the next 5 years. The increases for synthetic grit and powder are expected to be greater than for natural. The constant-dollar prices of these materials, especially the synthetic diamond products, should continue to decrease or at least remain constant. This is because planned production increases will make them more cost-effective. The contract construction industry is an area in which the greatest increases will occur. This is because large quantities of saw-grade diamond will be required for highway and bridge repair and replacement. Large increases also are expected in the dimension stone industry as a cutting and polishing media. The stone, clay, and glass industries will increase their uses in cutting, shaping, and polishing media. Additionally, polycrystalline synthetic diamond compacts and shapes will continue to displace natural diamond stone and tungsten carbide drill bits in the mineral services sector. The probable average annual growth rate in U.S. production is about 6%, based on estimates by the U.S. producers. U.S. production of synthetic material is sufficient to supply U.S. diamond grit and powder demand. The United States will continue to be a major exporter.

The major domestic end use for industrial stones in the next 5 years will continue to be in the oil, gas, and mineral industries. These stones are natural and cannot yet be manufactured commercially. Polycrystalline synthetic diamond compacts and shapes have had a major negative impact on the natural industrial diamond stone markets. This will limit the growth of U.S. demand for stone during the next 5 years. U.S. consumption should average between 6 and 7 million carats per year for the next 5 years. Approximately 50% of the potential natural stone applications will be replaced by the synthetic compacts and shapes by the year 2000.

MANUFACTURED ABRASIVES

Manufactured abrasives include fused aluminum oxide, silicon carbide, alumina-zirconia oxide, and metallic shot and grit. Production data for fused aluminum oxide, silicon carbide, and alumina-zirconia

TABLE 14

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

(Thousand carats)

Country	1986			1987			1988				1989				1990[e]			
	Natural			Natural			Natural			Synthetic[3]	Natural			Synthetic[3]	Natural			Synthetic[3]
	Gem[2]	Industrial	Total	Gem[2]	Industrial	Total	Gem[2]	Industrial	Total		Gem[2]	Industrial	Total		Gem[2]	Industrial	Total	
Angola	240	10	e250	180	10	e190	950	50	e1,000	—	r1,165	r80	r1,245	—	1,200	80	1,280	—
Australia	13,145	16,066	29,211	13,650	16,683	30,333	r17,413	r17,413	r34,826	—	17,540	17,540	35,080	—	17,331	17,331	4,34,662	—
Botswana	9,590	3,500	13,090	9,368	3,840	13,208	10,660	4,569	15,229	—	10,676	4,576	15,252	—	12,146	5,206	4,17,352	—
Brazil	310	315	625	r300	r200	r500	353	180	533	—	350	r150	r500	—	350	150	500	—
Central African Republic	259	99	358	304	108	412	284	59	343	—	r334	r81	r415	—	300	80	380	—
China[e]	200	800	1,000	200	800	1,000	200	800	1,000	15,000	200	800	1,000	15,000	200	800	1,000	15,000
Cote d'Ivoire[e 5]	10	4	14	15	6	21	8	3	11	—	r9	r3	r12	—	9	3	12	—
Czechoslovakia[e]	—	—	—	—	—	—	—	—	—	5,000	—	—	—	5,000	—	—	—	5,000
France[e]	—	—	—	—	—	—	—	—	—	4,000	—	—	—	4,000	—	—	—	4,000
Ghana[6]	88	498	586	65	400	465	r155	r465	re620	—	r124	r370	re494	—	129	386	515	—
Greece[e]	—	—	—	—	—	—	—	—	—	1,000	—	—	—	1,000	—	—	—	1,000
Guinea[6]	190	14	204	163	12	175	136	10	146	—	138	10	148	—	130	5	135	—
Guyana	3	6	9	2	5	e7	1	3	4	—	r3	r5	r8	—	3	5	8	—
India	13	3	16	r16	r3	r19	r11	3	r14	—	3	r12	r15	—	3	12	15	—
Indonesia[e]	6	22	28	7	22	29	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	63	189	252	r112	r183	re295	67	100	167	—	r62	r93	r155	—	40	60	100	—
Namibia	970	40	1,010	971	50	1,021	901	37	938	—	r910	r17	r927	—	735	13	4748	—
Romania[e]	—	—	—	—	—	—	—	—	—	5,000	—	—	—	4,500	—	—	—	4,500
Sierra Leone[5]	215	100	315	150	75	225	r12	r6	r18	—	r90	r39	r129	—	100	50	150	—
South Africa, Republic of:																		
Finsch Mine	1,821	3,208	5,029	1,455	2,701	4,156	1,372	2,548	3,920	—	1,613	2,997	4,610	—	1,462	2,716	4,4,178	—
Premier Mine	882	1,977	2,859	772	1,713	2,485	696	1,543	2,239	—	689	1,526	2,215	—	724	1,604	4,2,328	—
Other De Beers' properties[7]	1,428	529	1,957	1,427	546	1,973	1,388	531	1,919	—	1,360	520	1,880	—	1,240	474	4,1,714	—
Other	342	41	383	409	30	439	361	65	426	—	348	63	411	—	400	74	4474	—
Total	4,473	5,755	10,228	4,063	4,990	9,053	3,817	4,687	8,504	e55,000	4,010	5,106	9,116	e60,000	3,826	4,868	4,8,694	60,000
Swaziland	23	16	39	48	32	e80	44	29	73	—	33	22	55	—	19	13	32	—
Sweden[e]	—	—	—	—	—	—	—	—	—	25,000	—	—	—	25,000	—	—	—	25,000
Tanzania[e]	133	57	190	105	45	150	105	45	150	—	105	45	150	—	105	45	150	—
U.S.S.R.[e]	r7,400	r7,400	r14,800	r7,400	r7,400	r14,800	r7,500	r7,500	r15,000	41,500	r7,500	r7,500	r15,000	41,500	7,500	7,500	15,000	41,000
United States	—	—	—	—	—	—	—	—	—	W	—	—	—	W	—	—	—	W
Venezuela	r46	r165	r212	r38	r68	r106	r54	r74	r128	—	r70	r185	r255	—	88	245	4333	—
Yugoslavia[e]	—	—	—	—	—	—	—	—	—	5,000	—	—	—	5,000	—	—	—	5,000
Zaire	4,661	18,643	23,304	3,885	15,540	19,425	r2,724	r15,439	r18,163	—	r2,663	r15,092	r17,755	—	2,700	15,300	18,000	—
Total[8]	r42,038	r53,702	r95,741	r41,042	r50,472	r91,514	r45,402	r51,494	r96,896	241,500	r45,992	r51,751	r97,743	246,000	46,921	52,175	99,096	245,500

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.

[1]Table includes data available through May 17, 1991. Total diamond output (gem plus industrial) for each country actually is reported except where indicated by a footnote to be estimated. In contrast, the detailed separate production data for gem diamond and industrial diamond are Bureau of Mines estimates in the case of every country except Australia (1986–87), Botswana (1987), Brazil (1987), Central African Republic (1986–89), Guinea (1986–89), and Liberia (1986), 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. Estimated distribution figures have been revised as necessary to correspond to reported total production figures.

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

[3]Includes all synthetic diamond production.

[4]Reported figure.

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

[6]Figures do not include smuggled artisanal production.

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

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

TABLE 15

CRUDE MANUFACTURED ABRASIVES PRODUCED IN THE UNITED STATES AND CANADA, BY KIND

Kind		1986	1987	1988	1989	1990
Silicon carbide[1]	metric tons	112	113	118	117	105
Value	thousands	$48,064	$48,790	$50,559	r$56,430	$51,336
Aluminum oxide (abrasive grade)[1]	metric tons	137	r151	205	195	185
Value	thousands	$50,584	r$56,393	$71,325	$81,785	$77,758
Aluminum-zirconium oxide	metric tons	W	W	W	W	W
Value	thousands	W	W	W	W	W
Metallic abrasives[2]	metric tons	189	198	222	224	224
Value	thousands	$75,210	$62,410	$88,114	$89,546	$89,113
Total[3]	metric tons	438	r462	r545	536	515
Total value[3]	thousands	$173,858	r$167,593	$209,998	$227,761	$218,207

r Revised. W Withheld to avoid disclosing company proprietary data.
[1]Figures include material used for refractories and other nonabrasive purposes.
[2]Shipments for U.S. plants only.
[3]Excludes U.S. and Canadian production and value of aluminum-zirconium oxide.

TABLE 16

CRUDE ARTIFICIAL ABRASIVES MANUFACTURERS IN 1990

Company	Location	Product
Washington Mills Electro Minerals (Canada) Corp.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular).
Washington Mills Electro Minerals (US), Corp.	Niagara Falls, NY	Fused aluminum oxide (high-purity).
The Exolon-Esk Co.	Hennepin, IL	Silicon carbide.
Do.	Thorold, Ontario, Canada	Fused aluminum oxide (regular) and silicon carbide.
General Abrasives, a division of Abrasive Industries Inc.	Niagara Falls, NY	Fused aluminum oxide (regular and high-purity).
Do.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular) and silicon carbide.
Norton Co	Huntsville, AL	Fused aluminum oxide (high-purity) and aluminum-zirconium oxide.
Do.	Worcester, MA	General abrasive processing.
Do.	Chippawa, Ontario, Canada	Fused aluminum oxide (regular and high-purity) and aluminum-zirconium oxide.
Do.	Shawinigan, Quebec, Canada	Silicon carbide.
Washington Mills Ltd.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular).

oxide were for the United States and Canada. Data for metallic shot and grit were for the United States only.

The fused aluminum oxide and silicon carbide industries underwent consolidation and reorganization during the year. Many of the changes were related to the purchase of the Norton Co., the world's largest producer of abrasives, by Campaign de Saint Gobain of France. Additional changes in the silicon carbide industry resulted from a closing of a Canadian plant for economic and environmental reasons and the construction of another unit of capacity at the single U.S. plant.

Fused Aluminum Oxide

Government Programs.—The NDS, as of December 31, 1990, contained 227,152 tons of crude fused aluminum oxide and 46,169 tons of abrasive-grain fused aluminum oxide. The NDS goal for abrasive-grain fused aluminum oxide is 340,000 tons. There is no NDS goal for crude fused aluminum oxide; it is held as an offset against the abrasive-grain goal.

Production.—At yearend, four firms were producing fused aluminum oxide at seven plants in the United States and Canada. Production of regular-grade fused aluminum oxide in 1990 was 164,226 tons, essentially unchanged from that of 1989. The average annual production for the past 10 years was 140,322 tons. The high was 172,157 tons in 1988, and the low was 105,893 tons in 1982. The production trend for the past 10 years was one of sharp decline, 27% in 3 years, followed by up and down years to full recovery. The 1990

production was 8% greater than that of 1981.

Production of high-purity fused aluminum oxide decreased 30% to 21,383 tons. The average annual production for the past 10 years was 21,155 tons. The high was 33,569 tons in 1981, and the low was 13,468 tons in 1982. The production trend for the past 10 years began with a very sharp decline, 60%, between 1981 and 1982. Then production swung between about 14,000 and 28,000 tons until the major increase of 82% in 1988, followed by 2 years of decline. The period ended with production 37% less than that of 1981. Total 1990 production of 185,479 tons was 5% less than 1989 production, 36% higher than the low of 119,361 tons in 1982, but essentially the same as that of 1981.

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 slightly in 1990, but were still only 78% of the 10-year high recorded in 1988. Total value of sales by individual end use were a mixture of increases and decreases. Sales for use in bonded abrasives were down, coated abrasives were down 22%, refractories increased 13%, tumbling media were up 15%, wiresawing abrasive were up slightly, polishing cake and buffing compounds were up 22%, antislip abrasives were down 21%, polishing abrasives were up slightly, and all other uses were up about 11%.

TABLE 17

WORLD FUSED ALUMINUM OXIDE ANNUAL PRODUCTION RATED CAPACITY,[1] DECEMBER 31, 1990

(Metric tons)

Country	Capacity
North America:	
United States and Canada	270,000
South America:	
Brazil	96,162
Europe:	
Austria	58,967
France	45,359
Germany, Federal Republic of	86,183
Italy	18,144
Spain	13,880
United Kingdom	63,503
Total	286,036
Eastern Europe:	
Hungary, Poland, U.S.S.R., and Yugoslavia	285,763
Asia:	
China	136,078
India	4,536
Japan	54,431
Total	195,045
World total	1,133,006

[1]Includes capacities of operating plants as well as plants on stand-by basis.

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 $394 per ton. The average annual value for the past 10 years was $363 per ton, with a high of $394 in 1990 and a low of $324 in 1988. In 1990, the average value of high-purity fused aluminum was $611, down 4% from the 1989 10-year high at $635 per ton. The average annual value of the past 10 years was $551 per ton, with a low of $476 per ton in 1988. The average value of all grades of fused aluminum oxide in 1990 was $419 per ton, essentially unchanged from the 10-year high in 1989. The average annual value for the past 10 years was $387 a ton, with a low of $348 in 1988. The trend for fused aluminum oxide values for the past 10 years was a general upward trend from 1981 to 1983, then a general downward trend from 1983 to 1988. The 1989 and 1990 average values increased about 21% compared with that of 1988 and 5% with that of 1981. Mineral price quotations in various December issues of trade magazines listed prices for regular-grade fused aluminum oxide of $832 to $925 per ton, while high-purity was quoted at $1,110 to $1,221 per ton.

Foreign Trade.—The quantity of exports plus reexports of fused aluminum oxide decreased 21% to 13,675 tons; the value of exports plus reexports decreased 8% to $17.7 million. The average value of 1 ton of fused aluminum oxide, exported or reexported, increased 16% to $1,294. During the past 10 years, exports plus reexports have averaged 14,360 tons per year, with an average annual value of $18.3 million and an average value per ton of $1,361. The largest quantity of material exported in a single year in the past 10 years was 26,638 tons in 1982, and the smallest amount was 9,915 tons in 1986. During the past 10 years, no trend developed in the export and reexport of fused aluminum oxide. Quantities increased and decreased randomly, and the period ended in 1990 with exports about 7% below those of 1981.

Imports increased about 4% in 1990 to 102,342 tons, and the value of imports increased about 6% from $62.8 million in 1989 to $66.7 million in 1990. Average annual imports for the past 10 years were 128,704 tons, with a high of 170,589 tons in 1981 and a low of 98,000 tons in 1989. The trend of fused aluminum oxide imports for the past 10 years was one of general decline throughout 1986, then stabilizing for 3 years at about 81% of the 1981 level. This was followed by a significant 32% decline in 1989 and the 4% increase in 1990.

World Review.—An Australian company and a Japanese partner announced plans for a high-purity fused alumina plant in Western Australia. The 10,000-ton-per-year plant would upgrade alumina into high-quality abrasive and refractory material. The project was fostered by the Ministry of Economic Development.

Silicon Carbide

Government Programs.—The NDS, as of December 31, 1990, contained 43,634 tons of silicon carbide; the goal was 26,364 tons. During 1990, the Defense National Stockpile Center of the Defense Logistics Agency disposed of 9,253 tons of silicon carbide at an average price of about $591 per ton for a total of $5,470,760. Existing legislation authorizes disposal of 17,384 tons in the future.

Production.—During 1990, four firms produced silicon carbide at six plants in the United States and Canada. At year-end, three firms were operating only four plants, one having closed during the third quarter of the year and another at the end of the third quarter. Production of abrasive-grade material increased slightly to a 10-year high of 54,339 tons. Average annual production for the past 10 years of abrasive silicon carbide was 46,620 tons, with a low of 36,193 tons in 1983. Production of metallurgical-grade silicon carbide decreased about

20% to 49,890 tons. Average annual production of metallurgical-grade silicon carbide for the past 10 years was 55,716 tons, with a high of 64,998 tons in 1988 and a low of 38,374 tons in 1983. Production of refractory and other grades of silicon carbide increased 4% from the 10-year low of 980 tons in 1989 to 1,022 tons. It was only 4% of the 1981 production, the high for the past 10 years. The average annual production of refractory and other grades of silicon carbide for the past 10 years was 11,059 tons, with a high of 25,903 tons in 1981. Total production of silicon carbide decreased 19% in 1990 to 105,251 tons, compared with a 10-year average annual production of 113,401 tons. The high was 141,442 tons in 1981, and the low was 98,973 tons in 1983. The 10-year production trend for all grades of silicon carbide was one of sharp decline, 30% in 3 years, and then slow growth and recovery through 1989 to 82% of the 1981 production level, followed by the 1990 decline.

Consumption and Uses.—Silicon carbide has a number of different end uses in the form of graded grain. The total value of sales of silicon carbide-graded grain for all uses decreased about 8% in 1990 and was only 81% 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 down, coated abrasives were up slightly, refactories decreased 14%, tumbling media decreased, wiresawing abrasive were up slightly, polishing cake and buffing compounds were up 20%, antislip abrasives were down slightly, polishing abrasives were up slightly, and all other uses were down.

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 $514; metallurgical-grade averaged $458; refractory- and other-grade material averaged $571; and the average value of all grades was $488. The average value per ton of abrasive-grade material for the past 10 years was $507, with a high of $626 in 1982 and a low of $436 in 1985. Metallurgical-grade silicon carbide averaged $432, with a high of $466 in 1983 and a low of $391 in 1988. Refractory grade was $545, with a high of $644 in 1988 and a low of $442 in 1986. For all grades the average was $468, with a high of $535 in 1982 and a low of $417 in 1985. The trend for the value of all grades of silicon carbide for the past 10 years was one of increase, 10% in 1 year, followed by a general decrease through 1985, then stabilization with 3 years essentially unchanged at 88% of the 1981 value. Then 1989 saw a significant increase of 13% compared with the average value of the past 3 years, and 1990 was only slightly higher than 1989. 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 1990 were 8,179 tons, essentially the same as those of 1989. While the total value of silicon carbide exported plus reexported increased about 4% to $10.3 million, the value per ton increased 7% to $1,263 and was within 32% of the 10-year high of $1,865 in 1986. The average annual exports plus reexports for the past 10 years were 6,199 tons, with a high of 10,442 tons in 1981 and a low of 3,859 tons in 1986. The average annual value per ton of exports plus reexports for the past 10 years was $1,454, with a high of $1,865 in 1986 and a low of $1,068 in 1981. The value of exports plus reexports fluctuated greatly during the past 10 years; values were up as much as 75% of the value at the beginning of the period and closed the period 18% greater than at the beginning.

Imports of silicon carbide in 1990 decreased 23% in quantity to 75,640 tons, 19% in total value to $52.5 million, and increased 5% in average value per ton to $694. The average annual imports for the past 10 years were 76,966 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 $597, with a high of $694 in 1990 and a low of $539 in 1986. The trend of silicon carbide imports for the past 10 years was one that generally decreased to a low in 1985, followed by continuing increases until 1988, followed by continuing decreases until 1990 imports were only slightly greater than those of 1981.

TABLE 18

WORLD SILICON CARBIDE ANNUAL PRODUCTION RATED CAPACITY,[1] DECEMBER 31, 1990

(Metric tons)

Country	Capacity
North America:	
Canada and United States	125,000
Mexico	22,680
Total	147,680
South America:	
Brazil	12,701
Europe:	
France	16,329
Germany, Federal Republic of	36,287
Italy	36,287
Netherlands	50,001
Norway	73,936
Spain	18,144
Total	230,984
Eastern Europe:	
Czechoslovakia, Poland, U.S.S.R., and Yugoslavia	158,757
Asia:	
China	145,150
India	13,608
Japan	86,183
Total	244,941
World total	795,063

[1]Includes capacities of operating plants as well as plants on stand-by basis.

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. Output increased in both tonnage and value compared with that of 1989. Publishing production data would disclose company proprietary data. Export and import data were not available.

Metallic Abrasives

Production.—Nine firms produced metallic abrasives in 11 plants at the end of 1990. During the year, one firm closed its plant and went out of business, and another firm closed one of its plants, but opened another. The quantity and value of steel shot and grit produced increased about 4%. The average value per ton was essentially the same as that for 1989, $386 per ton. The average annual

TABLE 19

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

Use	1989			1990		
	Quantity (metric tons)	Value (thousands)	Yearend stocks	Quantity (metric tons)	Value (thousands)	Yearend stocks
SILICON CARBIDE						
Abrasives	r53,454	r$27,197	2,634	54,339	$27,912	3,261
Metallurgical	r62,189	r28,636	3,067	49,890	22,840	7,196
Refractories and other	980	r597	550	1,022	584	371
Total	r116,623	56,430	6,251	105,251	51,336	10,828
ALUMINUM OXIDE						
Regular: Abrasives plus refractories	r164,226	r62,339	5,976	164,096	64,687	8,342
High purity	30,634	19,446	1,479	21,383	13,071	1,039
Total	r194,860	r81,785	7,455	185,479	77,758	9,381

rRevised.

TABLE 20

PRODUCERS[1] OF METALLIC ABRASIVES IN 1990

Company	Location	Product (shot and/or grit)
Abrasive Materials Inc.	Hillsdale, MI	Cut wire, steel.
Chesapeake Specialty Products	Baltimore, MD	Steel.
Durasteel Abrasive Co.	Pittsburgh, PA	Do.
Ervin Industries Inc.	Adrian, MI	Do.
Do.	Butler, PA	Do.
Globe Steel Abrasives Co.	Richland, OH	Do.
Do.	Buckle, PA	Chilled and annealed iron and steel.
Metaltec Steel Abrasives Co.	Canton, MI	Do.
National Metal Abrasive Co.	Wadsworth, OH	Do.
Pellets Inc.	Tonawanda, NY	Cut wire.
Steel Abrasives Inc.[2]	Hamilton, OH	Chilled and annealed iron and steel.
U.S. Abrasives, Inc.[2]	Tippecanoe, IN	Do.
The Wheelabrator Corp.	Bedford, VA	Steel.

[1]Excludes secondary (salvage) producers
[2]Plant closed during 1990.

production for the past 10 years was 178,167 tons, with a high of 213,879 tons in 1990 and a low of 135,843 tons in 1982. The average value per ton during the period was $359, with a high of $402 in 1982 and a low at $310 in 1987. The trend of steel shot and grit production for the past 10 years was one of decline to the low in 1982 and then general continued recovery. The 1990 production was equal to about 114% of the 1981 production level. Michigan, Ohio, Pennsylvania, Virginia, and Indiana, in decreasing order of quantity, supplied the production of steel shot and grit.

During 1990, two companies, one each in Indiana and Ohio, produced chilled and annealed iron shot and grit; by yearend, the Indiana plant was closed. Additionally, two firms, one in Michigan and one in New York, reported production of cut wire shot. Production of chilled and annealed iron and cut wire shot and grit declined significantly in 1990, 41% in quantity to 10,260 tons and 37% in value to $6.6 million. The average value per ton increased about 7% to $646. The average annual production of these types of shot and grit for the past 10 years was 16,373 tons, with a high of 19,848 tons in 1981 and a low of 13,352 tons in 1986. The average value per ton for the past 10 years was $474, with a high of $646 in 1990 and a low of $344 in 1981.

Consumption.—The quantity of steel shot and grit sold or used increased slightly to 209,095 tons, the total value increased 6% to $86.6 million, and the

TABLE 21

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

Product	Production		Shipments		Annual capacity[2] (metric tons)
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	
1989:					
Chilled iron shot and grit	W	W	W	W	W
Annealed iron shot and grit	W	W	W	W	W
Steel shot and grit	206,278	$78,980	r202,428	$81,263	363,700
Other[3]	r17,452	10,566	r16,826	11,457	XX
Total	223,730	89,546	r219,254	92,720	XX
1990:					
Chilled iron shot and grit	W	W	W	W	W
Annealed iron shot and grit	W	W	W	W	W
Steel shot and grit	213,879	82,485	209,095	86,568	226,279
Other[3]	10,260	6,628	10,485	7,781	XX
Total	224,139	89,113	219,580	94,349	XX

rRevised. 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.

average value per ton increased slightly to $414. The average annual quantity of steel shot and grit sold or used for the past 10 years was 178,542 tons. The high was 214,787 tons in 1988, and the low was 133,275 tons in 1982. The trend for sold or used steel shot and grit for the past 10 years was one of fluctuating decreases and increases. The 1990 sold-and-used value was 13% greater than the value in 1981.

The quantity of chilled and annealed iron and cut wire shot and grit sold or used decreased 38% to 10,484 tons. The value decreased about 32% to $7.8 million. The average value per ton increased 9% to $742. The average annual quantity of these shot and grit sold or used for the past 10 years was 15,546 tons, with a high of 18,192 tons in 1984 and a low of 9,152 tons in 1985. The trend for the sold-and-used value for the past 10 years was one of large individual increases and decreases. Changes were as much as 50% in 1 year, with the low in 1985. Since then, continued growth resulted in the 1989 value equaling 178% of the 1981 level before the significant decrease in 1990.

The estimated apparent domestic consumption of all types of metallic shot and grit decreased 6% in quantity to 201,368 tons, 4% in total value to $86.4 million, and increased slightly in average value per ton to $428. 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 188,090 tons, with a high of 224,216 tons in 1988 and a low of 144,986 in 1982. The average value per ton for the same period was $403, with a high of $432 in 1985 and a low of $375 in 1987. The trend of apparent consumption for the past 10 years was one of rapid increases and declines until 1985. This was followed by general growth until 1988 consumption was 13% greater than that of 1981, but with the declines in 1989 and 1990 consumption, it was slightly less than that of 1981.

Foreign Trade.—U.S. exports of metallic shot and grit increased 53% to 25,559 tons. The total value of exports increased 98% to $12.9 million, and the average value per ton decreased 29% to $505. The average annual tonnage of metallic shot and grit exports for the past 10 years was 10,473 tons, with a high of 12,900 tons in 1990 and a low of 6,334 tons in 1986. The average value per ton for the past 10 years was $739, with a high of $948 in 1987 and a low of $390 in 1989. The trend for metallic abrasive exports for the past 10 years was one of general decline from 1981 through 1983, followed by fluctuating increases and decreases. The 1990 exports were 77% greater than the level of 1981 exports.

U.S. imports of metallic abrasives increased 76% in quantity to 7,346 tons, increased about 46% in total value to $5.0 million, and decreased 18% in value per ton to $678. The average annual imports for the past 10 years were 4,566 tons, with a high of 8,509 tons in 1984 and a low of 2,699 tons in 1987. The average value per ton for the period was $877, with a high of $965 in 1988 and a low of $280 in 1984. The trend for the quantity of imports for the past 10 years was one of up-and-down fluctuations resulting in a general decline through 1987, followed by an increase until 1990 imports were about 154% of those of 1981.

The United State was a net exporter of metallic abrasives in 1990, a position it has enjoyed by a significant ratio for the past 10 years.

[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.

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ADVANCED MATERIALS

By Rustu Kalyoncu

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Advanced materials are metals, metal alloys, ceramics, polymers, and composites developed during the past 20 years that have higher strength-to-density ratios, greater hardness and wear resistance, and one or more superior thermal, electrical, optical, or chemical properties compared with traditional materials. They offer savings in energy consumption, improved performance at reasonable cost, and less dependence on imports of strategic and critical mineral resources.

The decade of the 1980's witnessed the recognition of advanced materials as critical to future technologies by the industrialized nations, with the United States, Japan, and the European Community (EC) being major competitors. All three have identified communications and information technologies, as well as biotechnology and advanced materials synthesis and processing as the key to future industrial leadership. The closing decade of the 20th century is expected to be an era of rapid development and restructuring of the advanced materials industries. Significant challenges are posed to the position of the United States in the world economy. European Community 92 is seriously challenging the United States through its effort to develop uniform standards and remove trade barriers in Western Europe. The Japanese are challenging the United States in their attempts to commercialize advanced structural ceramics, alloys, composites, and superconductors. Developing countries and other industrialized nations, such as Australia, Canada, and the Republic of South Africa, have recognized the need to move from the status of commodity mineral and materials suppliers to full participants in advanced materials technologies.[1]

A growing awareness by the U.S. Government of the importance of advanced materials in the race for global technological leadership has led to the reorganization of the Office of Science and Technology Policy (OSTP) in the Executive Office of the President. The Director of the OSTP, who is also the Science Advisor to the President, designated advanced materials as the essential element of technical and industrial competitiveness. The Federal Coordinating Council for Science, Engineering, and Technology (FCCSET), chaired by the Science Advisor, has Assistant Secretary level participation by all agencies having responsibilities in materials research and development. The newly formed President's Council of Advisors on Science and Technology (PCAST), also chaired by the Science Advisor, has industrial and academic members with knowledge of and interest in advanced materials. Both FCCSET and PCAST report directly to the President.

The National Competitiveness Technology Transfer Act of 1989 (Public Law 101-189) was signed by the President in November 1989. The law is designed to link industry, universities, and national laboratories to accelerate commercialization of new technologies, including advanced materials. The law makes provisions allowing national laboratories to enter into cooperative research and development agreements; 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. It also assigns a technology transfer mission to the nuclear weapons laboratories.

The Department of Commerce established a new Office of Technology Administration in 1989. The Undersecretary for Technology is to work closely with the President's Science Advisor to help coordinate strategies and programs in the Federal agencies. The focus will be to remove barriers to and provide incentives for rapid commercialization of technology in the United States. Advanced materials are essential components of all new technologies and are to receive increased attention.

Two bills addressing advanced technologies and materials were introduced in the Congress in 1989. No action was taken. One bill, the American Technology Preeminence Act of 1990 (H. Res. 3042), was reintroduced in 1990. This bill provides appropriations to strengthen the role of the National Institute of Standards and Technology (NIST, formerly the National Bureau of Standards) in assisting private industry in commercialization and marketing of new technologies and processes needed to remain competitive in the global marketplace. The funds, provided to the Commerce Department Advanced Technology Program, are to be administered by NIST. Prospects for this bill appeared to be positive at the time of its introduction. Congressman Don Ritter (R-PA), the only materials scientist in Congress, said a comprehensive effort such as H. Res. 3042 is needed to pull together tax, trade, regulatory, and research and development policies to improve U.S. competitiveness.

In the fall of 1990, an individual group workshop was asked to diffuse major hurdles so that composites representatives from the aerospace, automotive, electronic, and construction industries could identify critical barriers in composite processing and serious performance issues. The most important problems stated were the inability to control resin flow and fiber orientation. Higher priority was given to process monitoring, measurement, and control of fiber-matrix adhesion, and joining techniques as technical barriers to full exploitation of emerging fabrication technologies.

The energy crises of the second half of the 1970's not only resulted in low economic growth and recession on a global basis, but also indicated the extent to which the industrial health and economic well-being of the EC, Japan, and the United States were dependent on suppliers of energy, minerals, and commodity materials around the world. The need for improved energy efficiency and less reliance on other nations for raw materials have fueled the motivation for development of structural materials with higher strength-to-weight ratios, greater resistance to high temperatures, better corrosion resistance, and enhanced durability and reliability. The

candidates for new structural materials (advanced structural ceramics, superalloys, engineering polymers, and their composites) have become subjects of intense research and development and constitute one of the major areas of international competition.

Advanced structural ceramics possess a number of outstanding high-temperature mechanical and chemical properties that make their application ideal in thermally and chemically demanding environments. They can replace metals and plastics in many existing systems to provide better performance and durability and are enabling components in new technologies. Advanced structural ceramics have been slow to develop owing to technical and economic factors. It is fair to say that advanced structural ceramics are in their infancy, but are predicted to become increasingly important as problems are solved and new applications requiring superior properties from materials are developed.

Advanced or superalloys are materials formed by combining two or more metals. They exhibit properties far superior to those of the individual metals comprising the alloy. Advanced alloys containing nickel, iron, and cobalt are generally used at temperatures above 500° C. Development of advanced alloys has played an important role in creating interest in advanced materials.

Composite materials are two component materials in which one material of differing morphology, usually in the form of a fiber or whisker, is scattered within a powder matrix of similar or different composition. Fiber composites combine desired properties of ductility and high-fracture toughness of the matrix with high-temperature strength and stiffness of fibers in order to offer superior performance. Composites have dominated materials use in aerospace and defense applications for many years.

Advanced polymer matrix composites (PMC), consisting of a wide variety of engineering plastics reinforced with continuous fibers, filaments, or tapes or with short, discontinuous fibers, whiskers, or particles, also hold great promise for a variety of structural applications. Their superior strengths, high strength-to-weight ratios, corrosion resistance, and potential for reduction of the numbers of parts to be assembled in a given system ensure that their application areas will widen. Use of PMC's as replacements for metals, glass, or ceramics requires, however, essentially different plants and equipment, necessitating large capital expenditures and development of automated equipment. For these reasons, PMC's are finding rapidly increasing applications in defense, aerospace, and sporting goods where improved performance justifies the higher costs. They have been slow to find extensive applications in the automobile industry. However, new fuel consumption standards, rising fuel costs, more stringent exhaust emission standards, and demand for improved durability and performance are adequate incentives for automobile manufacturers to reevaluate their use.

A significant portion of research and development (R&D) in advanced materials is conducted or sponsored by the U.S. Government. Expenditures are not available for estimating the extent of R&D and pilot plant operations in industry. Estimates put these industrial efforts on a par with, or even twice as much as, the Federal spending. Table 1 summarizes total materials R&D expenditures for a number of Federal agencies in fiscal years 1990 through 1992. The total R&D support for materials for 1990 was almost $1.5 billion, with a significant increase in fiscal year 1991, and the President's request to the Congress for fiscal year 1992 shows a slight increase over that of fiscal year 1991.

TABLE 1

TOTAL FEDERAL MATERIALS RESEARCH AND DEVELOPMENT FUNDING, BY AGENCY

Agency	Fiscal year 1990 (actual)		Fiscal year 1991 (anticipated)		Fiscal year 1992 (President's budget)	
	Million dollars	Percent	Million dollars	Percent	Million dollars	Percent
Department of Commerce/National Institute of Standards and Technology	39.1	2.6	44.5	2.5	48.4	2.7
Department of Defense	362.2	24.4	470.3	26.6	384.2	21.1
Department of Energy	624.3	42.0	729.6	41.3	800.8	43.9
Department of Interior/U.S. Bureau of Mines	24.1	1.6	25.0	1.4	23.8	1.3
Department of Transportation	5.3	.4	10.0	.6	8.8	.5
Environmental Protection Agency	2.2	.2	3.2	.2	3.5	.2
Department of Health and Human Services/ National Institutes of Health	60.8	4.1	66.6	3.8	71.7	3.9
National Aeronautics Space Administration	97.4	6.6	116.3	6.6	137.4	7.5
National Research Council	13.3	.9	9.0	.5	12.2	.7
National Science Foundation	221.8	14.9	241.0	13.6	277.8	15.2
U.S. Department of Agriculture	36.5	2.5	51.9	2.9	54.2	3.0
Total materials research and development funding	1,486.9	100.0	1,767.4	100.0	1,822.8	100.0

Source: Committee on Materials, Office of Science and Technology Policy, Executive Office of the President.

The U.S. Department of Energy (DOE) funds almost 50% ($729.6 million in FY 1991) of Federal materials R&D, 70% of which is for research conducted in the DOE National Laboratories, 25% of which is provided in grants to universities, and 5% of which is given to industry. DOE's interests cover the entire range of ceramic science: processing and synthesis; deformation, fracture, and cyclic fatigue; stress corrosion; electronic ceramic, microstructure, defects, and dislocations; surfaces, interfaces, and grain boundaries; radiation effects; toughening mechanisms; and superplasticity.

The Department of Defense funds a wide variety of materials R&D, with the major emphasis on development and rapid application to military systems. Total funding for fiscal year 1991 was $470.0 million, 26% of the total. The research is accomplished partly in-house, in such laboratories as the Army Materials Technology Laboratory, the Naval Research Laboratory under the Office of Naval Research (ONR), the materials laboratories of the Wright Research and Development Command, and the Naval Surface Warfare Center. The remainder is conducted by universities and industry through funding by the Army Research Office—Durham, ONR, the Air Force Office of Scientific Research, and the Defense Advanced Research Projects Agency.

Table 2 summarizes fiscal year 1992 Federal Government R&D expenditures as requested by the President from the U.S. Congress, by type of material and Government agency. For ceramics R&D, $68.6 million was requested by DOE alone. This represents more than 55% of the total ceramic R&D expenditures. Department of Defense is the second with $21.4 million or more than 17% of the total. National Science Foundation is the third major agency, with $17.1 million.

The significance of advanced materials to the economic future of the United States has been made explicit by a number of official reports to the Congress and interested Federal agencies.[2] The Office of Technology Assessment, at the request of the Congress, prepared a report outlining the role advanced structural ceramics, engineering polymers, and composites would play in determining the future leadership among individualized nations. Along the same lines, the National Research Council (NRC) released a report,[3] emphasizing the inadequacy to synthesis and processing of new materials by Federal research establishments. The U.S. Bureau of Mines published volumes 1 and 2 of the New Materials Society series that give a summary of the science and technology, economic and policy issues, and the status of new materials markets.[4] The Bureau reports give adequate coverage to recent and potential developments in advanced materials with emphasis on improved processing for better physical properties.

DOMESTIC DATA COVERAGE

The structure of the advanced materials industries of the United States is diverse in terms of the wide variety of products and the kinds of companies engaged in manufacturing.[5] Unfortunately, no systematic data collection on the structure of the advanced materials industry or production of materials has been done. Between the U.S. Bureau of Mines data on commodity minerals and metals and the Bureau of the Census data on commodities and finished products, the flow of processed materials through various value added steps between commodity and product is not covered. The U.S. Bureau of Mines is in the process of developing data acquisition methods to cover advanced materials production but presently must rely on data from existing sources. The limited accuracy

TABLE 2

FISCAL YEAR 1992 MATERIALS R&D FUNDING, BY MATERIALS CLASS AND AGENCY[1]

(Million dollars)

Materials class	DOC	DOD	DOE	DOI	DOT	EPA	HHS	NASA	NRC	NSF	USDA	Total[2]
Bio/biomolecular materials	0.2	18.6	2.3	—	0.8	—	71.7	4.4	—	16.8	45.0	159.7
Ceramics	5.3	21.4	68.6	2.4	—	0.8	—	8.8	—	17.1	—	124.4
Composites	4.0	85.1	28.0	1.4	1.9	—	—	54.1	—	10.5	1.6	186.6
Electronic	6.3	57.5	45.6	—	—	.3	—	10.3	—	48.7	—	168.7
Magnetic	1.2	2.0	5.5	—	—	—	—	1.6	—	13.3	—	23.5
Metals	8.2	36.1	216.1	6.4	3.6	.4	—	19.6	11.4	28.9	—	330.7
Optical/photonic	1.1	70.9	29.0	—	.7	—	—	5.4	—	28.1	—	135.2
Polymers	3.6	22.1	23.8	.1	.7	.5	—	11.5	—	20.5	7.6	90.4
Superconducting	3.5	28.1	119.8	—	.1	—	—	5.8	—	25.1	—	182.4
Total[2] specific materials R&D	33.4	341.8	538.6	10.3	7.7	2.0	71.7	121.4	11.4	209.0	54.2	1,401.5
Other/nonspecific materials R&D	15.0	42.4	262.2	13.5	1.1	1.5	—	16.0	.8	68.8	—	421.1
Total[2] materials R&D	48.4	384.2	800.8	23.8	8.8	3.5	71.7	137.4	12.2	277.8	54.2	1,822.8

[1]DOC—Department of Commerce/National Institute of Standards and Technology, DOD—Department of Defense, DOE—Department of Energy, DOI—Department of Interior, DOT—Department of Transportation, EPA—Environmental Protection Agency, HHS/NIH—Department of Health and Human Services/National Institute of Health, NASA—National Aeronautics Space Administration, NRC—National Research Council, NSF—National Science Foundation, USDA—U.S. Department of Agriculture.

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

Source: Committee on Materials, Office of Science and Technology Policy, Executive Office of the President.

and inadequacy of these data, mostly in highly aggregated form, permit only broad generalizations about the current status of new materials and virtually allow the depiction of no historically valid trends.

The publishers of Ceramic Industry magazine, over the past 9 years, have conducted the only systematic survey of the industry, relying on voluntary reporting of sales figures and their own estimates of those of nonreporting companies. Most of the information on ceramics reported here is from the results of the Ceramic Industry surveys of 1986, 1987, 1988, 1989, and 1990.[6] The data for 1990 were generously provided in advance of publication by Ms. Patricia Janeway, Editor in Chief and Associate Publisher. Similarly, data on production and costs of PMC's are from the open literature.

In 1990, the Suppliers of Advanced Composite Materials Association (SACMA) and the European Trade Association of Advanced Composite Materials Suppliers (ETAC) jointly reported more than 10,000 metric tons of advanced fibers and almost 13,000 metric tons of preimpregnated composites were shipped worldwide as shown in table 3. On a dollar value basis, shipments increased 14% for advanced fibers and 11% for preimpregnated composites over the comparable period in 1989. More than 90% of the total world production was by the 26 member companies of SACMA. Twelve companies in the United States accounted for the 60% of total production, 10 companies in Europe represented about 15% of the total, and 4 companies in Japan delivered most of the 26% share of Asian production. Epoxy resins continued to make up the bulk (more than 90%) of the matrix materials, with carbon fibers accounting for almost 60% of fiber production by weight, followed by Aramid fibers with 25% and glass fibers with 13%.

The aerospace sector continued to be the primary beneficiary, accounting for 50% to 55% of advanced polymer composite shipments, recreational use with about 30%, and the remaining for marine and other industrial applications. Total shipment of advanced composite materials was $1.1 billion, with about $700 million the U.S. share. Estimated production figures for 1991 are reported to be 11,550 metric tons of fibers and almost 14,000 metric tons for preimpregnated composites for a total of 25,500 metric tons with total dollar value of $1.25 billion. Again, the expected share of the United States is 60%.

ADVANCED STRUCTURAL CERAMICS

Background

Definitions, Grades, and Specifications.—Advanced structural ceramics are a relatively new class of high-performance ceramics with significant potential for future economic impact. They differ from traditional ceramics by the nature of their specialized properties such as high-temperature strength and higher resistance to chemical corrosion. On the other hand, these materials also require more expensive, sophisticated fabrication techniques.

TABLE 3

WORLDWIDE ADVANCED COMPOSITE SHIPMENTS

Year	Fiber				Preimpregnated composites			
	Shipments		Value		Shipments		Value	
	Quantity (thousand metric tons)	Percent change	Amount (million dollars)	Percent change	Quantity (thousand metric tons)	Percent change	Amount (million dollars)	Percent change
1985	5.28	—	312.97	—	6.99	—	301.79	—
1986	5.95	12.7	355.63	13.6	8.22	17.5	385.67	27.8
1987	6.83	14.8	397.79	10.2	8.89	12.3	452.42	17.3
1988	8.11	10.8	498.65	25.3	10.28	15.6	498.60	10.2
1989	8.94	10.2	397.49	−25.3	12.03	8.0	586.21	17.5
1990	10.13	13.3	453.26	14.0	12.89	7.1	653.36	11.5
1991[e]	11.55	14.0	483.17	6.6	13.99	8.6	763.12	16.8
1992[e]	13.17	14.0	515.06	6.6	15.20	8.6	891.33	16.8

[e]Estimated.

Source: U.S. Bureau of Mines and Suppliers of Advanced Composites Materials Association.

In recent years, great interest has been shown in advanced, high-technology ceramics by scientists, engineers, and policymakers. This interest has been especially fueled by the competition between the United States and other industrial nations in developing new commercial applications for advanced ceramics. Nowhere is the attention given to advanced ceramics more pronounced than in Japan. Interest in the "new ceramics," or "fine ceramics" as they are referred to in Japan, has reached a "fever" pitch. This interest is evident by the large number of nonceramic manufacturers entering into ceramic R&D and production.

Ceramics are defined by the National Academy of Sciences 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 kaolin used in pottery, brick, and classical porcelain. On the other hand, advanced, high-technology ceramics include a wide variety of oxides, nitrides, carbides, borides, and others. Unique properties of these inorganic materials enable applications ranging from electronic components to heat- and wear-resistant parts to optical devices. These properties are high-temperature strength, controlled thermal and electrical conductivity, and resistance to high-temperature corrosion and erosion. Depending on the specific application, these materials can also exhibit singular electrical, electronic, magnetic, and optical properties.

The number of chemical compositions and processing variables in advanced structural ceramics is quite large. However, potentially important materials for large-scale applications are limited. These 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). Attention is focused on these, with brief mention of other materials and their uses.

Alumina (aluminum oxide), though one of the most abundant oxides in the crust of the Earth, is for practical purposes obtainable only from bauxite, a complex mixture of hydrated aluminum oxides. Bauxite must be refined to produce anhydrous oxide suitable for use as feedstock for reduction to aluminum, refractory grain, or other specialty products. Alumina is used for a wide variety of ceramic products,

including refractory brick, cements, and castable refractories. High-purity alumina compositions, those with 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. The high strength and hardness of alumina make it suitable for seal surfaces for rotary pumps, nozzles for a variety of applications, cutting tools, nonlubricated roller bearings, grinding media, and a host of other applications requiring strength, hardness, and wear resistance. Alumina retains about 90% of its mechanical strength up to 1,100° C, though its high thermal expansion coefficient results in poor thermal shock resistance, which limits its use in applications involving rapid temperature changes. A promising new material is transformation-toughened alumina, with 8% to 15% by volume of ZrO_2 included in the composition. Cracks that normally develop during rapid cooling are prevented from growing and causing catastrophic failure by the transformation in ZrO_2, which is discussed later. A family of alumina fibers targeted for use as reinforcement in a variety of composites is now commercially available. These are spun from solutions or slurries of alumina-containing precursors, followed by heat treatment. They are available as woven preforms, papers, and mats.

Boron carbide (B_4C) is harder than all known materials, other than diamond and cubic boron nitride. It has found use, therefore, as an abrasive, abrasion-resistant component, and ceramic armor. Because of the high neutron cross section of boron, both boron and boron carbide have been used as reactor control elements, radiation shields, and moderators.

Silicon carbide (SiC) has been used for almost 100 years as an abrasive and as a component of electrical heating elements and, more recently, as a super refractory. High-purity silicon carbide, with less than 1.2% impurities, is a prime candidate for many structural applications requiring high strength at high temperatures and good wear resistance, such as in automotive engines. High-strength fibers of silicon carbide have been produced by chemical vapor deposition; platelets and whiskers have also found use as reinforcements for ceramic, metal, and polymer composites.

Silicon nitride (Si_3N_4) exhibits excellent corrosion and oxidation resistance over a wide temperature range and retains its high strength up to 1,100° C. Because of such properties and high hardness, it has been under evaluation for use as components in gas turbine engines and heat engines and as high-temperature bearings, cutting tools, industrial wear parts, and ceramic armor. Sialons, oxynitrides of silicon and aluminum, are similar in structure and properties to silicon nitrides. They are being used as lubrication-free bearings, rocket nozzles, and gas shrouds for orbital welders.

Zirconia (ZrO_2), produced from the mineral zircon ($ZrSiO_4$) or less commonly from baddeleyite (ZrO_2), exists in three different crystalline forms, depending on temperature and amounts of other oxides (magnesia, MgO; lime, CaO; or Yttria, Y_2O_3) included in the crystal structure during synthesis. By incorporation of several percent of the stabilizing oxide, a mixture of cubic and tetragonal forms can be produced. Stress applied to the materials, by external mechanical force or resulting from rapid temperature change, causes transformation of the tetragonal form to the low-temperature monoclinic form. This results in an increase of 3% to 5% in the volume of the crystal, effectively blocking crack growth and total fracture of the ceramic body. This phenomenon is called transformation-toughening because the impact resistance is increased manyfold. Zirconias containing both cubic and tetragonal phases are called partially stabilized zirconia (PSZ). Those containing only tetragonal zirconia are called tetragonal zirconia polycrystal (TZP). Ceramics with added zirconia are called transformation-toughened ceramics (TTC); transformation-toughened alumina (TTA) has found application as a grinding and cutting material.

Other ceramics used or being evaluated for advanced applications include aluminum titanate, Al_2TiO_5, stable to 1,865° C, for use as shock-resistant materials in catalytic converters and diesel engine components, and cordierite, $Mg_2Al_4Si_5O_{18}$, with a low thermal expansion coefficient, in similar applications.

Products for Trade and Industry.—Advanced ceramic products may be categorized in several ways. A pragmatic classification is illustrated in figure 1, taking into account functions, applications, and materials.[7]

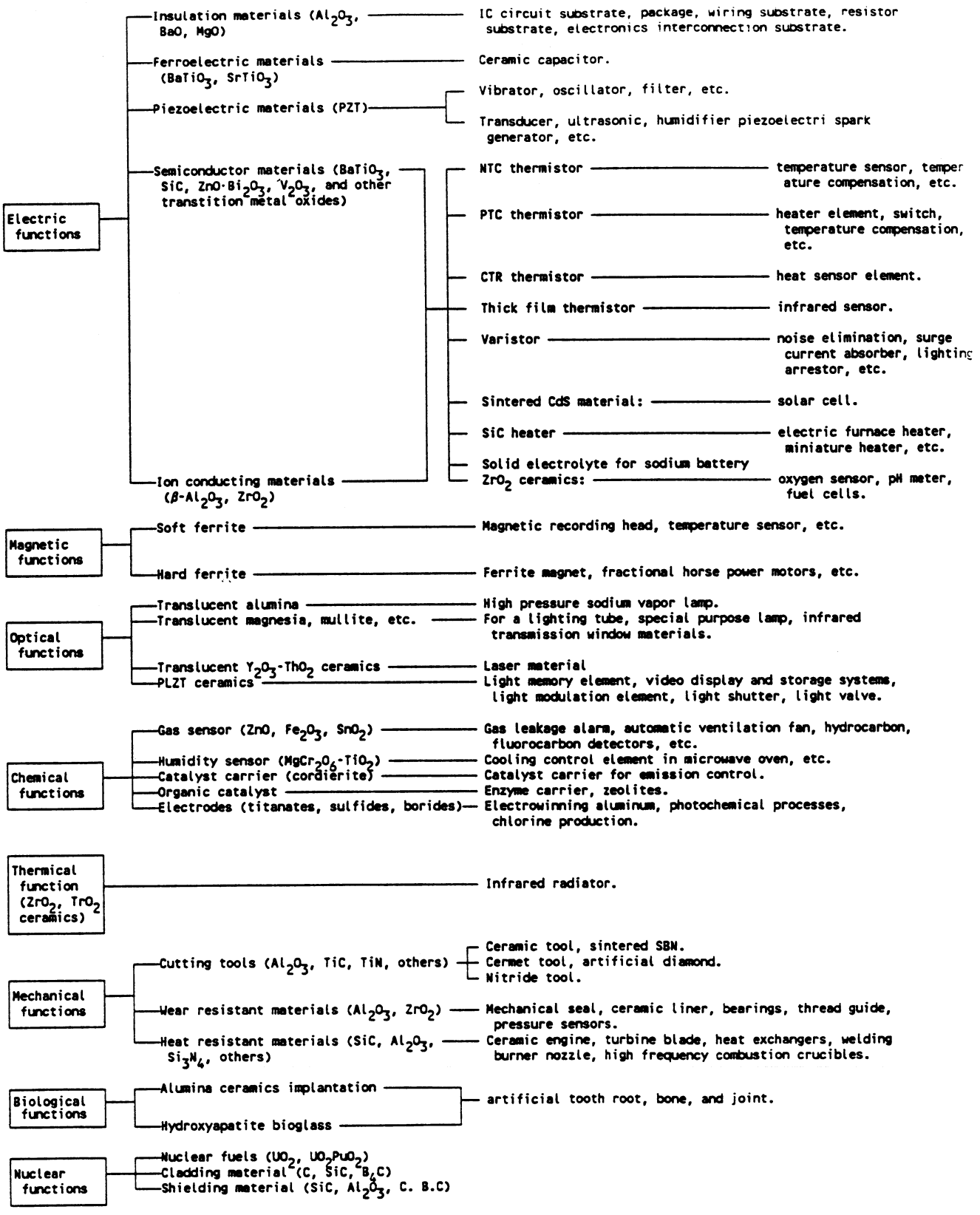
As figure 1 illustrates, electrical, magnetic, optical, thermal, mechanical, and nuclear properties of advanced structural ceramics dictate their suitability for a specific application. On the one hand, they can be employed as insulators, while on the other, they can be used as semiconductors or even superconductors. Ferrite compositions are used in many magnetic applications as soft and hard magnets. Fiber-optic technology owes its advances to translucent yttria-thoria ceramic compositions. Many well-known ceramic materials find applications as sensors (titania), catalyst supports (cordierite), and electrodes (borides, sulfides, etc.) because of their unique chemical characteristics. High-temperature stability of refractory compounds (alumina, magnesia, etc.) make metal and gas refining technologies possible. Refractories are also used as wear-resistant (cutting tools) and heat-resistant (silicon carbide) structural materials because of their superior hardness and strength. Finally, advanced ceramics find utility in nuclear applications as shielding (carbon, silicon carbide, boron carbide, etc.), cladding (carbon, silicon carbide, etc.), and nuclear fuels (uranium oxide and plutonium oxide).

Industry Structure.—The structure of the ceramic industry of the United States is diverse in terms of the wide variety of products and the kinds of companies engaged in manufacturing. Table 4 is a synthesis of information available for calendar year 1990, derived from the Ceramic Industry survey and compared with data for 1986, 1987, 1988, and 1989.[8]

Two of the largest U.S. producers of advanced structural ceramics are Corning Inc., Corning, NY, a major manufacturer of glass, glass ceramics, and other commodity ceramics, whose major advanced products are ceramic honeycomb for automotive catalyst carriers and optical fibers, and Cooper Industries, Houston, TX, which recently acquired the Champion Spark Plug Co. Reported sales for Corning were $895.3 million and for Cooper Industries were $460 million for 1990. Within the $200 to $500 million range are AC Spark Plug Div. of General Motors Corp., which accounted for $336 million in sales of spark plugs; GTE, Stanford, CT, reporting sales of $398.3 million; and Allied Signal, Morristown, NJ, whose Autolite Div. posted spark plug sales of $212 million. Table 5 shows the number of largest U.S. and worldwide advanced ceramics producers for 1990.

FIGURE 1

CLASSIFICATION OF ADVANCED CERAMICS, BY FUNCTIONS, MATERIALS, AND APPLICATIONS



Source: Charles River Associates

TABLE 4

SALES OF ADVANCED CERAMICS[1]

(Million dollars)

Year	Low-voltage porcelain	Capacitors, packaging	Engineering ceramics	Other electronic	Optical fiber	Ferrites	High-voltage porcelain	Total
1986	924	807	1,010	527	514	376	160	4,317
1987	1,151	888	976	354	459	394	153	4,376
1988	1,132	1,199	851	434	317	362	231	4,526
1989	1,157	724	896	467	420	287	227	4,287
1990	NA	NA	NA	NA	NA	NA	NA	3,840
1990	1,663	6,525	1,359	2,310	1,224	([2])	([2])	13,594

NA Not available.
[1]Sales are reported for only United States in 1986–89. In 1990, only a total U.S. value is available; however, a breakdown by category is given for the top 145 producers in total worldwide sales.
[2]The categories of ferrites and porcelain add up to $513 million.

Source: Ceramic Industry, 1991.

TABLE 5

SALES BY THE LARGEST ADVANCED CERAMICS PRODUCERS IN 1990

Range of sales (million dollars)	Number of companies		Publicly owned	Privately owned
	Worldwide	United States		
Greater than 500	5	1	5	—
200 to 500	6	4	6	—
100 to 200	7	3	7	—
50 to 100	3	3	3	—
40 to 50	5	4	3	—
30 to 40	4	3	2	1
20 to 30	16	12	9	6
10 to 20	19	14	9	10
5 to 10	25	20	—	—

Source: Ceramic Industry, 1991.

TABLE 6

SALES OF MAJOR CATEGORIES OF FINISHED CERAMIC PRODUCTS

(Million dollars)

Year	Glass	Advanced ceramics	Porcelain	Whitewares	Refractories	Total
1986	17,462	4,317	3,827	2,745	NA	28,351
1987	17,574	4,376	4,569	2,908	1,678	31,105
1988	20,553	4,526	4,649	3,040	1,985	34,753
1989	18,558	4,287	5,486	3,459	2,156	33,946
1990	[1]8,100	3,840	5,680	3,420	1,620	32,660
1990	[2]23,100	9,754	1,720	2,680	3,180	40,434
1990	[3]41,200	13,594	7,400	6,100	4,800	73,094

NA Not available.
[1]U.S. sales.
[2]Other countries.
[3]World figures.

Source: Ceramic Industry, 1991.

Among the top 10 advanced ceramics producers with sales of more than $50 million dollars, all but 1 are primarily manufacturers of spark plugs, optical fiber, electronic components, and porcelain insulators.

The smaller companies with sales of less than $50 million, as tabulated in table 5, are the major producers of advanced structural ceramics. As evident in table 5, many of these are privately held entrepreneurial companies. Ownership of these small companies over the past 5 years has been changing rapidly through mergers and acquisitions, many with and by foreign companies. Some large foreign companies such as Kyocera America Inc., which has plants in nine locations within in the United States, have been expanding rapidly in the United States and Europe.

In summary, 1990 was a relatively active year in terms of acquisitions and cooperative agreements. Acquisition by foreign companies interested in expanding capacity for production of advanced ceramics and developing new markets for these materials continued.

Table 6 summarizes sales of major categories of finished ceramic products. The importance of advanced ceramics to the economy can be noted in that sales constitute 23% of the total ceramic industry.

***Technology.*—Processing.**—Conventional processing methods of the 1950's, consisting of dry pressing, slip casting, and firing into final shape, have proved to be inadequate to create superior properties within advanced structural ceramics. However, through intensive R&D efforts in the 1970's and 1980's, a number of novel powder processing and fabrication methods

have been devised. These novel methods can be broadly classified according to whether solutions, vapor phases, or solid-state decomposition of salts are involved.[9] Further division of these methods into subcategories can be made according to how the solvent is removed or by the presence and nature of the vapor phase reactions.

Solution preparation methods remove the solvent while maintaining as much of the homogeneity of the solution as possible. Such methods need to be easy to perform and still allow close control of desired compositions and purity. Sol-gel process is a well-known example of this type of solution preparation method. Sol, consisting of very small crystals dispersed in an aqueous solution, is introduced into a dehydrating solvent, such as alcohol, to form a gel. The gel is separated and dried further, leaving behind a fine powder residue with a high degree of chemical homogeneity and morphological (shape) uniformity. This method has been successful in preparing advanced structural ceramic powders, such as titanium and zirconium oxides.

Vapor phase preparation methods, both condensation and decomposition types, have been successfully used to synthesize ultrapure and ultrafine non-oxide ceramic powders, such as silicon nitride and silicon carbide. A straightforward way of producing a vapor of a desired composition is to evaporate or sublimate the ceramic material. Vapor decomposition and vapor-vapor reactions are more commonly used for fine powder preparation. An excellent example of the latter reactions is the synthesis of silicon nitride from silicon tetrachloride and ammonia gas. Vapor decomposition of precursor salts is also an important step in the preparation of many fine powders. For example, fine powders of many carbonates and metallo-organic precursors are thermally decomposed into fine oxide and non-oxide powders.

The industry's ability to produce ultrapure, ultrafine ceramic powders created the need for new and improved fabrication methods beyond the more conventional ceramic processing techniques, such as extrusion and slipcasting. The dispersion of fine powders in liquids had to be improved in order to prepare stable suspensions. This improvement led to a better understanding of the physical chemistry of the solid-liquid interfaces, which in turn led to new colloidal forming techniques. Among such techniques, injection molding and isostatic pressing are the most prevalent.

Injection molding is a relatively inexpensive, high-volume method for making near-net-shape, fine powder ceramic components.[10] This method essentially consists of mixing fine ceramic powder with a thermoplastic or thermosetting polymer in a mold at a temperature that allows the mixture to have the proper fluidity under pressure. A plunger is then pressed against the heated mixture, forcing it into a tool cartridge of the desired shape. Injection molding, which was initially developed for the plastics industry, is finding increased use in the manufacture of advanced structural ceramic components.

Hot isostatic pressing involves heating an already fired ceramic piece at a very high constant pressure.[11] The pressing is usually accomplished in an inert gas at a high temperature. This method has proven to be invaluable in the sintering of difficult to densify materials such as silicon carbide and silicon nitride.

Research efforts are in pursuit of better fabrication methods for advanced structural ceramics, especially fiber composites. One such method under development is called the Dimox method[12] developed by Lanxide Corp. This method makes a preform using a conventional ceramic forming process and a unique oxidation method discussed in greater detail under metal matrix composites.

Joining Methods.—Because of their size and complexity, some large components cannot be processed as a single unit. Moreover, different components have been made of different materials that usually require different processing methods. Such considerations make manufacturing of many structural parts as a single unit virtually impossible, requiring the joining of many advanced ceramics in structural applications. Among a number of new joining methods currently being considered are liquid phase brazing, active metal brazing, and solid-state and diffusion joining.[13]

Thermal expansion mismatch between ceramics and metals poses the greatest difficulty in the ceramic-to-metal joints. Large thermal expansion difference results in high residual stresses at the joints, thus lowering joint strengths. Therefore, all the joining techniques concentrate on minimizing the residual stresses at the joint. Use of a ductile compliant metal layer helps minimize residual stress concentrations by distributing the stresses over the entire metal-to-ceramic interface. Choosing a compliant metal with an intermediate thermal expansion value between the two materials to be joined helps to further reduce the residual stress.

Compression joining or shrink-fit brazing takes advantage of the thermal expansion mismatch between the ceramic and the metal by brazing the ceramic component into the metal at a temperature that allows the plastic deformation of the metal around the ceramic component.[14] Upon brazing, the metal with higher thermal expansion shrinks around the ceramic, providing a "good joint" and compressive stress on the ceramic.

A liquid phase brazing technique is a highly developed method for joining dissimilar materials.[15] Brazing of metals poses little or no difficulty, but brazing of ceramics is extremely difficult mostly due to high temperature requirements, difficulty of wetting of the ceramic surface by the metal, and differential thermal expansion between ceramics and metals. Most R&D efforts go into alleviating these problems in ceramic-metal joint systems. Wetting problems have mostly been overcome by inserting an intermediate layer between the metal and the ceramic. Eutectic compositions of Ni-Cr-Si, Nb-Mo, Ti-Al-Fe, and Ag-Al-Ti have been extensively studied as potential interlayers.

High-strength silicon nitride-metal joints have been made with a thin layer of aluminum metal sandwiched between two layers of aluminum-10% silicon alloy. Similarly, silicon carbide-steel joints have been successfully formed with copper-35% manganese and copper-carbon composite compliant layer.

The greatest disadvantage of active metal joints is their lack of high-temperature capability compared to the ceramic component. The use of very high temperatures during the brazing process—in order to form liquid for wetting of the ceramic surface—results in the formation of high residual stresses, which in turn cause high strain levels, leading to weakening of the joint.

Reduction of residual stresses at the joint has been the subject of numerous investigations.[16] Ceramics and metals with large thermal expansion differences have been shrink-fitted to form a compression joint. The essence of compression joint is to design a ceramic component with a hub or platform upon which the metal can be isothermally forged using a compliant interlayer. The metal component, momentarily heated to effect its plastic deformation under applied pressure, is placed around

the ceramic shaft and is shrink-fitted by gradual cooling. The shrink-fit joining is relatively simple and reproducible and gives joint strengths of 200 Mega Pascal or higher at 600° C.[17] Moreover, this technique, which is the most expensive of joining methods, provides an intimate contact between the joined surfaces of complex shapes, uniformly distributes the residual stresses over the whole ceramic face so as to eliminate any stress concentrations, and avoids potentially harmful chemical reactions between the ceramic and metal. This method is especially appropriate for forming blades-to-disc, valve-to-shaft, and rotor-to-shaft joints.[18]

Although surface morphology of the ceramic component in ceramic-metal joints appears to play an important role in the joint quality, very few studies have been concerned with surface morphology effects. Rough surface morphology leads to good mechanical bond when a ceramic-metal joint is formed using a metallic filler layer. However, excessive roughness can limit effective wetting of the ceramic by the liquid metal, thereby leaving voids in the joint that may act as fracture origin and stress concentration centers. When this happens the joint is significantly weakened.

Nitride glass compositions (in the system Y-Al-Si-O-N) have been shown to be excellent candidates for joining ceramics to ceramics, especially silicon nitride to silicon nitride, in the same manner the grain boundary phases join individual silicon nitride grains in monolithic polycrystalline ceramics on a microstructural level.[19] Outstanding physical characteristics of nitride glasses, such as hardness, Young's modulus, and very high melting points help form strong high-temperature ceramic-ceramic joints. Such properties improve with nitrogen content. Close joints, formed by intimate glass-ceramic interaction, prevent the formation of voids, lead to excellent bond strengths, and exhibit excellent room temperature toughness.

Applications.—Current and potential areas for advanced structural ceramics range from heat engines to electronic devices and optical sensors. Theoretically, the development of an all-ceramic heat engine could increase efficiency threefold to fourfold. Currently, heat engines with cooling systems, such as automobile engines, operate at about 25% efficiency. Almost 65% of the energy is dissipated by internal cooling and through the exhaust system. The remaining 10% is lost in the form of frictional heat.

Advanced ceramics also are used in capacitors, integrated optic devices, gas sensors, and cutting tools. Capacitors have electric components that store electric charges and are employed in conjunction with other active electric components to perform a variety of functions, such as reducing noise levels in an electric signal (static in radios). Ceramics used for nonconductive parts in capacitors serve as dielectric layers that insulate the conducting components from the electrical charge. Aluminum oxide, tantalum pentoxide, and natural mica are examples of ceramics used as dielectrics.

Integrated optic circuits are devices that perform a variety of functions on the light beams they guide. The largest end use for these devices will be in fiber-optic communication systems, especially for computer-to-computer data links. Other potential optical end uses may include sensing and signal processing. In the near term, these devices are expected to be manufactured using single-crystal ceramics, such as lithium niobate.

Sensors are devices that respond to a changing condition. As such, they are used to monitor a number of mechanical, chemical, electrical, magnetic, and thermal stimuli. For example, ceramic oxygen sensors are installed in automobiles to help monitor fuel combustion by responding to the amounts of oxygen levels in the fuel mixture. Other places that ceramic gas sensors are used in automobiles are self-regulating heaters and current limiters.

Metal cutting and machining tools have been used since ancient times to remove excess materials during the manufacturing process. A relatively new class of cutting tools made from advanced structural ceramics, such as alumina, silicon carbide, and silicon nitride, have enhanced power efficiency and cutting precision. In addition, a series of new ceramics, cubic boron nitride and alumina-titanium carbide, have allowed even higher cutting speeds, better precision, and longer tool life of cutting tools.

Testing.—Advanced structural ceramics are usually required to retain high strength, stiffness, and integrity in several thermal and chemical environments where stress, fatigue, corrosion, and impact are encountered. Development of such materials of diverse characteristics demands improved nondestructive evaluation (NDE) technology currently unavailable. Techniques[20] used in the characterization and testing of advanced ceramics include: X-ray diffraction (XRD), ultrasonics, acoustic emission measurement used to determine Young's modulus, and high-resolution optical and electron microscopy. During the past decade, special efforts have been devoted to developing high-sensitivity and high-resolution NDE methods suitable for ceramics. High sensitivity denotes the ability of a technique to detect small differences in the property of a material. For example, an NDE method of high sensitivity designed to measure the elastic modulus of a solid will enable the tester to differentiate between two materials of elastic moduli very close to each other. The term resolution, usually, refers to a microscopic technique. A high-resolution light microscope, for instance, could independently observe two of the smallest grains on a polycrystalline surface. Conventional NDE methods designed to deal with metals and alloys have been modified to be helpful in studying surface and near surface regions in ceramics, but they are very limited in penetrating power to provide similar analysis for the bulk regions.[21]

A synergistic approach to ceramic component design, development, and fabrication needs to address the question of NDE as a part of each step. No one technique implemented at a single point in the process can provide sufficient information to produce a reliable ceramic component. Multiple NDE methods, carefully selected and implemented throughout the design and fabrication stages and correlated with one another, can help achieve this goal. NDE as a materials characterization method has been demonstrated, yet such techniques have not been applied systematically to advanced structural ceramic component fabrication. Better materials characterization through NDE will help improve the reliability and reduce the occurrence of nonconforming components in the production line. X-ray diffraction techniques (with relatively low X-ray intensities) are useful in phase identifications and in the study of the microstructure of surface and near surface regions.

Acoustic emission (AE) is sensitive to even very small cracks, thus showing promise in NDE of structural ceramics and ceramic-to-metal joints. In principle, the method involves application of a nominal load (stress) on the test specimen, reciprocal response of the test piece to the load, and recording of that response in the

form of acoustic waves. AE has been used to study the lifetime and integrity of plasma-sprayed thermal barrier coatings (TBC's). The integrity of the coating can be observed during thermal cycling.[22] Acoustic microscopy techniques appear to qualify for certain specific application areas. Three such methods, scanning laser acoustic microscopy (SLAM), scanning acoustic microscopy (SAM), and C-SAM, find their own unique area of application in materials characterization. SLAM is a transmission technique in which the specimen is illuminated with an ultrasonic wave. It is suitable for inspection of complex geometries as well as thin, flat parts. Both qualitative and quantitative information may be obtained. SAM and C-SAM are reflection mode instruments that are suitable only for surface and near surface characterization. SAM, by virtue of the higher frequencies utilized, gives the highest resolution and, therefore, is the technique of choice. Neutron diffraction stress analysis, nuclear magnetic resonance (NMR) imaging, pulse video thermography, holographic interferometry, and microfocus X-ray diffraction analysis techniques are upcoming new methods currently being developed.[23]

Accurate mapping of spatial variations in residual stresses, especially in ceramic-metal joints at various stages of production, is extremely important. Such knowledge of stress distribution patterns can be used to optimize the manufacturing process and improve product quality and reliability. Neutron diffraction stress analysis, still in the development stage, can be applied to metals and ceramics alike. It is similar to X-ray diffraction stress analysis with one very important advantage over XRD in that neutrons can penetrate many orders of magnitude (106) greater distances into the material than X-rays. This feature enables the technique to characterize the bulk material rather than only surface region. The bulk accuracy of the method, however, needs to be improved.

Nuclear magnetic resonance (NMR) imaging techniques developed at Argonne National Laboratory (ANL) have been used to study whiskers and short fiber distribution and orientation in ceramic matrix composites to varying degrees of success.[24]

Conventional radiographic techniques are not suitable for imaging volume (bulk) defects. For internal defects in complex ceramic components, microfocus X-ray diffraction provides high-resolution imaging beyond the surface regions. In this technique, regular X-rays are concentrated by using a microfocusing tube equipped with an X-ray lens that can reduce focal spot sizes down to 1 micrometer. The method is capable of mapping both short-range (<5 millimeters) and long-range (>5 millimeters) density gradients, detecting and sizing high- and low-density inclusions and, to a limited extent, microcracks, in both green and sintered ceramic components. It is capable of characterizing the bulk sample and appears to be suitable for complex shapes, such as turbocharger rotors and rotor shrouds.

Recycling.—The advanced ceramic industry, in spite of its rapid growth, is still in its infancy in comparison to established industries such as plastics, steel, and glass, and as such, the questions of waste management and recycling have received little attention from the industry or the Government.

The general understanding is that advanced materials are more difficult to recycle. Recycling many advanced ceramics may do little to alter the resource base for these materials, unlike many traditional materials that heavily rely on secondary recovery (e.g., steel, aluminum, and glass).

Advanced ceramic cutting tools offer the most promising and immediate potential for recycling, as they have a finite service life. Recovery of cemented carbide cutting and machining tools, including tungsten carbide (WC), using a number of chemical methods; e.g., cold stream, zinc, binder leaching, nitrate, and molten alloy fusion, has been studied.

Research on identification of recycling problems and opportunities is limited at present to several small-scale efforts to separate valuable components from used components. For example, the feasibility of separating Ti-Al-V alloy matrix components from SiC and B_4C-fiber reinforced metal matrix composites (MMC's) using eddy currents has been demonstrated. Similar techniques may be adapted for other MMC compositions to separate the reinforcements from the matrix. Recycling of the metallic component in MMC's should be relatively easy if the extent of chemical reactions between the metal matrix and the ceramic reinforcement is negligible at the melting temperature of metal. Separation can be accomplished by heating and simple filtration. However, if reinforcement significantly reacts with the molten metal, e.g., the case with B or SiC in contact with molten superalloy composition, separation of the components by physical means may present serious practical problems. New separation techniques may be needed for such systems.

Annual Review

Production.—Production data for individual advanced ceramic powders are not available from a single consistent source. This is due in part to the proprietary nature of the information and also because the production levels are, in many cases, a small part of the individual company's total business.

The U.S. Bureau of Mines estimates total production of silicon carbide in the United States and Canada was 115,540 metric tons in 1989, most of it for abrasives and refractories. High-purity "green" silicon carbide production for advanced structural ceramics is primarily for R&D use and is produced in-house for those purposes or is imported from Japan and Western Europe.

Silicon nitride and sialons (silicon aluminum oxynitrides) find use strictly in advanced structural ceramics. Reliable figures for production are unavailable; it appears that the only U.S. production is by manufacturers for their own use, and there is no domestic supplier of high-purity powder. Powder can be purchased from sources in Canada, the Federal Republic of Germany, Japan, Sweden, and the United Kingdom. Worldwide production is estimated at about 400 metric tons. Production data for the various forms of zirconia for advanced structural applications are also unavailable. A rough estimate, based on conversations with major producers in the United States, is that 1,000 to 2,000 metric tons is currently produced. Though no reliable data are available, it can be reasonably assumed that production of advanced ceramic powders is a very small percentage of total ceramic production.

Consumption.—Sales of the advanced structural ceramic components (glass included) of the major categories of ceramics by U.S.-owned companies, derived from the Ceramic Industry surveys for 1986-90,[25] are listed in table 4. Worldwide sales are included for 1990. These data provide a perspective from which to view advanced ceramics (which include porcelain insulators, electronic, optical, and magnetic materials). In 1990, worldwide sales of advanced structural ceramics reached $13.6 billion. While not inclusive, this figure represents the sales volume reported by

145 worldwide advanced structural ceramic producers in the Ceramic Industry's Annual Giants in Ceramics survey. Approximately 28% of these sales is from U.S.-owned companies. Electronic applications dominated the field in 1990. Sales of capacitors, substrates, and packages captured 48% ($6.5 billion) of the total; 12% ($1.6 billion) went to low-voltage electrical porcelain; and the remaining 17% ($2.3 billion) went to various electrical-electronic components (ferrites, piezoelectrics, and other sensors). Sales of engineering ceramics, ceramics used with optical fibers, and other ceramics captured 10% ($1.4 billion), 9% ($1.2 billion), and 4% ($0.6 billion), respectively, of the total market.

Current Research.—TBC's have been gaining wide acceptance in heat engine applications.[26] Coatings typically consist of an insulating ceramic coating with an underlying oxidation-resistant metallic interface between the substrate and itself. The TBC's must endure repeated thermal cycling and severe chemical environment of operating engine. Coating of the combustion chamber with TBC's allows the operation of the engine at higher temperatures, leading to increased thermodynamic efficiency. In addition to insulating the metal against high temperatures, TBC's also protect the metal components against the corrosive environment of the combustion chamber.[27]

Currently, zirconia-base coatings are most commonly used as TBC's as they possess the properties of low thermal conductivity (good insulation), high thermal expansion (good match with metals), and high mechanical strength at elevated temperatures. Zirconia, however, undergoes polymorphic transformation (changes from one crystalline form to another), which causes volume changes, leading to excessive thermal strains and subsequent mechanical failure.[28] This, however, can be controlled by additions of stabilizing compounds, which are magnesium and yttrium oxides. For heat engine applications, partial stabilization of ZrO_2 with magnesium oxide prevents this harmful transformation. Stabilized zirconia (Mg-PSZ) is one of the toughest ceramics developed that comes close to meeting the property requirements automotive applications pose for engine cylinder liners, valves, valve seats, and follower inserts and valve guides. For automotive engine applications, major property requirements of ceramic TBC's are low thermal conductivity and low specific heat, high strength, high thermal shock resistance, matching thermal expansion to steel and/or iron, high fracture toughness, and high resistance to erosion and corrosion.

Outlook

Projections pertaining to advanced structural ceramic production are many with wide variations. Surveys and studies have been conducted and published. Among these more notable studies are those offered by R. N. Katz,[29] and Abraham.[30] Katz used a number of sources, including data from the U.S. Department of Commerce, the Long Term Credit Bank of Japan, and trade publications, as well as private discussions. The estimates, shown in table 7, do not include present or projected military applications, which could be significant.

TABLE 7

WORLDWIDE MARKET PROJECTIONS FOR HIGH-PERFORMANCE STRUCTURAL CERAMIC PARTS

(Million dollars)

Applications	1995	2005
Heat engine ceramics	1,000	4,000
Bearings	200	400
Cutting tools and metalworking	150	300
Industrial wear parts	450	900
Biomedical and dental, including crown	2,000	4,000
Total	3,800	9,600

Source: R. N. Katz.

Abraham's forecast of U.S. advanced ceramic markets is presented in table 8 for several different categories. Both Abraham's and Katz' predictions were made in the 1988-89 timeframe and reflect their opinion that advanced ceramics, which have held steady in sales during the latter part of the 1980's (see table 1), would experience rapid growth during this decade. Abraham estimates an almost doubling of the U.S. advanced market by 1995 and doubling again by the year 2000. Katz predicts similar doubling of sales between 1995 and 2005 for structural ceramics, as illustrated in table 7.

As of 1990, this rapid growth has not started; U.S. ceramic sales remained sluggish at a slightly lower level than that of 1986-89. The projections, however, are still reasonable expectations if continued progress is made in joining and testing technologies and cost efficiency for large-volume automotive applications as previously discussed.

TABLE 8

FORECAST U.S. ADVANCED CERAMICS MARKETS

(Millions of current dollars)

Applications	1990	1995	2000
Electronics	3,740	6,565	11,360
Structural:[1]			
Aerospace and defense-related	80	200	445
Automotive	81	310	820
Bioceramics	15	34	60
Cutting tools	92	246	500
Heat exchangers	15	50	100
Wear parts and other industrial	150	320	720
Total	433	1,160	2,645
Grand total	4,173	7,725	14,005

[1]Includes ceramic composites.

Source: Abraham, T. Advanced Ceramic Matrix Composites and Ceramic Fibers and Whiskers: New Developments, Applications, and Markets. Business Communications Co., Norwalk, CT. Summary from company prospectus. Oct. 1988, pp. 32.

POLYMER MATRIX COMPOSITES

Background

Definitions, Grades, and Specifications.—A polymer matrix composite (PMC) is a combination of an organic resin (matrix) and a reinforcing material in the form of continuous fibers in a number of patterns and weaves or short fibers, whiskers, or particles. Polymer composites reinforced with continuous fibers are generally referred to as advanced polymer matrix composites (APC). APC's are low-volume, high-value polymers that exhibit excellent strength-to-density ratios, high stiffness, and usually require specialized processing techniques. Matrix materials may consist of polyimides, polyacrylates, polyesters, or a number of other high-temperature resins. Fibers may be of

high-strength glass, carbon, boron, various ceramics such as alumina and silicon carbide, or other high-strength organic polymers. In general, the important physical properties of APC's are determined by the properties of the fibers rather than the matrix, so a myriad of polymers, blends, and alloys may be used.

Polymers are classified as two basic types: thermoplastic and thermoset. Thermosets are those polymers that form by irreversible chemical reaction and consist of strongly cross linked chains. Thermosets cannot be remelted and reformed but, rather, decompose at elevated temperatures. Because of the cross-linking, thermosets are strong and heat resistant but tend to be brittle. Examples of thermosets are epoxies, phenolics, vinyl esters, polyesters, and urethanes. Thermoplastics are polymers, with less cross-linking, that can be remelted and reformed. They tend to be less brittle (tougher), more flexible, and stronger in the direction across the strongly linked chains than between. Consequently, if the chains are aligned, the polymer is much stronger in one direction than the others.

In the case of advanced polymer composites, the materials of interest are the engineering and high-performance thermoplastic polymers and epoxies. The epoxies presently are used in about 95% of composites, while performance polymers are still being evaluated for use as polymer matrices. Detailed definitions, grades, and specifications for the hundreds of polymer materials are beyond the scope of this work but are readily available in the Plastics Encyclopedia.[31] Specifications for the composites themselves are not written as with commodity materials; the specifications are written for each individual application. About 95% of polymer matrix composites manufactured in 1989 were composed of an epoxy matrix reinforced with carbon fiber or high-strength glass fiber. This is a result of two factors. First, at the time, about 10 to 15 years ago, when property and performance specifications were written for current aerospace systems, epoxy was the only matrix material sufficiently developed and understood to be used successfully. Second, epoxy composites are relatively easy to fabricate because the resin-catalyst mixture has a low viscosity, suitable for a variety of prepregging and forming operations. Moreover, epoxies wet fibers effectively to produce a strong bond and possess the strength, stiffness, corrosion resistance, and high-temperature stability needed for many 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. Because epoxies are thermosets, they are difficult to recycle as they are formed by irreversible chemical reactions. They do not soften or melt but decompose.

Products for Trade and Industry.—Advanced polymer composites, because of cost, are afforded relatively few uses, most notably in defense, aerospace, and sporting goods where performance benefits outweigh cost considerations. In defense and aerospace they are used in helicopter rotors, blades, and tail assemblies and in weapons systems as rocket motor cases on missiles and space vehicles. They are finding increasing use in secondary aircraft structures such as control surfaces (flaps, rudders, and stabilizers) or fairings (streamlining covers for aerodynamics) and more recently as primary structures such as wing, tail, and fuselage sections. Composites used in McDonnell Douglas aircraft's military planes, for example, have increased from about 2% in the F-15 to 27% on the AV-8B Harrier currently in production.[32] Boeing Co. has teamed with Bell Helicopter to manufacture the V-22 tilt-rotor aircraft and with Sikorsky Aircraft to make the new LH helicopters, both with airframes and skins largely constructed of epoxy-carbon composites.

For commercial aircraft, the major manufacturers are planning to increase use of polymer composites in new generation planes. Boeing, for example, plans to increase the composite content of its highly successful 757 line from the present 3% to 24.5% during the 1990-2000 timeframe.[33]

In sporting goods, the desire for better performance regardless of cost has created a market for fiberglass and carbon reinforced polymers in tennis rackets, golf club shafts, skis, sleds, and toboggans; fishing poles; and bicycles.

In the industrial market, the primary use of polymer composites is in tooling, but many other applications are developing. Robot arms, for example, with less inertial mass than metals, contribute to greater speed and lower systems costs in automated manufacturing.

Technology.—**Processing.**—Most PMC materials processing technologies influence the properties of the finished product, perhaps far more than metals or ceramics. Various fabrication technologies applicable to PMC's are listed and described briefly in table 9.[34] The table also lists the predominant type of polymer processed, the form of the polymer prior to processing, and the typical shape of PMC made. The exact details of many of the techniques are proprietary. New processing techniques are often cited as reasons why a product has enhanced performance properties.

Properties can be controlled by conditions under which materials are processed. In particular, fibers and films are made by processes that include close control of polymer chain orientation by drawing under controlled temperatures. Orientation of polymers affects strength, stiffness, and elevated temperature properties. For example, PET bottles can now be made under controlled conditions to achieve a thermal stability to 190° F. This capability opened the hot-filled food packaging market to this resin for the first time. Another example showing the importance of this kind of processing technology is the optical disk. A new injection molding technology using a two-stage clamping cylinder and contractible mold (both patented) can lower disc stress through more even cooling. As a result, birefringence, the measure of the deflection of a laser beam designed to "read" the binary-coded disk, is reduced. Therefore, deflection is reduced from 40-60 to 10-20 nanometers, permitting faster cycle times (25% to 30%). The polycarbonate resin used by optical disk manufacturers has not changed for the new technology, but the final product is improved.

Mold design is a preliminary fabrication step. Molds must allow for surface appearance and be able to withstand corrosiveness of both the material and the process. It must also match the flow properties of the resin, the geometry of the part, and the mold materials. Most importantly, the mold should be tested as a prototype, just as the product itself should be tested. If the mold is changed, the product must again be prototyped. An example showing the importance of proper processing and mold design is reinforced thermosets. Because the long fibers in the thermosets are broken up and do not flow into the thinner sections, transfer or plunger molding will degrade strength compared to compression molding. In addition, fibers may flow off into thin, intricate sections of a resin product during compression molding. In such a case, equal properties may be available from a less expensive material that can be injection molded.

TABLE 9

POLYMER MATRIX COMPOSITES FABRICATION TECHNOLOGIES

Process	Predominate polymer processed	Materials type or form	Shape characteristics and common products	Process description
Open mold (contact molding)	Thermosetting (primarily RP forming process 40% of total)	Liquid resin (spray, hand applied) or thermoplastic sheet; reinforcing material	Large, complex	Reinforced shapes are formed by using open molds and room-temperature curing resin is brushed, poured, or sprayed onto reinforcing material layered in mold. Spray up method, resin and chopped fibers sprayed onto mold. Reinforced vacuum formed sheet method, mainly acrylic sheet is vacuum formed and reinforced resin applied to back surface. The process also includes encapsulating or potting.
Reaction injection molding (RIM)	Thermosetting (urethanes)	Liquid	Large, intricate, high-performance, solid, or cellular	Reactive components are generally mixed by impingement in a chamber and then injected into a closed mold.
Rotational molding	Thermoplastic	Powder, liquid, precatalyzed	Hollow bodies, complex	Premeasured material poured into mold. The mold is closed, heated, and rotated in the axis of two planes until contents have fused to inner walls of mold. The mold is opened and part removed.
Thermo-forming	do.	Film sheet	Simple, thin-wall	Film is continuously roll-fed or sheet is cut and either placed over male or female mold. Part is formed by vacuum forming, draping and heating, pressing or many other variations.
Bag molding	Reinformed thermosets	Prepregs (partly cured), epoxy or polyester soaked	Simple, contoured, large	A number of layers of reinforced material are placed (hand layup) between two inexpensive mold halves; the entire assemble is placed in plastic bag and low pressure applied (via vacuum, external air or auto-clave methods); the assemble is heated and cured.
Centrifugal casting	Thermosetting	Liquid resin, fiber reinforcement	Uniform wall thickness	Resin is applied to the inside of a rotating cylindrical mold and is uniformly forced against the reinforcing material. Heating flowing and curing.
Continuous laminating	Polyester	Resin, reinforcement	Thin, flat or curved profiles	Reinforcement is passed through a resin bath, faced with cellophane, passed through squeeze rolls, and heated.
Filament winding	Epoxy, polyester	Resin	Round, rigid	Continuous filaments (usually glass) in form of roving are saturated with resin and machine wound onto mandrels having shape of desired finished part. Once winding is completed, part and mandrel are placed in oven for curing. Mandrel is then removed through porthole at end of wound part.

With the advent of sophisticated computer technology has come the plethora of computer-assisted design-computer aided manufacturing (CAD-CAM) software and supporting hardware.[35] These CAD-CAM programs save labor by using computers to perform jobs formerly requiring large amounts of materials and design engineers' time. Skilled people are freed from repetitive tasks. Moreover, these tools have enhanced the ability of engineers to design products that can meet demanding physical, chemical, or other environments. From the moldmakers' viewpoint, the advantages are similar: elimination of costly prototyping, rapid optimization of mold cavity configurations, and computerization of mold component selection.

Joining Methods.—Though the number of component parts in a system is generally less with polymer composites than with metal parts, particularly in aerospace systems, parts must still be assembled with fasteners or adhesives. Obviously, if the strength of the joint is less than that of the composite parts, much of the advantage of the composite is nullified. Joining methods are, therefore, receiving a great deal of attention. Improved metal and polymer materials for use as bolts and rivets are being sought, and high-strength adhesives and direct bonding methods are under

investigation. Perhaps more importantly, new computer-aided design methods have been developed 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.

Applications.—Polymers have been replacing glass, ceramics, metals, and paper in many applications. They are being used in applications from microwave food packaging to sporting goods and satellites. Their special properties have been exploited by design engineers in structural applications as engineering plastics. Polymers have much to offer. In general, they are corrosion resistant, less expensive to produce, higher in strength-to-density ratios, and readily adaptable to a single fabrication of a multifunctional component.

Recycling.—In 1990, the total U.S. resin production will reach about 54 billion pounds, and about 38 billion pounds will be discarded as waste.[36] In the case of APC's, the problem is how to separate the fiber from the resin and reuse them economically. Recycling APC scrap may be economically feasible because of the high cost of carbon fibers. Because the matrix materials currently used are predominantly epoxy resins, studies have been conducted for that type of material.[37] In the uncured condition, epoxies are soluble in organic solvents such as acetone or methyl ethyl ketone. After the epoxy is dissolved, the recovered carbon fiber can be reused. After curing, however, epoxies are insoluble, so this procedure can only be used for prompt scrap and rejects.[38] Epoxies can also be decomposed thermally below 400° C and the fiber may be recovered; the fiber surface, however, is affected so that lower fiber-matrix adhesion is observed in new products. Fiber breakage may be sufficient to render fibers useful only as discontinuous reinforcement. To date, the only satisfactory use for epoxy scrap is as finely ground filler for virgin resins.

Annual Review

Sales figures for 1989 and 1990 for a number of common polymeric products are summarized in table 10. Although polymers (especially thermoplastics) are put into three separate categories, namely commodity, engineering, and high-performance or advanced composites, no sharp, unambiguous distinction exits among them. Polyvinyl chloride and copolymers are the common examples of commodity products, whereas polyimides and polycarbonates represent two of the well-known engineering polymers.

TABLE 10

U.S. PLASTICS SALES

(Million pounds)

Material	1989	1990
Acrylonitrile-butadiene-styrene	1,237	1,213
Acrylic	739	751
Alkyd	325	320
Cellulosics	91	80
Epoxy	483	464
Nylon	580	570
Phenolic	2,097	2,827
Polyacetal	143	143
Polycarbonate	624	620
Polyester, thermoplastic	2,097	2,337
Polyester, unsaturated[1]	1,319	1,227
Polyethylene, high-density	8,173	8,505
Polyethylene, low-density[2]	10,803	11,876
Polyphenylene-base alloys	196	199
Polypropylene and copolymers	7,303	8,132
Polystyrene	5,131	5,137
Other styrenics[3]	1,180	1,116
Polyurethane	3,224	3,265
Polyvinyl chloride and copolymers	8,536	9,297
Other vinyls	900	915
Styrene acrylonitrile (SAN)	108	134
Thermoplastic elastomers	542	584
Urea and melamine	1,381	1,439
Others	310	330
Total	58,251	61,480

[1]Resin only.
[2]Includes LLDPE.
[3]Excludes ABS and SAN.

Source: Modern Plastics.

Polyetherimide and polyether sulfur, among the fastest growing advanced polymer composites, represent two of the better know advanced polymer materials. Table 11 summarizes the estimated consumption of some of the Advanced and Engineering polymers by industrial sector through 1995.

Legislation and Government Programs.—Some important governmental decisions may affect the polymers industry within the immediate future. According to the Society of Plastics Industry (SPI), Congress is considering the reauthorization of the Resource Conservation and Recovery Act for solid waste regulations. This act could ultimately dictate national recycling goals. The 1990 version of the Clean Air Act and the new energy taxes are also symptomatic of the new upcoming issues. In light of these happenings, an SPI task force is reviewing the industry's stand on a workable energy policy.

TABLE 11

U.S. CONSUMPTION OF ADVANCED AND ENGINEERING POLYMERS, BY INDUSTRY

(Thousand metric tons)

Industry	1985	1990	1995
Aerospace and automobile	115	170	260
Electrical and electronic	140	185	285
Building and construction	65	100	95
Home appliances	35	65	75
Other	155	240	337
Total	510	760	1,050

Source: U.S. Bureau of Mines.

Consumption and Uses.—During the 1980's, PMC's grew at an average annual rate of 5%. This time period saw the introduction and market success of such products as all-composite business aircraft, composite frames for sports equipment, fiberglass underground gasoline storage tanks, and composite-skinned vehicles. On the whole, the PMC industry has weathered the current recession well, with significant downturns only in the construction, marine, and consumer products markets. The 1989 drop in shipments reflects general economic conditions rather than a reduction in the likehood for continued growth in PMC usage. The GNP, industrial production, housing starts, and retail sales experienced a decline in 1989, the first year since 1982. The market rebounded in 1990 with a strong performance in consumer products and electrical, transportation, and corrosion-resistant products, despite a weak economy. For the immediate future, higher gasoline prices due to new taxes should increase the use of PMC's in cars and trucks in order to further improve fuel economy through weight reduction.

U.S. polymer matrix composite markets can be divided into nine categories: aircraft-aerospace-military, construction,

consumer products, appliance-business equipment, corrosion-resistant equipment, electrical-electronic, marine, transportation, and other. Table 12 presents the shipments of these materials by market category for the years 1986-90 with 1991 estimated figures. Data for this table were compiled by the U.S. Bureau of Mines, The Society of the Plastics Industry Inc. and Composites Institute, and Kline & Co. Inc.[39]

The U.S. aircraft-aerospace-military market has remained somewhat stagnant during the past few years. The 1989 market was 41 million pounds. In 1990, the market reflects a similar figure. Sales for 1991 are expected to remain at 41 million pounds, through the replacement of existing aircraft parts containing PMC's.

The appliance-business equipment market used 152 million pounds of PMC's in 1989. Shipments in 1990 grew almost 2% to 155 million pounds, and 1991 figures are expected to remain about 155 million pounds.

The U.S. construction industry felt the recession with a 3.4% drop in PMC consumption in 1989 to 479 million pounds, down from 495 million pounds in 1988. No significant rebound was observed in 1990. The forecast for 1991 is a further decrease, down to about 450 million pounds.

The U.S. consumer products market stood at 162 million pounds in 1989. Shipments rose by 1.0% in 1990 to 164 million pounds. This market is not expected to change in 1991.

In 1989, the U.S. corrosion-resistant market stood at 349 million pounds. A modest rise was seen in 1990 to 354 million pounds. Shipments in 1991 are expected to be 358 million pounds. PMC's continue to replace other materials in places where corrosion resistance, high strength, and ease of assembly are required.

Shipments to the electrical market reached 231 million pounds in 1989. An increase of 2.2% was seen in 1990, with shipments to 236 million pounds. No increase in 1991 is expected. Penetration of PMC's into the electrical market is driven by the trend for smaller components. High strength, high electrical and corrosion resistance, and continually improved high-temperature performance should lead to increased use of PMC's.

The popularity of fiberglass boats over the past decade made the marine market the fastest growing user of PMC's. High interest rates, overproduction, and the economic slump left the retailers with excess inventories, resulting in a market decline in 1989 sales. Continued high retail inventory caused the 1990 market to remain about the same. Purchases are expected to continue to decline in 1991, and shipments of PMC's should drop to 400 million pounds.

In 1989, U.S. PMC use in the transportation market stood at 685 million pounds. In 1990, use increased 2.6% to 703 million pounds. The 1991 market is expected to grow by 1.5% to 713 million pounds.

Other products using PMC's include medical equipment, orthopedic appliances, and dental materials. In 1989, consumption totaled 78 million pounds. This market increased to 80 million pounds in 1990. A modest increase to 81 million pounds is expected in 1991.

TABLE 12

PROFILE: PLASTIC MATERIALS AND RESINS POLYMER COMPOSITE SHIPMENTS, BY MARKET (THERMOSET AND THERMOPLASTIC RESINS)[1]

(Million pounds)

Market	1985	1986	1987	1988	1989	1990	1991[e]
Aircraft-aerospace-military	32	37	36	39	41	42	41
Appliance-business equipment	133	137	141	150	152	155	155
Construction	445	456	506	495	479	482	450
Consumer products	142	149	167	169	162	164	164
Corrosion-resistant equipment	295	291	329	349	349	354	358
Electrical-electronic	191	201	214	230	231	236	236
Marine	335	340	413	452	412	414	400
Land transportation	563	585	656	695	685	703	713
Miscellaneous	82	83	75	80	78	80	81
Total	2,218	2,279	2,537	2,659	2,589	2,630	2,598

[e]Estimated.
[1]Includes reinforcements and fillers.

Sources: U.S. Bureau of Mines, The Society of the Plastics Industry Inc. and Composites Institute, and Kline & Co., Inc..

World Review.—There are 70 to 75 producers of AP resins worldwide, most of them in Japan, the United States, and Western Europe. The United States is the largest producer of advanced polymer resins, accounting for one-fourth of world production. It is a net exporter of the largest volume polymers.

The use of PMC's is highly concentrated in the aerospace sector. Of the 42 million pounds produced in 1990, 48% was consumed by the aerospace industry. In terms of dollars, $4 billion was generated in 1990, with almost 68% used in the aerospace industry. Owing to its large aerospace industry, the United States is the leading producer and end user of PMC's. Within the aerospace market, military-defense applications contain nearly one-half the market share, 25% of the total world market. Western Europe has a rapidly developing commercial aerospace business, which will trigger PMC growth in this region.

The second largest market for PMC's in 1990 was the recreational market. Japan dominates the use of PMC's for recreational applications. The recreational sector accounted for 21% of the PMC's produced in 1990. In dollars, the recreational market was $520 million or 13% of the world market.

Current Research.—The level of research effort in polymer technologies for structural, electronic, optical, magnetic, and medical uses is very high in the Federal, industrial, and academic sectors. General activities are summarized below.

New Matrix Materials.—Current research to develop new matrix materials is aimed at overcoming the disadvantages, such as low-fracture toughness, processing by irreversible reactions, and high viscosity. A number of epoxy blends with greater fracture toughness than epoxies and lower viscosity than thermoplastics are being formulated and evaluated. These materials will find uses in areas demanding improved

impact resistance, but will also be difficult to repair or recycle. A number of liquid crystal polymers and engineering polymers are also being evaluated as matrix materials to optimize strength, stiffness, fracture toughness, corrosion resistance, repairability, and recyclability.

New Fibers.—The effectiveness of fibers as reinforcements in advanced polymer composites 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 for PMC is in high gear. A variety of silica, aluminosilicate, boron, silicon nitride, silicon carbide, and organic fibers is also being developed and evaluated for the formation of improved composite structural materials.

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 readily detectable by visual inspection. Methods for inspection of each component prior to incorporation into a finished assembly are being tested as nondestructive evaluation methods. 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).

Any structural material under stress deteriorates with use because of formation of microcracks, weakening of the fiber-matrix bond, and fiber breakage. Environmental conditions, such as exposure to chemical agents, ultraviolet radiation, heat, atomic oxygen (in space), and ionizing radiation, contribute to degradation of the properties of materials. Because of the lack of experience in longtime use of advanced polymer composites and the variability of properties and structures resulting from lack of uniformity in processing, much effort is being expended to evaluate new materials for deterioration in use. Nondestructive evaluation methods are being developed for periodic inspection of components in use, but the most promising methods being investigated at present are based on continual monitoring during service. Two methods presently under development involve incorporation of pressure sensitive detectors (piezoelectric or light emitters) coupled with wires or optical fibers to transmit data to a computer system or sound detectors to receive acoustic emissions from critical points in the component to be transmitted to an analyzing computer.

Outlook

The outlook for PMC's is steady growth. The aerospace industry is expected to continue to dominate the PMC marketplace, reaching about $6 billion in sales by the year 2000. Industrial sales are expected to overtake recreational sales and become the second largest PMC market by the year 2000. In fact, current industrial sales, now at the $400 million level, are expected to reach more than $950 million, whereas the $520 million recreational market is expected to reach about $850, as forecasted by Kline & Co. Inc.

The current recession, which has affected the PMC shipments since 1988, may continue its negative effect in 1992 shipments, but a modest increase for 1992 shipments can be expected. In spite of the current recession in the construction and marine markets, which may continue through 1992, long-term prospects for the plastics industry look promising. The automotive and aerospace industries should more than offset the slowing market in the construction industry. Major U.S. auto manufactures are geared to producing 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) in order to meet the demands for fuel efficiency, which is more readily achieved by weight reduction. With the anticipated price reductions, due mostly to improved processing methods, PMC's should continue penetrating the aerospace, corrosion-resistant products and electrical markets.

ADVANCED ALLOYS AND METAL MATRIX COMPOSITES

Background

Definitions, Grades, and Specifications.—Metallic alloys are materials formed by combining two or more metals in order to develop a second material that has physical, mechanical, and thermal properties superior to any of the original metals. Brass, bronze, and stainless steel are the most commonly used alloys, but new compositions are constantly being developed. Advanced, or superalloys, which contain nickel, iron, or cobalt with significant amounts of chromium, frequently are used at temperatures above 500° C. Even though alloys originated a long time ago, there have recently been major advances in developing superalloys and processing technology. Their development has been a major contributor to the current interest in advanced materials. Compositions of selected superalloys that possess outstanding properties, including high-temperature strength and corrosion resistance, are shown in table 13.[40]

Although some metal matrix composites (MMC's) existed since the 1960's, they started gaining commercial significance in 1983 with the introduction of a composite diesel engine piston by Toyota Motor Corp. Virtually every piston manufacturer in the world is now developing composite pistons. 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 modulus) to offer greater strength in shear and compression and higher service temperature capabilities. As a result of availability of relatively inexpensive reinforcements and the development of various processing routes, interest in MMC's for aerospace, automotive, and other structural and high-technology applications has increased during the past 5 years.

Reinforcement materials for MMC's include carbides (SiC, B_4C), nitrides (Si_3N_4, AlN), oxides (Al_2O_3, SiO_2), as well as elemental materials, such as carbon. SiC, for example, is utilized in aluminum and magnesium MMC's in all three forms (fiber, whisker, and particulate), and carbon is usually used as continuous fiber reinforcement. Discontinuously reinforced MMC's employ particulates, whiskers, or short fibers as reinforcing components. Table 14 provides a list of currently available fibers, whiskers, and particulates for reinforced aluminum in composites with aluminum. This class of MMC's has, recently, attracted considerable attention as

TABLE 13

COMPOSITIONS OF SELECTED SUPERALLOYS[1]

Alloy	Composition percent										Other
	Cr	Ni	Co	Mo	W	Nb	Ti	Al	Fe	C	
Fe-Ni-base:											
19-9DL	19.0	9.0	—	1.25	1.25	0.4	0.3	—	66.8	0.30	1.10 Mn; 0.6 Si
Incoloy 800	21.0	32.5	—	—	—	—	.38	0.38	45.7	.05	0.8 Mn; 0.5 Si
A-286	15.0	26.0	—	1.25	—	—	2.0	.2	55.2	.04	0.005 B; 0.3 V
V-57	14.8	27.0	—	1.25	—	—	3.0	.25	48.6	[2].08	0.01[2] B; 0.5 V
Incoloy 901	12.5	42.5	—	6.0	—	—	2.7	—	36.2	[2].10	—
Inconel 718	19.0	52.5	—	3.0	—	5.1	.9	.5	18.5	[2].08	0.15[2] Cu
Hastelloy X	22.0	49.0	1.5	[2]9.0	.6	—	—	2.0	15.8	.15	—
Ni-base:											
Waspaloy	19.5	57.0	13.5	4.3	—	—	3.0	1.4	[2]2.0	.07	0.006 B; 0.09 Zr
M252	19.0	56.5	10.0	10.0	—	—	2.6	1.0	<.75	.15	0.005 B
Udimet 500	19.0	48.0	19.0	4.0	—	—	3.0	3.0	[2]4.0	.08	0.005 B
Udimet 700	15.0	53.0	18.5	5.0	—	—	3.4	4.3	<1.0	.07	0.03 B
Astroloy	15.0	56.5	15.0	5.25	—	—	3.5	4.4	<.3	.06	0.03 B; 0.06 Zr
Rene 80	14.0	60.0	9.5	4.0	4.0	—	5.0	3.0	—	.17	0.015 B; 0.03 Zr
IN-100	10.0	60.0	15.0	3.0	—	—	4.7	5.5	<.6	.15	1.0 V; 0.06 Zr 0.015 B
Rene 95	14.0	61.0	8.0	3.5	3.5	3.5	2.5	3.5	<.3	.16	0.01 B; 0.05 Zr
MAR-M 247	8.25	59.0	10.0	.7	10.0	—	1.0	5.5	<.5	.15	0.015 B; 0.05 Zr 1.5 Hf; 3.0 Ta
IN MA-754	20.0	78.5	—	—	—	—	.5	.3	—	—	0.6 Y_2O_3
IN MA-6000E	15.0	68.5	—	2.0	4.0	—	2.5	4.5	—	.05	1.1Y_2O_3; 2.0 Ta; 0.01 B; 0.15 Zr
Co-base:											
Haynes 25 (L-605)	20.0	10.0	50.0	—	15.0	—	—	—	3.0	.10	1.5 Mn
Haynes 188	22.0	22.0	37.0	—	14.5	—	—	—	[2]3.0	.10	0.90 La
S-816	20.0	20.0	42.0	4.0	4.0	4.0	—	—	4.0	.38	—
X-40	22.0	10.0	57.5	—	7.5	—	—	—	1.5	.50	0.5 Mn; 0.5 Si
WI-52	21.0	—	63.5	—	11.0	—	—	—	2.0	.45	2.0 Nb + Ta
MAR-M 302	21.5	—	58.0	—	10.0	—	—	—	.5	.85	9.0 Ta; 0.005B; 0.2 Zr
MAR-M 509	23.5	10.0	54.5	—	7.0	—	.2	—	—	.6	0.5 Zr; 3.5 Ta
J-1570	20.0	28.0	46.0	—	—	—	4.0	—	2.0	.2	—

[1]Cr—Chromium, Ni—nickel, Co—cobalt, Mo—molybdenum, W—tungsten, Nb—niobium, Ti—titanium, Al—aluminum, Fe—iron, C—carbon.
[2]Maximum percentage of composition.

Sources: Metals Handbook, 9th ed., v. 3, 1980, and Metal Progress 1982 Materials and Processing Databook, June 1982, except for IN MA-6000E and J-1570.

a result of availability of reinforcements at affordable prices (e.g., SiC particulates at $2.20 per pound) and suitability to standard metalworking processes for manufacturing.[41]

***Technology.*—Processing.**—Significant advances have been made in processing superalloys that have led to the development of compositions with much improved performance. Methods, such as directional solidification, single crystal growth, hot isostatic pressing, mechanical alloying, and rapid solidification, have fabricated alloys with controlled and refined microstructure leading to tailormade properties. Metal refining methods, such as vacuum induction melting, vacuum and remelting, and electroslag remelting, have allowed metallurgists to produce very high-purity metals and alloys.

Fabrication of MMC's ranges in complexity, from simple pouring of molten metal into molds containing preformed fiber reinforcement skeletons, to intricate methods .involving partially solidified metal, with or without reinforcement that agitate vigorously and quickly force the molten metal under high pressure into a mold. Every method offers its own particular advantages in terms of cost, protection of reinforcement, and adaptability. A number of the processing methods discussed under advanced structural ceramics are applicable to MMCs. The hot-rolling, hot-pressing, and hot-isostatic-pressing methods can be used to consolidate MMC preforms made by chemical or physical vapor deposition (CVD or PVD), thermal spraying, and

TABLE 14

ALUMINUM MATRIX COMPOSITES

Reinforcement material[1]	Percent (by volume)	Tensile strength (mPa)	Elastic modulus (GPa)	Density (g/cm^3)
None	—	140-620	70	2.70
B(c)	50	1,380	230	2.49
Al_2O_3(f)[2]	50	1,170	210	3.60
SiC(c)	50	1,480	230	2.93
SiC(w)	20	340	100	2.80
Graphite(c)	41	620	320	2.44
SiC(p)	15	455	97	2.77

[1]C—continuous fiber, f—fiber, w—whisker, p—particulate.
[2]Range of values for Al alloys from ref. (99).

TABLE 15

POTENTIAL COMMERCIAL APPLICATIONS OF MMC'S

Application	Desired properties	Anticipated composite system(s)[1]
Automotive:		
Engine blocks	Lightweight, heat resistance, strength, stiffness	SiC^1/Al
Push (connecting) rods	do.	SiC^2/Al,B/Al
Frames	Lightweight, strength, stiffness	SiC^1/Al
Springs	do.	SiC^2/Al
Piston rods and inserts	do.	SiC^1/Al
Battery plates	Stiffness	Gr/Pb
Driveshaft		
Electrical:		
Motor brushes and heat sinks	Electrical conductivity, wear resistance	Gr/Cu
Cable, electrical contacts	Electrical conductivity, strength	Gr/Cu
Utility battery plates	Stiffness, strength, corrosion resistance	Al_2O_3/Pb,Gr/Pb, fiberglass/Pb
Medical:		
X-ray tables		
Prosthetics	Lightweight, stiffness, strength	B/Al,SiC^2/Al
Wheelchairs	do.	B/Al,SiC^2/Al
Orthofies	do.	B/Al,SiC^2/Al
Walkers/canes	do.	B/Al,SiC^2/Al
Sports equipment:		
Tennis racquets	do.	B/Al,Gr/Al,SiC^1/Al
Ski poles	do.	B/Al,Gr/Al,SiC^1/Al
Skis	do.	B/Al,Gr/Al,SiC^1/Al
Fishing rods	Lightweight, strength, flexibility	B/Al,Gr/Al,SiC^1/Al
Golf clubs	do.	B/Al,Gr/Al,SiC^1/Al
Bicycle frames	Lightweight, strength, stiffness	B/Al,Gr/Al,SiC^1/Al
Motorcycle frames	do.	B/Al,Gr/Al,SiC^1/Al
Textile industry:		
Shuttles	Lightweight, wear resistance	B/Al,Gr/Al,SiC^2/Al
Looms	do.	B/Al,Gr/Al,SiC^2/Al
Other:		
Bearings		Gr/Pb
Chemical process equipment		Al_2O_3/Pb
Abrasive tools		B/Al_2O_3,SiC/Al_2O_3
Robotic manipulator arms		

[1]SiC whisker and/or continuous SiC filament.
[2]SiC whiskers only.

electrodeposition. For example, carbon fibers are coated with aluminum vapors (PVD) to produce carbon-reinforced aluminum preforms that are subsequently consolidated using hot-pressing techniques. In addition to the methods already discussed, several novel MMC processing technologies in the advanced stage of development are ready for prototype production. One such method is the Dimox process. This method, which is even better suited to MMC, has also been discussed under advanced structural ceramics.

Another relatively novel method for preparing MMC's involves the introduction of reinforcement into a vigorously agitated, practically solidified melt or slurry, called "compocasting." The visocity of the melt or slurry is controlled to maintain uniformity in the reinforcement distribution. Sufficiently high viscosity prevents the settling of the reinforcement phase. Recently, an aluminum-copper alloy reinforced with alumina fibers has been prepared using this method.[42]

Applications.—MMC's are currently used in several applications. Boron fiber reinforced aluminum tubes, for example, are used as cargo bay struts in the space shuttle and some sporting and recreational goods such as skis and bicycle frames. Aluminum-base MMC's are finding additional applications in airframes and in selective turbojet engine components. Titanium-base MMC's are being developed for turbojet compressors and superalloy-base MMC's for the thrust turbine airfoils. Additional application areas include advanced automotive components, such as pistons, rocker arms, and cylinder heads.

Recycling.—In the alloy-melting industry, making use of alloy scrap is common practice. Scrap metal is usually less expensive than primary metal and sometimes more available. There is a problem, however, with contamination of some of the scrap superalloys. The recycling chain begins with scrap produced from alloy production with contributions of obsolete scrap from part manufacturers, fabricators, and users of superalloys, mainly from commercial airlines or Government military aircraft. A user is defined as an organization that uses a finished product until the product is retired from service owing to wear, corrosion, inefficiency, or obsolescence. The user generates "obsolete scrap" when equipment is overhauled and parts replaced, or when equipment is

dismantled at the end of its useful "life-cycle." The scrap is usually in the form of solids, such as turbine blades and vanes.[43]

There are relatively few data available on the amounts of superalloy scrap being recycled, partly because of the proprietary nature of the data and partly because of the complexity of the recycling industry. Estimates, however, have been made by the U.S. Bureau of Mines for individual commodities based on reports received from producers. In a recent study conducted for the Air Force, based on superalloy scrap processor responses to the Bureau and extrapolated to account for the entire industry, about 55 million pounds of clean and contaminated superalloy scrap was processed in 1986. Of the scrap processed, about 92% was sold to domestic buyers and the remainder to foreign buyers. Most of the foreign material was refinery-destined grindings; the balance was vacuum-melting-grade superalloy scrap. In addition, about 72% of the total scrap processed was recycled into the same alloy, 20% was downgraded to a nonsuperalloy, and 10% was sold to refineries. The average composition of superalloy scrap processed in 1986 contained about 44% nickel, 16% chromium, 5% cobalt, less than 1% manganese and tantalum, and nil for rhenium. The remaining 30% is primary iron, but also includes aluminum, hafnium, molybdenum, titanium, tungsten, and other minor constituents.

No significant research has been reported on methods to identify and recycle MMC's. Recent preliminary research[44] has shown that it is possible to separate conventional Ti-6Al-4V alloy from SiC or B_4C-fiber-reinforced Ti-6Al-4V using eddy current measurements. Similar techniques should be applicable for other MMC's, but since reinforcement may serve as a contaminant if mixed for recycling, segregation of MMC's from other alloys will be necessary.

For many MMC's recycling of the metallic fraction should be relatively straightforward. If the metal and reinforcement do not interact chemically at the melting point of the metal, purely physical separation, such as filtration, should present no problems. However, if significant reactions are likely to occur, techniques will be needed for separation. Currently, the amount of MMC's going into scrap is very low, but recycling should be expected to increase significantly as production of these materials increases.

Annual Review

The estimated worldwide market in 1990 for carbon-carbon composites is $200 million (figure 2) for four different applications: aircraft brakes ($50 million), rocket nozzles ($70 million), nose tips-ablatives ($64 million), and other ($16 million). According to Kline & Co., the United States represents 75% of the worldwide carbon-carbon composite market, primarily due to its dominance in military and aerospace technology. Western Europe and Japan account for the remaining 25% of market share.

The estimated worldwide market in 1990 for metal matrix composites is $60 million for four different applications (figure 3): automotive ($15.6 million), aerospace ($42.0 million), recreation ($1.2 million), and other ($1.2 million). Again, according to Kline & Co. the United States accounts for 60% of the worldwide market value due to the high cost of prototype materials used by the aerospace industry. The Japanese share is only 20% of this worldwide market. Note, however, that Japan is the leading consumer of MMC components, mainly because of its production of MMC engine pistons. A variety of aerospace applications appear to be large for MMC's. Military jet and rocket structures are specific target areas for MMC's.

A notable feature in figure 3 is the difference in the aerospace industry's share in terms of weight and dollar values; 15% by weight of the aerospace share accounts for 70% of the cost indicates that the average cost of MMC's for aerospace applications is an order of magnitude higher than those for automotive and other applications. These higher costs are attributed to involved labor-intensive fabrication and low-volume production. Potential commercial applications of MMC's are listed along with their desired properties in table 15.

World Review.—Currently, the United States is the leader in applications of all advanced fiber composites, including MMC's. Composites are being developed and used in spacecraft, land vehicles, fighter aircraft, tactical missiles, and virtually every weapon system. Although in 1990 the U.S. aerospace industry led manufacturing industries by posting almost $30 billion positive trade balance, growing foreign activity is a definite threat to U.S. competitiveness in the composites field. U.S. dependence on foreign suppliers for raw materials adds another dimension to the erosion of U.S. competitiveness. Japan and Western Europe are primary suppliers of high-grade fine ceramic powders and fibrous reinforcements, raw materials essential for ceramic matrix composites. The high cost of raw materials and manufacturing processes and shortage of skilled engineers cut further into the U.S. lead over its major competitors.

Major competitors and trading partners of the United States are spending significant sums to develop fiber composites. The Japanese focus their efforts on industrial applications, while in Western Europe and the United Kingdom, military and aerospace applications are emphasized. In the United States, NASA and Department of Defense are conducting programs for military and aerospace applications as well.

Current Research.—Matrix fiber adherence is an important factor in determining MMC properties. Optimum adherence of the matrix to the reinforcement may sometimes involve some degree of chemical reaction between the matrix and the reinforcement. However, if the reaction is extensive, matrix-reinforcement bonds may be weakened, and degradation of the reinforcement may limit the strength of the composite. For example, boron fiber-reinforced aluminum has been observed to fail during fracture through debonding at the fiber-matrix interface. Upon heat treatment of the composite at 300° C, in an inert atmosphere, at room temperature, strength increased and fracture occurred within the fiber itself, rather than along the fiber-matrix interface. Additional research efforts will be necessary to improve the understanding of reactions at the fiber-matrix interface in order to develop optimum adherence of the reinforcing phase to the matrix.

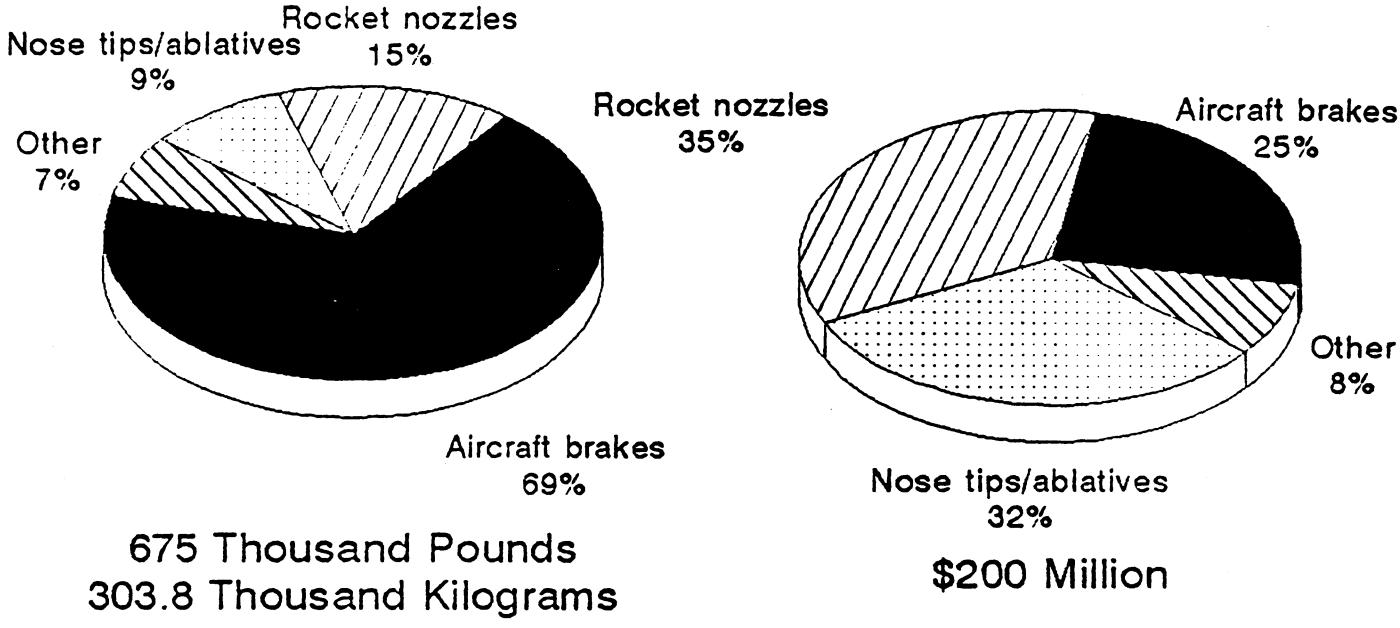
Outlook

Lockheed has taken delivery of the first lot of MMC's for use in the vertical tail fins on the Advanced Tactical Fighter, which is expected to result in a 25% weight reduction over current tail fins.

A wide range of metal companies are currently very active in fiber composites development, integrating their fiber operations to the point of composites production, especially particulate reinforced composites, in billet or ingot form. These companies, however, have not extended their business to production of specific components.

FIGURE 2

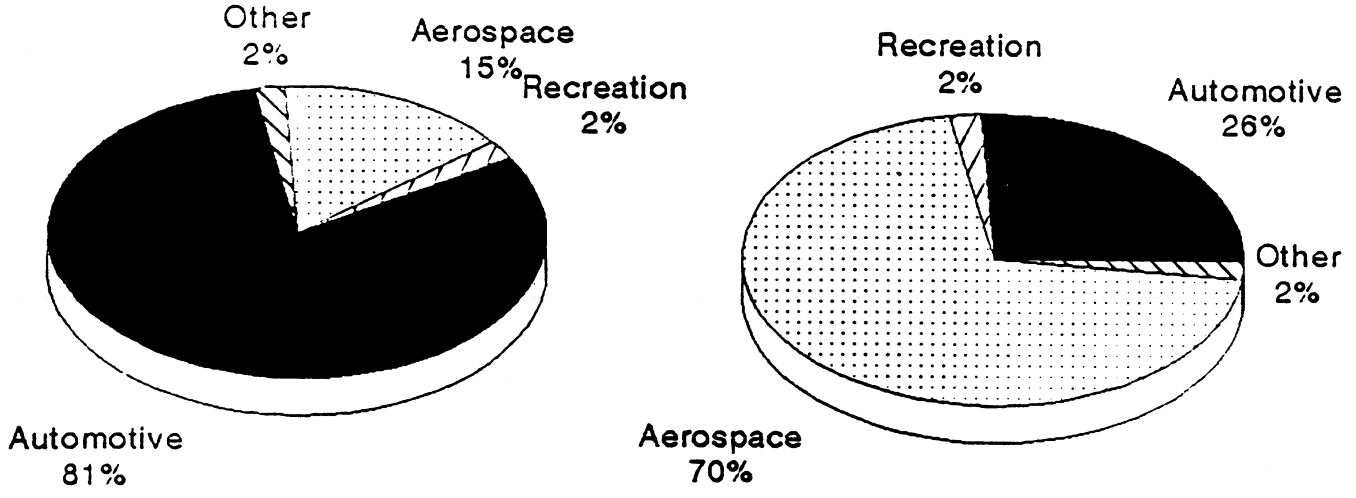
ESTIMATED WORLD MARKET FOR CARBON-CARBON COMPOSITES, 1990



Source: Kline & Co., Inc.

FIGURE 3

ESTIMATED WORLD MARKET FOR METAL-MATRIX COMPOSITES, 1990



Source: Kline & Co., Inc.

Pratt and Whitney Aircraft[45] is developing a fan blade for jet engines, utilizing an aluminum matrix composite with continuous boron fiber reinforcement wrapped around a titanium core. Arco Chemical Co. uses SiC aluminum composites in the manufacture of mirrors that maintain dimensional stability over an extensive temperature range.

For the airframe applications, Rockwell International and General Dynamics are leading the way with carbon-carbon and titanium-aluminum composites. In the development of jet engine components, ceramic matrix, and composites, along with superalloys, are the primary materials.

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ALUMINUM, BAUXITE, AND ALUMINA

By Patricia A. Plunkert and Errol D. Sehnke

Ms. Plunkert, a physical scientist with 22 years U.S. Bureau of Mines experience, has been the commodity specialist for aluminum since 1987. Domestic survey data for aluminum were prepared by Shonta E. Osborne, statistical assistant; and international data tables were prepared by Audrey D. Wilkes, international data coordinator.

Mr. Sehnke is a physical scientist with 17 years of minerals industry and U.S. Bureau of Mines experience. Domestic survey data for bauxite and alumina were prepared by Shonta E. Osborne, statistical assistant; and international data tables were prepared by Harold D. Willis, international data coordinator and William L. Zajac, Chief, Section of International Data.

Aluminum is the second most abundant 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 just over 100 years. It weighs about one-third as much as steel or copper; is malleable, ductile, and easily machined and cast; and has excellent corrosion resistance and durability. Measured either in quantity or value, aluminum's use exceeds that of any other metal except iron, and it is important in virtually all segments of the world economy.

Although the growth rate for world aluminum demand began to decrease toward the end of 1990, most primary aluminum smelters continued to operate at or near their rated capacity levels. 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 $6.6 billion.

World production of bauxite and alumina, feedstocks for the aluminum industry, rose in 1990 to new record levels in response to the sustained high rate of primary aluminum metal output. Mine production of bauxite was reported from 27 countries, and alumina was produced in 24 countries.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for aluminum, bauxite, and alumina are developed by the U.S. Bureau of Mines from five separate voluntary surveys of U. S. operations. Typical of these monthly, quarterly, and annual surveys is the "Consumption of Alumina" survey. Of the 18 operations canvassed by this form, all responded.

BACKGROUND

Definitions, Grades, and Specifications

Bauxite is a heterogeneous material composed chiefly of the aluminum oxide minerals gibbsite ($Al_2O_3 \cdot 3H_2O$), the trihydrate, and boehmite and diaspore ($Al_2O_3 \cdot 3H_2O$), the monohydrates.[1] Domestic bauxites and those imported from Brazil, Guyana, and Suriname are of the trihydrate gibbsitic type. Imports from the Sangaredi deposits of Guinea and the north coast of Jamaica are predominantly gibbsitic, but they also contain 4% to 10% of the monohydrate mineral boehmite. In most European and northern Asian bauxite deposits, boehmite is the principal alumina mineral. Recovery of the aluminum oxide in boehmite requires a higher temperature and higher caustic concentration than is needed in processing gibbsite. Major impurities in bauxite ores include iron oxides, silica, aluminum silicates, and titanium oxides.

Free moisture in crude bauxite, as mined, may range from 5% to 30%. Dried bauxite is produced by heating crude bauxite in rotary drying kilns at about 315° C, which removes most of the free moisture. Calcined bauxite is produced by heating bauxite at 925° to 1,040° C to reduce total volatile matter, including chemically combined water, to less than 1%. About 2 tons of crude ore is required to produce 1 ton of calcined bauxite.

Aluminum metal has a relatively low density, high electrical and thermal conductivity, good resistance to corrosion, and good malleability. It is nonmagnetic, nonsparking, and highly reflective. It may be alloyed and treated to yield a high strength-to-weight ratio.

Ingot is a cast form of primary or secondary metal that is convenient to handle and store and is suitable for fabricating or remelting. Commercial-size ingots normally weigh about 30 pounds; however, some ingots weigh up to 9 tons. A significant portion of both primary and secondary metal is sold and transported in molten form.

Commercially pure aluminum usually contains about 99.7% aluminum. In the annealed condition, it has low strength and is relatively soft. However, it is available in strain-hardened conditions of higher strength and reduced ductility. Metal with more than 99.7% and up to 99.85% aluminum is available at higher cost than standard commercial metal. Superpurity aluminum contains a minimum of 99.99% aluminum.

Aluminum alloys have been developed that, after cold rolling, heat treating, annealing, or age hardening, have strengths approaching those of mild steels. More than 100 commercial alloys are available, and several new alloys are developed each year. The alloys offer a wide variety of combinations of mechanical strength,

ductility, electrical conductivity, and corrosion resistance.

Aluminum alloys are generally divided into two major groups: wrought and casting. The Aluminum Association uses a code to designate the purity and alloy content of wrought alloys and to register the composition of casting alloys and ingot. The range of compositions of wrought aluminum alloys and selected aluminum casting ingot alloys is given in table 3.

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. New aluminum scrap that is purchased from manufacturers of end products may be referred to as consumer scrap. Purchased new scrap is sometimes referred to as prompt industrial scrap.

Old scrap, all of which is considered as purchased, comes from discarded, used, and wornout products. It includes 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 melted (sweated) 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 components of aluminum supply—bauxite, alumina, and aluminum metal. World production figures during the past 30 years for each of these commodities provide some idea of the changes that have taken place within the industry.

TABLE 1

TYPICAL SPECIFICATIONS FOR GRADES OF BAUXITE

(Weight-percent, maximum content unless otherwise specified)

Constituent	Metal grade (dried Jamaica type)	Refractory grade (calcined)	Abrasive grade (calcined)
Al_2O_3	[1]47.0	[1]86.5	[1]83.0
SiO_2	3.0	7.0	6.0
Fe_2O_3	22.0	2.5	8.0
TiO_2	3.0	3.75	[2]3.0- 4.5
$K_2O + Na_2O$	NS	.2	.7
$MgO + CaO$	NS	.3	NS
CaO	NS	NS	.2
MgO	NS	NS	.4
$MnO_2 + Cr_2O_3 + V_2O_5$	2.0	1.0	1.0
P_2O_5	1.5	NS	.5
Loss on ignition	NS	.5	1.0

NS No specification.
[1]Minimum content.
[2]Range of content.

Bauxite resources (reserves plus subeconomic and undiscovered deposits) are currently estimated to be 55 to 75 billion tons. These resources occur 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. Presently, there are only two 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 utilized for refractory and other specialized applications.

The United States is entirely dependent on foreign sources for metallurgical-grade bauxite. What aluminum 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 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 major source of these imports.

TABLE 2

SMELTER-GRADE ALUMINA SPECIFICATIONS, IN WEIGHT-PERCENT

Impurity	Maximum content	Impurity	Maximum content
SiO_2	0.015	B_2O_3	0.001
Fe_2O_3	.015	TiO_2	.002
MnO	.002	P_2O_5	.001
NiO	.005	MgO	.002
Cr_2O_3	.002	CaO	.04
CuO	.01	Na_2O	.40
V_2O_5	.002	K_2O	.005
ZnO	.01	Chloride, residual	.05
Ga_2O_3	.02		

Source: Industry-U.S. Bureau of Mines Alumina Miniplant Steering Committee recommended specifications, May 1979.

TABLE 3

COMPOSITION LIMITS AND USES OF SOME ALUMINUM WROUGHT AND CASTING ALLOYS[1]

(Weight-percent)

Aluminum Association designation	Aluminum	Copper	Manganese	Magnesium	Silicon	Other constituents	Applications
Wrought alloy series:							
1000	99.00-99.75	0.2	0.05	0.05	[2]1.0	0.1 zinc, 0.05 titanium	Electrical conductor, chemical equipment, cooking utensils.
2000	Balance[3]	1.9 -6.8	0.2 -1.8	0.02- 1.8	0.1- 1.2	1.3 iron, 0.2 titanium, 2.3 nickel	Forgings, aircraft, rocket fuel tanks.
3000	do.[3]	.3	.3 -1.5	.2- 1.3	.6	0.4 zinc, 0.1 titanium, 0.7 iron	Ductwork, can bodies, hydraulic tubing.
4000	do.[3]	.10-1.3	.05-1.3	3.6-13.5	3.6-13.5	1.3 nickel, 0.2 zinc	Welding and brazing wire, pistons.
5000	do.[3]	.2	.01-1.0	.5- 5.6	.45	0.35 chromium, 0.2 titanium, 7 iron	Bus and truck bodies, screens, pressure vessels, aircraft tubing.
6000	do.[3]	.1 -1.2	.03-1.1	.35- 1.5	1.8	2.4 zinc, 1.0 iron	Heavy-duty structures, pipe, bus bars.
7000	do.[3]	.05-2.6	.1 - 0.7	.1- 3.4	[2].7	0.35 chromium, 8.0 zinc, 0.2 titanium	Aircraft structurals and skins.
Diecasting ingot:[4]							
A380	do.[3]	3.0 -4.0	.5	.1	7.5- 9.5	0.5 nickel, 3.0 zinc, 1.3 iron	General purpose castings.
A413	do.[3]	1.0	.35	.1	11.0-13.0	0.5 nickel, 0.5 zinc, 1.3 iron	Large instrument cases.
Sand and permanent mold casting ingot:[4]							
342	do.[3]	3.5 -4.5	.35	1.2 -1.8	1.0	2.3 nickel, 0.35 zinc, 0.25 titanium	Cylinder heads, engine pistons.
356	do.[3]	.25	.35	.2 -.4	6.5 -7.5	0.6 iron, 0.35 zinc, 0.25 titanium	Automotive transmission cases, aircraft and marine fittings.

[1]Maximum weight-percent of the casting ingot or at least one of the wrought alloys in the series unless a range is given, in which case the upper and lower limits do not necessarily apply to the same alloy in the series.
[2]Includes iron.
[3]Balance after deducting percent composition of specified alloying constituents, plus other normal impurities. Minimum impurities for casting alloys are normally specified but are not shown in this table.
[4]Composition of castings may differ from that of the ingot.

A continuing 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 1960, the United States accounted for more than 50% of the world's production of alumina. In 1990, U.S. dominance in alumina production had been replaced by production from Australia. 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 1960, have taken on a much stronger role. Some of these countries with a developing 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. In 1960, the United States accounted for just over 40% of the world's production. In 1990, the U.S. share of world production had decreased to 23%. 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 35,000 tons of primary metal. Other countries entering the world market today 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 electricity for newly announced smelter construction.

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 are borne by a number of different aluminum companies in joint ventures. Even though the number of different companies pro-

TABLE 4

WORLD BAUXITE PRODUCTION

(Thousand metric tons)

Country	1960	1970	1980	1985	1990[e]
Albania	NA	NA	NA	NA	[1]26
Australia	71	9,256	27,179	31,839	[1]40,697
Austria	26	—	—	—	—
Brazil	121	500	5,538	5,846	8,750
China[e]	350	498	1,500	1,650	4,000
Dominican Republic[2]	689	1,067	606	—	150
France	2,067	2,992	1,921	1,530	560
Germany, Federal Republic of	4	3	([3])	([3])	—
Ghana	228	342	225	170	[1]381
Greece	884	2,292	3,286	2,453	2,700
Guinea[e 4]	1,378	2,490	11,862	11,790	16,500
Guyana[2]	2,511	4,417	1,844	[e]1,675	1,600
Haiti	272	632	312	—	—
Hungary	1,190	2,022	2,950	2,815	2,600
India	387	1,359	1,785	2,281	5,000
Indonesia	396	1,229	1,249	830	[1]1,206
Italy	313	225	23	—	12
Jamaica[2 5]	5,837	12,010	12,054	6,239	[1]10,921
Malaysia	748	1,139	920	492	[1]398
Mozambique	5	7	—	5	[1]7
Pakistan	1	1	2	2	2
Romania[e]	88	304	710	600	300
Sierra Leone	—	440	766	1,185	1,600
Spain	3	5	8	2	3
Suriname	3,455	6,022	4,646	3,738	[1]3,267
Turkey	—	51	533	214	515
U.S.S.R.[e]	2,400	4,267	4,600	4,600	4,200
United States[2]	2,030	2,115	1,559	674	W
Venezuela	—	—	—	—	[1]771
Yugoslavia	1,025	2,099	3,138	3,538	[1]2,952
Zimbabwe	—	—	4	21	—
Total	26,479	57,784	89,220	84,189	109,118

[e]Estimated. NA Not available. W Withheld to avoid disclosing company proprietary data; not included in "Total."
[1]Reported figure.
[2]Dry bauxite equivalent of crude ore.
[3]Less than 1/2 unit.
[4]Dry bauxite equivalent of ore processed by drying plant.
[5]Bauxite processed for conversion to alumina in Jamaica plus kiln-dried ore prepared for export.

ducing 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., Pechiney, Kaiser Aluminum & Chemical Corp., Alusuisse-Lonza Holding AG, and Alumax Inc. 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.

Some of the most dramatic changes in the domestic aluminum industry occurred in the past 10 years. In 1980, there were 11 companies operating 33 smelters with a total annual domestic production capacity of 5 million tons of metal. By 1990, 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 just 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, 450,000 tons of aluminum was recovered from new and old scrap. In 1990, almost 2. 4 million tons of aluminum was recovered from scrap. More than 1 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 here 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

TABLE 5

WORLD ALUMINA PRODUCTION[1]

(Thousand metric tons)

Country	1960	1970	1980	1985	1990[e]
Australia	NA	2,152	7,246	8,792	[2]11,231
Brazil	31	119	517	1,096	1,600
Canada	NA	1,105	1,202	1,019	1,087
China[e]	175	254	750	825	1,500
Czechoslovakia[e]	—	73	100	154	200
France	594	1,130	1,173	736	664
Germany, Federal Republic of:					
Eastern states	59	54	43	47	50
Western states	510	757	1,608	1,657	1,175
Greece	—	312	494	380	[2]566
Guinea	185	610	708	572	[2]631
Guyana	—	317	214	—	—
Hungary	218	441	805	798	[2]826
India	—	327	500	587	1,455
Ireland	—	—	—	555	885
Italy[3]	222	314	900	555	752
Jamaica	676	1,716	2,456	1,622	[2]2,869
Japan	355	1,285	1,936	978	[2]459
Norway	NA	3	—	—	—
Romania	—	210	534	548	400
Spain[3]	—	—	58	725	900
Suriname[3]	—	1,014	1,329	1,242	[2]1,532
Taiwan	NA	42	—	—	—
Turkey	—	—	138	113	185
U.S.S.R.[e]	NA	1,814	2,700	3,500	3,300
United Kingdom	NA	107	102	110	115
United States[e]	3,652	6,485	6,810	3,465	5,230
Venezuela	—	—	—	1,085	[2]1,293
Yugoslavia	67	125	1,058	1,138	1,200
Total	6,744	20,766	33,381	32,299	40,105

[e]Estimated. NA Not available.

[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]Reported figure.

[3]Hydrate.

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

Once again, most primary aluminum smelters operated close to and, in some cases, above rated capacities during the year. Imports increased slightly after a 3-year downward trend as exports leveled off. A record 55 billion UBC's were recycled in 1990, equivalent to almost 64% of the aluminum can shipments for the year. Although aluminum metal prices trended upward during most of the year, they began to slide downward toward the end of the year as the overall world economy slowed. World production of primary aluminum decreased slightly following several years of steady growth.

Legislation and Government Programs

The Defense Logistics Agency (DLA) announced that Alcoa was awarded a $100.4 million firm fixed-price contract for upgrading approximately 243,900 tons of bauxite to 55,157 tons of aluminum metal ingots for the National Defense Stockpile (NDS). Delivery of the metal was expected to be completed by September 1992. As of December 31, 1990, the NDS goal for aluminum metal remained at 635,030 tons, and the stockpile inventory held steady at 1,889 tons of aluminum metal.

The U.S. Bureau of Mines released a study that analyzed the application and impact of the Resource Conservation and Recovery Act's (RCRA) regulations on the mineral industry's efforts at resource recovery. Spent potliners were examined as a case study to demonstrate the impact of RCRA regulations.[2]

Production

Primary.—Domestic primary aluminum production increased slightly compared with 1989 production levels. Most smelters continued to operate near their rated capacity levels during most of 1990.

Southwire Co. of Georgia became the sole owner of the 172,000-ton-per-year primary aluminum smelter in Hawesville, KY. Southwire purchased the 54.5% interest held by its former partner in the smelter, National Aluminum Corp., a subsidiary of National Intergroup Inc.

Ormet Corp. temporarily closed a 41,000-ton-per-year potline at its primary smelter in Hannibal, OH. The potline was closed in March, but restarted in September.

In June, Alcoa announced the restart of a 42,000-ton-per-year potline at its Wenatchee, WA, smelter that had been idled since August 1989.

Ravenswood Aluminum Co. announced its decision to delay indefinitely the restart of the fourth potline at its West Virginia primary aluminum smelter that had originally been scheduled for February. In June, the company reported that it would also temporarily idle one of the three remaining potlines at the smelter, after the company and the United Steel Workers of America (USWA) officials failed to reach an agreement on work scheduling. The labor contract between Ravenswood and the USWA expired on October 31. The two parties failed to reach an agreement on a new contract by the end of the year.

In February, the USWA ratified a new 4-year contract, scheduled to expire on August 31, 1993, that covered workers at

TABLE 6

WORLD PRIMARY ALUMINUM METAL PRODUCTION

(Thousand metric tons)

Country	1960	1970	1980	1985	1990[e]
Argentina	—	—	133	136	162
Australia	12	206	303	851	[1]1,234
Austria	68	90	94	94	[1]89
Bahrain	—	—	126	176	188
Brazil	18	57	261	549	[1]931
Cameroon	44	53	43	90	91
Canada	691	973	1,068	1,282	1,570
China[e]	80	127	360	410	850
Czechoslovakia	40	31	38	32	32
Egypt	—	—	120	209	179
France	239	381	432	293	[1]326
Germany, Federal Republic of:					
Eastern states[e]	40	59	60	60	50
Western states	169	309	731	745	[1]720
Ghana	—	113	188	49	[1]174
Greece	—	87	146	125	[1]150
Hungary	50	66	73	74	75
Iceland	—	38	73	73	[1]88
India	18	161	185	260	[1]433
Indonesia	—	—	—	217	[1]186
Iran[e]	—	—	16	43	49
Italy	83	146	271	224	[1]232
Japan	133	733	1,091	227	[1]34
Korea, North[e]	—	—	10	10	—
Korea, Republic of	—	15	18	18	4
Mexico	—	34	43	43	[1]68
Netherlands	—	75	259	251	[1]258
New Zealand	—	—	155	241	260
Norway	165	523	653	743	[1]845
Poland[2]	26	99	95	47	48
Romania[3]	—	102	241	247	180
South Africa, Republic of	—	—	87	165	166
Spain	29	120	386	370	[1]355
Suriname	—	55	55	29	20
Sweden	16	64	82	84	[1]96
Switzerland	40	92	86	73	[1]72
Taiwan	8	27	64	—	—
Turkey	—	—	34	54	60
U.S.S.R.[e]	640	1,100	1,760	2,200	2,200
United Arab Emirates: Dubai	—	—	25	153	168
United Kingdom	29	40	374	275	[1]290
United States	1,827	3,607	4,654	3,500	[1]4,048
Venezuela	—	23	328	396	[1]546
Yugoslavia	25	48	161	[e]280	290
Total	4,490	9,654	15,382	15,398	17,817

[e]Estimated.

[1]Reported figure.

[2]Primary unalloyed ingot plus secondary unalloyed ingot.

[3]Primary unalloyed metal plus primary alloyed metal, thus including weight of alloying material.

Noranda Aluminum Inc.'s New Madrid, MO, primary aluminum smelter. The contract reportedly included a 2% wage increase retroactive to January 1, 1990; a 2% increase effective July 1, 1990; and a 1% wage increase on September 1, 1992. A cost of living (COLA) increase of 29 cents per hour reportedly was included with an option for additional increases if the inflation rate rose above 3% per year. In addition to some enhancements in the worker benefit package, the contract also included changes in the company's profit-sharing plan. Retroactive to September 1, 1989, profit sharing would go into effect only if the company earned more than a 3% return on assets, and the return on assets threshold would be increased to 4.1% on September 1, 1992.

On June 2, members of the USWA ratified a new 3-year labor agreement covering workers at Ormet's primary aluminum smelter in Hannibal, OH. The new labor contract, scheduled to expire on May 31, 1993, reportedly included a $1,200 signing bonus, a $500 bonus for each of the remaining 2 years of the contract, a 50-cent-per-hour increase in wages, and negotiated improvements in the company's pension plan.

In November, the USWA and Kaiser Aluminum announced the ratification of a new 4-year contract. The contract covered workers at the company's primary aluminum smelters in Tacoma and Mead, WA; the Trentwood, WA, rolling mill; the alumina refinery at Gramercy, LA; and two fabrication plants in Ohio. The new contract, scheduled to expire on October 31, 1994, reportedly included a 50-cent-per-hour increase in base pay for the first and fourth year, an increase in the pension multiplier of $2 in the first year and $1 in each of the next 3 years, a $1,000 signing bonus, and bonuses of $500 each in the second and third year. The agreement also reportedly continued the bonus plan tied to the price of aluminum and optional, plant-specific bonus plans based on performance.

Big Rivers Electric Corp. and the Kentucky Public Service Commission announced that an agreement on power rates had been reached with the owners of the two primary aluminum smelters in Kentucky. The agreement covered Southwire's 172,000-ton-per-year smelter at Hawesville and Alcan Aluminum Corp.'s 163,000-ton-per-year smelter at Sebree. The agreement reportedly established a balancing account to ensure an average

rate of 29 mills per kilowatt hour and maintained the variable rate structure through August 1997.

Alumax announced the signing of a new power contract with Santee Cooper, the supplier of electricity to the Mount Holly, SC, primary aluminum smelter. Alumax reportedly agreed to maintain the current power load at its smelter through 1993 and to maintain at least one-half of that load throughout the period April 1, 1995, to March 31, 2000. The contract reportedly provided a reduced power rate applicable to one of the smelter's two potlines effective January 1, 1994, and continuing until April 1, 2000.

Kaiser Aluminum announced the closure of its Permanente, CA, aluminum foil facility. The closure marked the company's complete exit from the aluminum foil business.

Kaiser Aluminum also announced a $9 million expansion program at its Los Angeles extrusion facility, scheduled for completion in 1991. The project included a new 4,000-ton extrusion press and additional remelt and casting equipment for the production of 90 million pounds of high-quality aluminum billet and log annually.

Nichols-Homeshield announced plans to construct an aluminum minimill in Davenport, IA, with a potential 275 million pounds of capacity annually. The estimated $60 million cost of the project reportedly included site acquisition, scrap processing and melting equipment, a Hazelett continuous caster, and equipment for hot and cold rolling, annealing, coil coating, and slitting.

Matsushita Electronic Corp. of America announced plans to build a $10 million aluminum foil processing facility adjacent to the company's capacitor manufacturing operations in Knoxville, TN. The new plant was scheduled for completion by mid-1991.

Norsk Hydro A/S reported the purchase of Bohn Aluminum & Brass from Wickes Manufacturing Co. Bohn Aluminum operated two four-press operations in Adrian and Holland, MI. The automotive industry accounted for about 60% of the sales volume from these two plants. Norsk Hydro later announced that it merged Bohn Aluminum with its Florida-based subsidiary Hydro Aluminum Automotive. The new group would be known as Hydro Aluminum Bohn.

Secondary.—According to a survey conducted by the Aluminum Association Inc., the Institute of Scrap Recycling Industries, and the Can Manufacturers Institute, a record 54.98 billion aluminum UBC's were recycled in 1990, surpassing by more than 5.5 billion the number of UBC's recovered in 1989. The percentage of aluminum cans recycled in the United States increased from 60.8% of aluminum cans shipped in 1989 to 63.6% of can shipments in 1990.

Imco Recycling Inc. announced plans to expand its UBC recycling plant in Morgantown, KY. Upon completion, the plant's annual capacity reportedly would increase to almost 500 million pounds from its current level of 430 million pounds.

Alcan Recycling, a division of Alcan Aluminum, announced plans for a $7 million upgrade at its Greensboro, GA, recycling plant. The expansion program, which was expected to increase UBC processing capacity by 25% to 5 billion cans per year, included the installation of two new electric induction furnaces and a large melting furnace.

Reynolds Metals announced a pilot program in five U.S. metropolitan areas to boost the recycling of aluminum foil, TV dinner trays, pie pans, and other lightweight aluminum items. The recycling centers were planned for the Baltimore/Washington area, Richmond, San Francisco, Seattle, and Tampa.

Alcan Aluminum announced the purchase of Summit Alloys Co., formerly known as Southern Alloys Co. Summit Alloys operated a 25,000-ton-per-year secondary smelter in Shelbyville, TN. The plant produced secondary aluminum ingot alloys for sale to diecasters and foundries in the area.

Plasma Technology Corp. announced

TABLE 7

SALIENT ALUMINUM STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Primary production	3,037	3,343	3,944	4,030	4,048
Value	$5,422,993	$5,328,300	$9,572,066	$7,801,086	$6,604,398
Price: Average cents per pound					
U.S. producer list	[1]81.0	NA	NA	NA	NA
U.S. market (spot)	55.9	72.3	110.1	87.8	74.0
Secondary recovery	1,773	1,986	2,122	2,054	2,393
Exports (crude and semicrude)	753	917	1,247	[r]1,615	1,655
Imports for consumption (crude and semicrude)	1,967	1,850	1,620	1,470	1,514
Aluminum industry shipments[2]	6,545	6,813	6,851	[r]6,761	[p]6,498
Consumption, apparent	5,143	5,469	5,373	[r]4,957	5,263
World: Production	[r]15,412	[r]16,420	17,500	[p]18,020	[e]17,817

[e]Estimated. [p]Preliminary. [r]Revised. NA Not available.

[1]Based on 7 months in 1986.

[2]Shipped to domestic industry.

TABLE 8

PRIMARY ANNUAL ALUMINUM PRODUCTION CAPACITY IN THE UNITED STATES, BY COMPANY

Company	Yearend capacity (thousand metric tons)		1990 ownership (percent)
	1989	1990	
Alcan Aluminum Corp.:			
Sebree, KY	163	163	Alcan Aluminium Ltd., 100%.
Alumax Inc.:			
Ferndale, WA (Intalco)	254	254	AMAX Inc., 75%; Mitsui & Co., 11%; Toyo Sash, 7%; Yoshida Kogya K.K., 7%.
Frederick, MD (Eastalco)	160	160	Do.
Mount Holly, SC	181	181	AMAX, 73%; Clarendon Ltd., 27%.
Total	595	595	
Aluminum Co. of America:			
Alcoa, TN	200	200	Aluminum Co. of America, 100%.
Badin, NC	115	115	Do.
Evansville, IN (Warrick)	270	270	Do.
Massena, NY	127	127	Do.
Rockdale, TX	310	310	Do.
Wenatchee, WA	205	205	Do.
Total	1,227	1,227	
Columbia Aluminum Corp.:			
Goldendale, WA	168	168	Columbia Aluminum Corp., 70%; employees, 30%.
Columbia Falls Aluminum Co.:			
Columbia Falls, MT	163	163	Montana Aluminum Investors Corp., 100%.
Kaiser Aluminum & Chemical Corp.:			
Mead, WA (Spokane)	200	200	MAXXAM Inc., 100%.
Tacoma, WA	73	73	Do.
Total	273	273	
NSA:[1]			
Hawesville, KY	172	172	Southwire Co., 100%.
Noranda Aluminum Inc.:			
New Madrid, MO	204	204	Noranda Mines Ltd., 100%.
Northwest Aluminum Corp.:[2]			
The Dalles, OR	82	82	Martin Marietta Corp., 87.2%; private interests, 12.8%.
Ormet Corp.:			
Hannibal, OH	245	245	Ohio River Associates Inc., 100%.
Ravenswood Aluminum Corp.:			
Ravenswood, WV	166	166	Stanwich Partners Inc., 100%.
Reynolds Metals Co.:			
Longview, WA	204	204	Reynolds Metals Co., 100%.
Massena, NY	123	123	Do.
Troutdale, OR	121	121	Do.
Total	448	448	
Vanalco Inc.:			
Vancouver, WA	110	110	Vanalco Inc., 100%.
Grand total	4,016	4,016	

[1]Southwire Co. purchased 50% from National Steel Corp. in Apr. 1990.
[2]Northwest Aluminum Corp. signed a lease-purchase agreement for The Dalles smelter with Martin Marietta Corp. in 1986.

plans to construct a $12 million aluminum dross recycling plant in West Virginia. The plant would use a plasma-torch technology that was jointly developed by Alcan Aluminium and Plasma Energy Corp. Alcan Aluminium reportedly granted Plasma Technology the exclusive rights to use or license this technology for all markets except Alcan's own

system and Europe. The new plant in West Virginia was scheduled to start production in 1991.

Consumption and Uses

The container and packaging industry remained the largest domestic consumer of aluminum products. The Can Manufacturers Institute reported that about 88 billion aluminum beverage cans were shipped in 1990, representing about 95% of the total metal beverage can shipments.

Reynolds Metals and Campbell Soup Co. announced the signing of a long-term supply agreement whereby Reynolds Metals would supply aluminum for Campbell's juice cans, which had been made of steel. Some of the products involved were Campbell's V-8 and Juice Bowl products in 5.5-ounce and 11.5-ounce can sizes.

Crown Cork & Seal Co. Inc. announced the purchase of Continental Can Co. Inc.'s steel and aluminum canmaking facilities. The combining of the two companies reportedly would make Crown the largest domestic producer of aluminum beverage cans.

Alcan Aluminum's building products division announced the purchase of Alumax's building specialties division, consisting of fabrication and distribution facilities at seven locations throughout the United States. These facilities produced aluminum and steel commercial and industrial siding and roofing, architectural panels, and exterior building products.

During the year, several companies announced either new or expanded uses of aluminum in automotive applications. Ford Motor Co. introduced a two-piece aluminum hood on its 1990 Lincoln Town Car. Ford announced plans to expand the use of these hoods by including them on the 1991 Mercury Marquis and Ford Crown Victoria models. General Motors Corp. announced plans to use aluminum driveshafts on some of its next-generation pickup trucks and sports utility wagons scheduled for the mid-1990's. Chrysler Corp. reported that it planned to put aluminum cylinder heads on its new 24-valve, 3.5-liter V-6 engines scheduled for 1993. These were only a few of the many automotive applications for aluminum that were announced during the year.

In addition, several automakers and aluminum producers reported that they were joining forces to develop and produce aluminum-intensive vehicles. For example, Alcoa entered a partnership with Audi to produce an aluminum-intensive vehicle, and Alcan Aluminium was working with Ford's Jaguar subsidiary on an aluminum structural model, the XJ220. In September, Honda introduced its NSX luxury sports car, which featured an all-aluminum structure and body.

TABLE 9

U.S. CONSUMPTION OF AND RECOVERY FROM PURCHASED NEW AND OLD ALUMINUM SCRAP,[1] BY CLASS

(Metric tons)

Class	Consumption	Calculated recovery	
		Aluminum	Metallic
1989			
Secondary smelters	804,995	666,212	716,581
Primary producers	1,027,495	861,153	922,621
Fabricators	222,456	195,910	209,422
Foundries	83,024	67,581	72,842
Chemical producers	36,019	36,019	36,019
Total	2,173,989	1,826,875	1,957,485
Estimated full industry coverage	2,280,000	1,908,000	2,054,000
1990			
Secondary smelters	982,011	800,918	860,902
Primary producers	1,212,392	1,015,852	1,085,483
Fabricators	238,331	198,470	223,310
Foundries	71,626	58,893	63,531
Chemical producers	57,017	45,251	45,578
Total	2,561,377	2,119,384	2,278,804
Estimated full industry coverage	2,690,000	2,225,000	2,393,000

[1]Excludes recovery from other than aluminum-base scrap.

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 slightly from 1.822 million tons at yearend 1989 to 1.825 million tons at yearend 1990.

Markets and Prices

The monthly average U.S. market price for primary aluminum trended upward during the first three quarters of the year before beginning a downward turn that brought yearend prices back to their January levels. The London Metal Exchange (LME) and New York Commodity Exchange (COMEX) prices for aluminum futures followed the same general trend as the U.S. market prices.

Purchase prices for aluminum scrap, as quoted by the American Metal Market (AMM), fluctuated during the year, but began and closed the year at approximately the same levels. The yearend price ranges for selected types of aluminum scrap were as follows: mixed low-copper-content aluminum clips, 51 to 52 cents per pound; old sheet and cast aluminum, 42 to 44 cents per pound; and clean, dry aluminum turnings, 45 to 47 cents per pound.

Prices for UBC's fluctuated during the year, but closed 8 cents per pound lower than prices at the beginning of the year. Aluminum producers' buying prices for processed and delivered UBC's, which began the year at a range of 50 to 53 cents per pound, reached a high for the year of 56 to 60 cents per pound in September. The price range at the end of the year was 42 to 46 cents per pound.

Secondary aluminum ingot prices, as quoted by AMM, fluctuated during the year and closed slightly lower than prices at the end of 1989. The yearend 1990 price ranges for selected secondary aluminum

TABLE 10

U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF PURCHASED NEW AND OLD ALUMINUM SCRAP[1] AND SWEATED PIG IN 1990

(Metric tons)

Class of consumer and type of scrap	Stocks, Jan. 1[r]	Net receipts[2]	Consumption	Stocks, Dec. 31
Secondary smelters:				
New scrap:				
Solids	5,908	132,255	132,487	5,676
Borings and turnings	4,868	110,586	109,765	5,689
Dross and skimmings	1,630	38,143	36,378	3,395
Other[3]	2,321	100,573	98,388	4,506
Total	14,727	381,557	377,018	19,266
Old scrap:				
Castings, sheet, clippings	13,335	336,775	333,534	16,576
Aluminum-copper radiators	563	11,555	11,542	576
Aluminum cans	441	[4]204,457	[4]198,865	6,033
Other[5]	295	44,683	44,552	426
Total	14,634	597,470	588,493	23,611
Sweated pig	1,468	15,988	16,500	956
Total secondary smelters	30,829	995,015	982,011	43,833
Primary producers, foundries, fabricators, chemical plants:				
New scrap:				
Solids	11,303	447,965	448,691	10,577
Borings and turnings	143	27,794	27,876	61
Dross and skimmings	1,667	21,997	22,248	1,416
Other[3]	3,369	201,437	200,732	4,074
Total	16,482	699,193	699,547	16,128
Old scrap:				
Castings, sheet, clippings	1,152	169,485	169,201	1,436
Aluminum-copper radiators	54	38,304	38,283	75
Aluminum cans	38,331	637,611	654,905	21,037
Total	39,537	845,400	862,389	22,548
Sweated pig	751	17,512	17,430	833
Total primary producers, etc.	56,770	1,562,105	1,579,366	39,509
All scrap consumed:				
New scrap:				
Solids	17,211	580,221	581,179	16,253
Borings and turnings	5,011	138,380	137,640	5,751
Dross and skimmings	3,297	60,139	58,625	4,811
Other	5,690	302,010	299,120	8,580
Total new scrap	31,209	1,080,750	1,076,564	35,395
Old scrap:				
Castings, sheet, clippings	14,488	506,259	502,735	18,012
Aluminum-copper radiators	617	49,860	49,826	651
Aluminum cans	38,772	842,069	853,771	27,070
Other	294	44,683	44,551	426
Total old scrap	54,171	1,442,871	1,450,883	46,159
Sweated pig	2,219	33,499	33,930	1,788
Total of all scrap consumed	87,599	2,557,120	2,561,377	83,342

[r]Revised.
[1]Includes imported scrap. According to reporting companies, 4.27% of total receipts of aluminum-base scrap, or 109,241 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).

TABLE 11

PRODUCTION AND SHIPMENTS OF SECONDARY ALUMINUM ALLOYS BY INDEPENDENT SMELTERS IN THE UNITED STATES

(Metric tons)

	1989		1990	
	Production	Net shipments[1]	Production	Net shipments[1]
Die-cast alloys:				
13% Si, 360, etc. (0.6% Cu, maximum)	97,970	97,305	60,935	61,918
380 and variations	348,160	349,471	273,432	272,270
Sand and permanent mold:				
95/5 Al-Si, 356, etc. (0.6% Cu, maximum)	18,451	18,850	16,618	16,606
No. 12 and variations	W	W	W	W
No. 319 and variations	60,542	60,068	57,284	55,577
F-132 alloy and variations	6,826	6,763	8,693	11,279
Al-Mg alloys	49	68	695	700
Al-Zn alloys	1,913	2,170	2,648	2,489
Al-Si alloys (0.6% to 2.0% Cu)	9,710	9,837	11,896	11,906
Al-Cu alloys (1.5% Si, maximum)	350	449	1,753	1,745
Al-Si-Cu-Ni alloys	1,121	1,123	1,174	1,178
Other	1,209	1,237	1,468	1,357
Wrought alloys: Extrusion billets	126,482	124,714	125,604	125,937
Miscellaneous:				
Steel deoxidation	7,967	7,994	4,866	5,437
Pure (97.0% Al)	—	—	29	29
Aluminum-base hardeners	1,813	1,777	1,478	1,520
Other[2]	31,091	31,226	34,407	34,787
Total	713,654	713,052	602,980	604,735
Less consumption of materials other than scrap:				
Primary aluminum	55,731	—	43,336	—
Primary silicon	36,981	—	29,127	—
Other	3,536	—	3,320	—
Net metallic recovery from aluminum scrap and sweated pig consumed in production of secondary aluminum ingot[3]	617,406	XX	527,197	XX

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.

ingots were as follows: alloy 380 (1% zinc content), 73 to 74.5 cents per pound; alloy 360 (0.6% copper content) and alloy 413 (0.6% copper content), 76 to 77 cents per pound; and alloy 319, 74 to 75.5 cents per pound.

The LME announced the creation of a subcommittee to investigate the potential for an LME secondary aluminum ingot contract. The subcommittee was composed of members of the LME board and secretariat along with members of the international secondary aluminum industry. One major task of the subcommittee was to be the identification of a grade for the secondary ingot that could be traded and used worldwide.

Foreign Trade

Exports of all forms of aluminum from the United States leveled off in 1990. Canada and Japan continued to be the major recipients of U.S. aluminum materials, accounting for just over two-thirds of total U.S. exports. Exports of UBC's, which were included in the scrap category, decreased dramatically in 1990 compared with those of the previous year. UBC exports in 1990 totaled 2,854 tons compared with 17,354 tons in 1989. Japan continued to be the principal destination of UBC's exported, accounting for just over 40% of the total in 1990.

Imports for consumption of aluminum increased slightly compared with those of 1989. Canada remained the major shipping country to the United States, supplying three-fourths of the total imports in 1990. UBC imports in 1990 totaled 37,028 tons compared with 22,738 tons in 1989. Canada also continued to be the major source of UBC imports, accounting for almost two-thirds of the total in 1990.

TABLE 12

U.S. APPARENT ALUMINUM SUPPLY AND CONSUMPTION

(Thousand metric tons)

	1986	1987	1988	1989	1990
Primary production	3,037	3,343	3,944	4,030	4,048
Change in stocks:[1] Aluminum industry	+108	+341	+11	+61	-3
Imports	1,967	1,850	1,620	1,470	1,514
Secondary recovery:[2]					
New scrap	989	1,134	1,077	1,043	1,034
Old scrap	784	852	1,045	1,011	1,359
Total supply	6,885	7,520	7,697	7,615	7,952
Less total exports	753	917	1,247	r1,615	1,655
Apparent aluminum supply available for domestic manufacturing	6,132	6,603	6,450	r6,000	6,297
Apparent consumption[3]	5,143	5,469	5,373	r4,957	5,263

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 13

DISTRIBUTION OF END-USE SHIPMENTS OF ALUMINUM PRODUCTS IN THE UNITED STATES, BY INDUSTRY

Industry	1988		1989		1990p	
	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	2,036	26.7	2,112	27.0	2,168	28.4
Building and construction	1,316	17.2	1,294	16.5	1,208	15.8
Transportation	1,536	20.1	1,448	18.5	1,323	17.3
Electrical	671	8.8	663	8.5	590	7.7
Consumer durables	588	7.7	544	7.0	504	6.6
Machinery and equipment	435	5.7	436	5.6	444	5.8
Other markets	269	3.5	264	3.4	260	3.4
Total to domestic users[1]	6,851	89.7	6,761	86.5	6,498	85.2
Exports	787	10.3	1,060	13.5	1,130	14.8
Grand total	7,638	100.0	7,821	100.0	7,628	100.0

pPreliminary.
[1]Data may not add to totals shown because of independent rounding.
Source: The Aluminum Association Inc.

World Review

World aluminum demand, which remained strong during most of the year, began to slow toward the end of 1990. Inventories in market economy countries decreased during the first 9 months of the year before beginning an upward trend in the last quarter. Many of the world's producers of aluminum continued to operate their primary smelters at or near rated capacity levels.

In October, the LME announced the selection of Baltimore, MD, as the site for its first U.S. warehouse. The LME expected to accept delivery of aluminum at this location effective February 1, 1991.

Primary aluminum inventories held by members of the International Primary Aluminium Institute (IPAI), which represent the bulk of stocks held outside the centrally planned economy countries, decreased slightly from 1.576 million tons at yearend 1989 to 1.527 million tons at year-

TABLE 14

U.S. NET SHIPMENTS[1] OF ALUMINUM WROUGHT AND CAST PRODUCTS, BY PRODUCERS

(Metric tons)

	1989	1990[p]
Wrought products:		
Sheet, plate, foil	3,854,948	3,820,622
Rod, bar, pipe, tube, and shapes	1,285,881	1,207,398
Rod, wire, cable	326,271	301,947
Forgings (including impacts)	72,077	69,337
Powder, flake, paste	41,726	45,022
Total	5,580,903	5,444,326
Castings:		
Sand	112,682	NA
Permanent mold	195,611	NA
Die	661,827	NA
Other	27,802	NA
Total	997,922	NA
Grand total	6,578,825	NA

[p]Preliminary. 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 15

DISTRIBUTION OF WROUGHT PRODUCTS IN THE UNITED STATES

(Percent)

	1989	1990[p]
Sheet, plate, foil:		
Nonheat-treatable	57.9	59.0
Heat-treatable	4.0	3.5
Foil	7.2	7.6
Rod, bar, pipe, tube, shapes:		
Rod and bar (rolled and extruded)	1.5	1.8
Pipe and tube (extruded and drawn)	2.3	2.4
Extruded shapes	19.2	18.0
Rod, wire, cable:		
Rod and bar wire	.3	.8
Cable and insulated wire	5.6	4.8
Forgings (including impacts)	1.3	1.3
Powder, flake, paste	.7	.8
Total	100.0	100.0

[p]Preliminary.

Source: U.S. Department of Commerce.

end 1990. IPAI reported that total metal inventories, including secondary aluminum, decreased from a revised figure of 3.231 million tons at yearend 1989 to 3.138 million tons at yearend 1990.

Capacity.—The data in table 22 are rated annual capacity for plants producing primary aluminum as of December 31 for the years shown. Rated capacity is defined as the maximum quantity that can be produced on a normally sustainable long-term operating rate, based on the physical equipment of the plant and given acceptable routine operating procedures for labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Australia.—Comalco Aluminium Ltd. announced that expansion plans at its Boyne Island primary aluminum smelter have been put aside. The decision followed the failure to reach an agreement with the government of Queensland for the purchase of the Gladstone power station, which supplies power to the smelter.

Southern Aluminium Pty. Ltd. commissioned an aluminum wheel casting plant in Tasmania. Comalco, the plant's largest shareholder, managed the operation. During the year, monthly production increased from 6,000 wheels January to more than 40,000 wheels in December. Most of the production from the plant, which has a nominal capacity of 600,000 wheels per year, was exported.

Austria.—Reynolds Metals announced plans to double the capacity at its can plant in Enzesfeld, Austria, to 900 million cans per year. Earlier in the year, Reynolds Metals became the sole owner of the plant when it purchased the 50% interest held by its former partner, Austria Metall AG.

Bahrain.—Aluminium Bahrain Ltd. (Alba) announced plans to construct a fourth potline at its primary aluminum smelter. The $1.4 billion expansion included a 235,000-ton-per-year potline using Pechiney 300-amp technology, construction of a new powerplant, and an upgrade of existing facilities. Scheduled for completion by 1993, the expansion would increase the capacity of the smelter to 460,000 tons per year.

Brazil.—Increased energy costs and delays in the construction of new hydroelectric capacity were expected to slow the growth of primary aluminum production capacity in Brazil, which had expanded rapidly in recent years. A 32% increase in power rates raised electricity prices for most of the country's primary smelters to about 40 mills per kilowatt hour, one of the highest power rates in the world. The exceptions were the Consorcio de Alumí-

nio S.A. (Albras) and Alcoa Alumínio S.A. (Alumar) smelters, which had long-term power contracts that featured discounts and rate ceilings linked to aluminum metal prices. However, at the end of the year, these contracts were also being reviewed.

Canada.—Construction work began on Aluminerie Alouette Inc.'s 215,000-ton-per-year primary aluminum smelter at Sept Îles in Quebec. However, the projected capital cost of the project reportedly increased to $1.21 billion from the original estimate of $1.08 billion, and the

TABLE 16

AVERAGE PRIMARY ALUMINUM METAL PRICES

(Cents per pound)

	COMEX 1[1]	COMEX 2[1]	COMEX 3[1]	LME-cash (High grade)	U.S. market	U.S. transaction
1989: Annual average	87.10	86.82	82.19	88.51	87.84	88.92
1990:						
January	68.57	69.94	70.22	69.32	69.67	69.86
February	63.46	65.50	66.66	65.97	65.54	66.39
March	70.80	70.93	71.77	71.10	70.85	72.11
April	71.99	71.93	72.18	69.20	71.56	72.71
May	75.09	72.76	73.24	69.26	72.31	73.29
June	73.38	73.67	73.67	71.02	73.11	73.73
July	71.12	72.62	72.62	71.26	72.57	73.71
August	76.23	79.68	79.68	80.83	80.35	81.20
September	82.16	83.11	83.11	93.74	88.05	89.62
October	78.00	78.00	78.00	88.26	82.23	83.42
November	74.93	73.86	73.86	73.37	72.53	73.26
December	73.34	72.00	72.00	69.06	69.75	70.65
Annual average	73.42	73.67	73.92	74.37	74.04	75.00

[1]COMEX delivery positions: 1—within 1 month; 2—within 3 months; and 3—within 12 months.

Source: Metals Week.

TABLE 17

U.S. EXPORTS OF ALUMINUM, BY CLASS

Class	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Crude and semicrude:				
Metals and alloys, crude	[r]593,103	[r]$1,260,475	679,803	$1,160,509
Scrap	[r]575,419	[r]769,380	537,298	719,017
Plates, sheets, bars, strip, etc.	[r]416,384	[r]1,195,932	419,275	1,277,799
Castings and forgings	[r]20,482	[r]128,974	7,004	67,981
Semifabricated forms, n.e.c.	[r]9,367	[r]55,075	11,385	60,718
Total[1]	[r]1,614,755	[r]3,409,836	1,654,763	3,286,024
Manufactures:				
Foil and leaf	39,334	73,708	26,612	92,424
Powders and flakes	3,262	15,949	4,702	19,333
Wire and cable	4,553	19,087	5,765	22,964
Total[1]	47,149	108,744	37,079	134,721
Grand total[1]	[r]1,661,904	[r]3,518,581	1,691,842	3,420,745

[r]Revised.

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

Source: Bureau of the Census.

TABLE 18

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)
1989:								
Brazil	127	$988	2,430	$13,833	3,642	$4,606	6,200	$19,427
Canada	r28,568	r76,154	260,718	689,586	36,854	41,335	326,140	807,075
France	265	1,635	3,274	23,817	16,522	20,602	20,060	46,054
Germany, Federal Republic of	723	3,050	5,719	23,876	9,669	12,558	16,112	39,484
Hong Kong	2,964	6,548	10,468	30,483	1,150	1,279	14,582	38,310
Italy	173	735	6,238	36,530	13,000	15,908	19,411	53,173
Japan	444,617	932,457	24,838	85,566	337,163	488,785	806,619	1,506,807
Korea, Republic of	25,012	51,054	19,010	63,480	13,983	18,916	58,005	133,451
Mexico	r19,167	r43,969	40,721	139,115	26,509	38,150	86,397	221,234
Netherlands	14,619	29,433	2,726	12,168	11,503	17,250	28,848	58,852
Philippines	1,366	3,433	62	559	691	1,512	2,119	5,505
Saudi Arabia	3	4	12,944	34,907	—	—	12,947	34,911
Singapore	5,566	r9,733	1,673	19,021	453	565	7,692	29,319
Taiwan[r]	26,706	50,985	14,872	36,591	76,678	79,293	118,255	166,869
Thailand	5,016	10,186	1,318	4,105	417	655	6,752	14,947
U.S.S.R.	—	—	—	—	—	—	—	—
United Kingdom	2,137	4,898	8,303	40,937	5,122	6,619	15,562	52,454
Venezuela	1	20	6,576	16,689	45	141	6,622	16,849
Other[r]	16,073	35,191	24,343	108,719	22,016	21,205	62,432	165,115
Total[r 2]	593,103	1,260,475	446,233	1,379,982	575,419	769,380	1,614,755	3,409,836
1990:								
Brazil	173	1,495	5,759	27,272	3,047	4,243	8,979	33,010
Canada	74,433	143,730	267,909	735,779	49,674	62,677	392,015	942,187
France	8,259	15,253	4,243	27,410	13,817	15,347	26,319	58,010
Germany, Federal Republic of	3,710	8,417	5,604	27,351	5,521	7,905	14,836	43,673
Hong Kong	2,051	3,444	3,578	11,474	1,517	1,868	7,146	16,786
Italy	20	215	5,540	32,574	4,215	4,906	9,775	37,695
Japan	453,205	785,539	16,247	65,265	334,034	482,460	803,486	1,333,264
Korea, Republic of	39,309	42,161	12,448	45,661	23,351	28,426	75,108	116,247
Mexico	24,808	48,939	43,610	152,677	20,802	23,314	89,220	224,930
Netherlands	12,458	22,773	2,965	14,819	7,344	10,483	22,766	48,075
Philippines	2,750	4,730	302	1,874	918	735	3,970	7,339
Saudi Arabia	92	428	8,852	22,929	—	—	8,944	23,357
Singapore	2,828	5,086	1,233	6,854	325	438	4,385	12,379
Taiwan	34,472	45,121	13,198	38,862	55,892	56,771	103,563	140,754
Thailand	13,994	16,167	2,826	7,406	1,263	2,365	18,083	25,938
U.S.S.R.	—	—	36	292	—	—	36	292
United Kingdom	564	2,000	10,522	57,426	2,059	2,163	13,145	61,589
Venezuela	38	127	7,707	21,265	93	99	7,838	21,492
Other	6,638	14,882	25,082	109,308	13,428	14,819	45,148	139,008
Total[2]	679,803	1,160,509	437,662	1,406,498	537,298	719,017	1,654,763	3,286,024

[r]Revised.

[1]Includes castings, forgings, and unclassified semifabricated forms.

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

Source: Bureau of the Census.

TABLE 19

U.S. IMPORT DUTIES FOR SELECTED ALUMINUM PRODUCTS

Item	HTS No.	Most favored nation (MFN) Jan. 1, 1990	Non-MFN Jan. 1, 1990
Unwrought metal (in coils)	7601.10.30	2.6% ad valorem	18.5% ad valorem.
	7601.20.30	do.	Do.
Unwrought (other than Si-Al alloys)	7601.10.60	Free	11% ad valorem.
	7601.20.90	do.	10.5% ad valorem.
Waste and scrap	7602.00.00	Free	Free.

TABLE 20

U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM, BY CLASS

Class	1989 Quantity (metric tons)	1989 Value (thousands)	1990 Quantity (metric tons)	1990 Value (thousands)
Crude and semicrude:				
Metals and alloys, crude	923,030	$1,898,133	959,615	$1,596,886
Plates, sheets, strip, etc., n.e.c.[1]	r315,563	r867,208	320,599	774,442
Pipes, tubes, etc.	2,808	20,363	3,778	26,140
Rods and bars	22,012	63,331	15,958	42,631
Scrap	206,610	309,122	214,196	259,674
Total[2]	r1,470,022	r3,158,157	1,514,147	2,699,773
Manufactures:				
Foil and leaf[3]	25,832	123,223	32,974	124,505
Flakes and powders	r2,260	6,916	1,484	4,305
Wire	r26,472	68,683	10,898	27,757
Total[2]	r54,563	198,823	45,356	156,567
Grand total[2]	r1,524,586	3,356,980	1,559,503	2,854,340

rRevised.
[1]Includes plates, sheets, circles, and disks.
[2]Data may not add to totals shown because of independent rounding.
[3]Etched capacitor foil is excluded for 1990.
Source: Bureau of the Census.

scheduled startup was delayed by 2 months to June 1992. Also, in an effort to reduce costs, the smelter would produce 50-pound, high-quality remelt ingot rather than the previously planned product range of sheet metal ingot, extrusion ingot, and wirebar.

Aluminerie de Bécancour Inc. (ABI) announced the startup of its new 120,000-ton-per-year potline in late October, about 4 months ahead of schedule. When this third potline becomes fully operational in early 1991, the capacity of the smelter will be 360,000 tons per year.

Alcan Aluminium announced that its 200,000-ton-per-year primary aluminum smelter at Laterriere would be operating at full capacity early in 1991. As originally announced, Alcan Aluminium was scheduled to shut down three Soderberg-type potrooms at its Arvida smelter in Jonquière during the same period of time. Upon completion of the planned shutdowns at Arvida, the smelter there would operate four Soderberg and six prebake lines for a rated capacity of 230,000 tons per year.

Members of the Canadian Association of Smelter and Allied Workers ratified a new 3-year labor contract that covered approximately 1,500 unionized employees at Alcan Aluminium's primary aluminum smelter at Kitimat and the Kemano power station, both in British Columbia. The new contract, which expires on July 25, 1993, reportedly included a $1,750 (Canadian dollars) signing bonus per worker, a 6% wage increase in the first and third year, a flat increase of $1.24 (Canadian dollars) per hour in the second year, cost of living allowances triggered at 6% in the second and third year, and improvements in some fringe benefit items.

Reynolds Metals reported that construction began on an 80,000-ton-per-year aluminum redraw rod plant in Quebec. The plant was being constructed on a site adjacent to the ABI smelter, in

TABLE 21

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)
1989:								
Argentina	12,173	$23,046	6,889	$17,302	—	—	19,062	$40,348
Australia	5,764	12,084	11	70	666	$1,588	6,440	13,742
Bahrain	—	—	15,319	38,613	—	—	15,319	38,613
Belgium	76	467	29,993	83,693	101	116	30,170	84,276
Brazil	29,754	64,765	8,756	21,975	1	6	38,511	86,746
Canada	789,587	1,637,472	151,848	384,988	160,764	246,259	1,102,199	2,268,719
France	97	672	11,042	40,715	379	527	11,519	41,914
Germany, Federal Republic of	579	7,766	10,745	42,165	872	1,295	12,196	51,225
Italy	21	1,259	2,287	7,107	26	28	2,334	8,394
Japan	941	2,657	20,788	68,291	310	891	22,039	71,839
Korea, Republic of	—	—	268	1,814	95	175	363	1,989
Mexico	733	1,650	3,028	9,564	20,798	23,993	24,559	35,207
Netherlands	2	72	5,056	24,515	20	147	5,079	24,734
Norway	19	136	2,536	6,682	—	—	2,555	6,818
South Africa, Republic of	1,463	3,250	7,155	18,874	—	—	8,618	22,124
Spain	—	—	2,905	7,773	—	—	2,905	7,773
U.S.S.R.	100	226	—	—	5,845	10,054	5,945	10,280
United Arab Emirates	11,404	25,853	—	—	474	1,172	11,877	27,025
United Kingdom	356	1,789	11,470	41,960	541	1,077	12,367	44,825
Venezuela	59,552	90,694	16,454	36,612	4,747	7,800	80,753	135,106
Yugoslavia	19	50	13,289	31,320	—	—	13,307	31,371
Other[r]	10,392	24,225	20,543	66,870	10,970	13,993	41,905	105,089
Total[r 2]	923,030	1,898,133	340,382	950,902	206,610	309,122	1,470,022	3,158,157
1990:								
Argentina	3,496	5,865	2,874	5,585	82	108	6,451	11,558
Australia	6,119	10,445	135	667	62	107	6,316	11,219
Bahrain	—	—	16,063	34,397	—	—	16,063	34,397
Belgium	(3)	14	19,234	46,407	—	—	19,234	46,421
Brazil	38,657	62,566	7,800	15,696	274	504	46,731	78,766
Canada	824,899	1,363,000	145,452	324,006	163,536	207,227	1,133,887	1,894,233
France	193	1,539	11,446	39,082	5	21	11,643	40,641
Germany, Federal Republic of	447	7,459	13,667	51,922	421	677	14,536	60,058
Italy	21	1,032	1,909	6,187	34	38	1,963	7,257
Japan	415	944	38,590	108,240	65	235	39,071	109,419
Korea, Republic of	6	25	152	1,034	18	19	176	1,078
Mexico	821	1,373	3,931	10,948	28,830	27,747	33,582	40,068
Netherlands	1,203	1,804	4,088	16,944	156	128	5,447	18,877
Norway	92	667	1,377	2,589	—	—	1,469	3,257
South Africa, Republic of	1,745	2,846	8,328	18,023	127	148	10,200	21,017
Spain	145	295	2,337	5,746	69	95	2,550	6,137
U.S.S.R.	—	—	23	249	2,627	3,766	2,650	4,015
United Arab Emirates	2,820	5,193	—	—	—	—	2,820	5,193
United Kingdom	351	1,865	5,924	27,634	690	748	6,965	30,247
Venezuela	76,179	126,907	20,734	37,768	8,652	10,021	105,565	174,696
Yugoslavia	127	234	16,895	32,679	—	—	17,023	32,913
Other	1,880	2,813	19,375	57,409	8,549	8,085	29,804	68,307
Total[2]	959,617	1,596,886	340,334	843,213	214,196	259,674	1,514,147	2,699,773

[r]Revised.
[1]Includes circles, disks, rods, pipes, tubes, etc.
[2]Data may not add to totals shown because of independent rounding.
[3]Less than 1/2 unit.
Source: Bureau of the Census.

which Reynolds Metals has a 25% interest. Molten metal from the ABI smelter would be trucked to the rod plant, which was expected to be completed at the end of 1991.

Reynolds Metals also announced the signing of an agreement to purchase a 75% interest in an aluminum wheel plant in Collingwood, Ontario. Lemmerz Canada Inc., a subsidiary of Lemmerz-Werke K Ga A of Königswinter, Germany, would retain the remaining 25% interest in the 1-million-wheel-per-year plant. Reynolds Metals also announced plans to increase capacity at the plant to 1.5 million wheels per year by 1993.

Chile.—Proyectos de Aysten of Chile announced that they had contacted Kaiser Engineers International to conduct a feasibility study on the construction of a 200,000-ton-per-year primary aluminum smelter and a hydroelectric power station in southern Chile. The site chosen was on the Cuervo River.

Germany, Federal Republic of.—Alcan Norf GmbH (Alunorf), a joint venture of Alcan Deutschland GmbH and Vereinigte Aluminium-Werke AG (VAW), announced a $535 million expansion plan at its rolling mill. The program, which would increase capacity by 700,000 tons per year, involved the construction of a second hot-rolling mill and a two-stand tandem cold-rolling mill. Upon completion in 1994, the Alunorf plant was expected to be the largest single aluminum rolling plant in the world with a total annual capacity of 1.4 million tons.

Iceland.—Atlantal, a joint venture of Alumax, Granges AB, and Hoogovens Aluminium BV, announced plans to study the feasibility of constructing a 200,000-ton-per-year greenfield primary aluminum smelter at Keilisnes.

Iran.—The Dubai-based International Development Corp. announced the signing of a joint-venture agreement with the Government of Iran for the construction of a 220,000-ton-per-year primary aluminum smelter at Bandar Abbas. The $1.35 billion project also reportedly included a powerplant and desalination unit.

Japan.—Alcoa and Kobe Steel announced the formation of a joint venture to produce and market aluminum sheet for the beverage container market. The

TABLE 22

ALUMINUM: WORLD ANNUAL PRIMARY METAL PRODUCTION CAPACITY, BY COUNTRY[1]

(Thousand metric tons)

Continent and country	1988	1989	1990[P]
North America:			
Canada	1,594	1,594	1,594
Mexico	66	66	66
United States	3,960	4,016	4,016
South America:			
Argentina	160	160	160
Brazil	869	869	976
Suriname	30	30	30
Venezuela	460	590	610
Europe:			
Austria	92	92	92
Czechoslovakia	60	60	60
France	346	346	346
Germany, Federal Republic of:			
Eastern states	85	55	—
Western states	733	713	713
Greece	145	150	150
Hungary	[r]78	78	78
Iceland	86	86	86
Italy	276	276	276
Netherlands	266	266	266
Norway	843	851	851
Poland	[r]48	48	48
Romania	250	250	250
Spain	344	344	344
Sweden	91	91	91
Switzerland	72	72	72
U.S.S.R.	2,590	2,640	2,740
United Kingdom	287	287	287
Yugoslavia	[r]327	337	342
Africa:			
Cameroon	80	80	80
Egypt	170	170	170
Ghana	200	200	200
South Africa, Republic of	172	172	172
Asia:			
Bahrain	180	205	205
China	875	875	935
India	472	472	472
Indonesia	225	225	225
Iran	50	50	50
Japan	64	64	64
Korea, North	20	20	—
Korea, Republic of	18	18	18
Taiwan	50	50	—
Turkey	60	60	60
United Arab Emirates: Dubai	159	170	170
Oceania:			
Australia	1,177	1,188	1,240
New Zealand	250	250	259
Total	[r]18,380	18,636	18,864

[P]Preliminary. [r]Revised.

[1]Detailed information on the individual aluminum reduction plants is available in a two-part report that can be purchased from Chief, Division of Finance, U.S. Bureau of Mines, Bldg. 20, Federal Center, Denver, CO 80225. Part 1 of "Primary Aluminum Plants, Worldwide" details location, ownership, and production capacity for 1988-95 and sources of energy for foreign and domestic primary aluminum plants, including those in centrally planned economies. Part 2 summarizes production capacities for 1988-95 by smelter and country.

first project in this new venture, named KSL Alcoa Aluminium, was reported to be the construction of a new 180,000-ton-per-year cold-rolling mill adjacent to Kobe Steel's Moka plant. The targeted startup date for the mill was mid-1993.

Korea, Republic of.—In mid-1990, Aluminium of Korea Ltd. (Koralu) announced the suspension of operations at its primary aluminum smelter in Ulsan.

Nigeria.—Aluscon, a partnership of the Government of Nigeria, Ferrostaal AG of Germany, and Reynolds Metals, announced plans to construct a 180,000-ton-per-year primary aluminum smelter at Ikot Abasi in southeastern Nigeria. Financing of this project reportedly was incomplete.

Norway.—Norsk Hydro and Elkem Aluminium announced plans to expand capacity at their respective primary aluminum smelters. Elkem reportedly planned a total capacity expansion of 200,000 tons per year at its Mosjoen and Lista smelters. Norsk Hydro's plans reportedly included its smelters at Ardal and Sunndalsora with a total net increase in capacity of about 280,000 tons per year. A final decision on these plans reportedly was dependent on the companies' ability to secure long-term power supply contracts at internationally competitive prices.

Spain.—Instituto Nacional de Industria (INI), the state-owned industrial holding company, reported the purchase of Alcan Aluminium's 23.9% interest in the aluminum producer, Inespal. Following the purchase, INI became the sole owner of Inespal.

Norsk Hydro announced plans to purchase Riego Wright SA. Riego Wright reportedly was one of Spain's largest producers of extruded aluminum, serving primarily the construction market.

U.S.S.R.—Kaiser Aluminum reported the signing of an agreement to modernize 2 of the 23 potrooms at the Krasnoyarsk primary aluminum smelter. The modernization program reportedly involved the installation of Kaiser's computerized cell control technology, new emission control systems, and other anode and cell operations technology.

Current Research

The damping capabilities of a number of aluminum-matrix composites were measured over a wide range of frequencies at low strain amplitudes using a new laser vibrometer technique. The damping of composites of aluminum alloy 6061 reinforced with Al_2O_3 particulates, silicon carbide whiskers, continuous graphite (planar-random) fibers, and unidirectional graphite fibers was studied to determine which systems showed the most promise for improved damping in the 1- to 20-kilohertz range under ambient conditions.[3]

With their high stiffness and low weight, honeycomb materials reportedly are becoming an increasingly important element of advanced aerospace design concepts. Some of the factors that influenced the applicability of metallic-based honeycomb structural materials were examined.[4]

The Minerals, Metals, and Materials Society (TMS) published the proceedings of the Light Metals Committee technical sessions presented at the 119th TMS Annual Meeting held in Anaheim, CA, February 1990. More than 100 papers, in such topic areas as alumina and bauxite, reduction technology, carbon technology, and cast shop technology, were presented. The proceedings, entitled Light Metals 1990, were available from TMS, 420 Commonwealth Drive, Warrendale, PA 15086.

OUTLOOK—ALUMINUM

Demand for aluminum, both domestically and worldwide, continued to slow during the first half of 1991. This slowdown should continue through the end of the year before beginning a slow gradual rise in 1992. Thereafter, aluminum metal demand should show an average annual growth rate of about 2% per year over the next few years.

ANNUAL REVIEW—BAUXITE AND ALUMINA

World production of bauxite and alumina advanced during 1990 to new record levels in response to the continued high pace of primary aluminum metal output. Mine production of bauxite was reported from 27 countries. Domestic consumption of bauxite once again continued its upward movement, but at a reduced rate from that of 1989, with the majority of the growth driven by metal market requirements for primary aluminum. Within the specialty products area, consumption of abrasive-grade bauxite was comparable with 1989 usage, but bauxite consumption by the chemical and refractory industries declined slightly in 1990. Demand for alumina remained strong throughout the entire year, mainly in response to high primary aluminum smelter operating levels. In spite of a national economic recession in the latter part of 1990, U.S. production and shipments of smelter-grade alumina continued the climb to new heights, as has been the pattern in recent years. U.S. alumina consumption, however, moderated slightly from the high levels of 1989, and a slight softening of the alumina market developed in 1990 as a buildup developed in alumina supply levels. Alumina reportedly was produced in 24 countries around the world.

Legislation and Government Programs

Effective as of February 14, 1990, the Environmental Protection Agency (EPA) removed nonfibrous alumina from its list of toxic substances covered under Emergency Planning and Community Right-to-Know legislation passed by the U.S. Congress in 1986.[5] The action relieved U.S. alumina producers from a requirement to report releases of aluminum oxide that had occurred in 1989 and releases that could occur in the future because nonfibrous alumina was found not to cause adverse human health effects or environmental toxicity.

On July 31, 1990, as mandated by the U.S. District Court for the District of Columbia, the EPA released its Report to Congress concerning regulation of 20 special wastes from mineral processing operations that had been identified for temporary exemption from regulation as hazardous wastes under the Mining Waste Exclusion of RCRA.[6] This was EPA's second Report to Congress (RTC II) on wastes from the mineral industry. The Agency, within the detailed conclusions of the report, determined that red and brown muds generated from the

TABLE 23

ALUMINUM, PRIMARY: WORLD PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
Argentina	148	153	154	r e162	162
Australia	882	1,004	1,150	1,244	21,234
Austria	93	93	95	93	289
Bahrain	178	180	183	187	188
Brazil	757	843	874	890	2931
Cameroon	84	79	87	92	91
Canada	1,355	1,540	1,535	1,555	1,570
China[e]	410	615	r710	r750	850
Czechoslovakia	33	32	31	33	32
Egypt	175	179	173	180	179
France	322	323	328	335	2326
Germany, Federal Republic of:					
Eastern states[e]	61	62	61	r54	50
Western states	765	738	744	742	2720
Ghana	125	150	161	169	2174
Greece[3]	124	127	151	148	2150
Hungary	74	76	75	75	75
Iceland	76	85	82	89	288
India[3]	257	265	375	423	2433
Indonesia[3]	219	202	185	197	2186
Iran[e]	40	r45	40	r45	49
Italy	243	233	222	219	2232
Japan[4]	140	41	35	35	234
Korea, North[e]	10	10	10	10	—
Korea, Republic of[3]	19	22	18	18	4
Mexico[3]	37	r60	68	72	268
Netherlands	266	276	278	279	2258
New Zealand	236	252	264	258	260
Norway	726	r853	864	863	2845
Poland[5]	48	48	48	48	48
Romania[6]	269	260	265	269	180
South Africa, Republic of	170	171	170	166	166
Spain	r355	341	323	352	2355
Suriname	29	2	10	28	20
Sweden	78	81	99	97	296
Switzerland	80	73	72	71	272
Turkey	60	42	57	62	60
U.S.S.R.[e]	2,300	2,400	2,400	2,400	2,200
United Arab Emirates: Dubai	155	155	162	168	168
United Kingdom	276	294	300	297	2290
United States	3,037	3,343	3,944	4,030	24,048
Venezuela	r418	r428	437	540	2546
Yugoslavia[e 3]	282	244	260	r275	290
Total	r15,412	r16,420	17,500	18,020	17,817

[e]Estimated. [p]Preliminary. [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 May 24, 1991.

[2]Reported figure.

[3]Primary ingot.

[4]Excludes high-purity aluminum containing 99.995% or more as follows, in metric tons: 1986—8,140; 1987—12,099; 1988—13,628; 1989—15,696; and 1990—16,292.

[5]Primary unalloyed ingot plus secondary unalloyed ingot.

[6]Primary unalloyed metal plus primary alloyed metal, thus including weight of alloying material.

bauxite refining process exhibit none of the characteristics of hazardous waste and, therefore, should not pose a threat to human health or the environment.

There were no additions or withdrawals of bauxite from the NDS in 1990. The NDS goals for bauxite remained unchanged at 21.3 million tons of Jamaica-type and 6.2 million tons of Suriname-type metallurgical-grade bauxite. The goal for calcined refractory-grade bauxite was adjusted downward from 1.42 to 1.26 million tons, and the goal for calcined abrasive-grade bauxite was eliminated. The DLA, manager of the NDS, listed an inventory of 12.7 million tons of Jamaica-type and 5.4 million tons of Suriname-type metallurgical-grade bauxite at year-end. The NDS calcined refractory-grade bauxite inventory was listed as 280,500 tons at the close of 1990.

In a plan to upgrade the NDS stocks, DLA announced on September 28, 1990, the awarding of the first in a planned series of contracts to convert metallurgical grade bauxite ore in the NDS to aluminum metal. The fixed price contract, awarded to Alcoa, called for the conversion of approximately 243,900 tons of bauxite to 55,157 tons of aluminum metal ingot. Work on this $100.4 million contract was expected to be completed by September 1992.

Production

The total U.S. bauxite production during 1990 was markedly lower than that reported for 1989. The significant reduction in domestic mine production was partly attributed to the permanent closure of the last bauxite mining operation in Arkansas during mid-1990. The only currently active bauxite mines remaining in the United States are the surface operations in Alabama and Georgia that produce bauxitic materials, a natural mixture of bauxitic clay and bauxite with a very low iron oxide content, primarily used for the production of alumina calcines. Demand for these domestic ores remained relatively weak during 1990, and mine output was intermittent. Within this market sector, the Harbison-Walker Refractories Div. of Dresser Industries Inc. shipped bauxite from mines in Alabama to its local calcining plant and to Carbo Ceramic Co.'s proppant plant at Eufaula, AL. Throughout the year, C-E Minerals continued to operate and maintain its mines in Alabama and Georgia, with the

TABLE 24

SALIENT BAUXITE STATISTICS

(Thousand metric tons and thousand dollars)

	1986	1987	1988	1989	1990
United States:					
Production: Crude ore (dry equivalent)	510	576	588	W	W
Value[e]	$10,361	$10,916	$10,566	W	W
Exports (as shipped)	69	201	63	44	74
Imports for consumption[1]	6,456	9,156	9,944	10,893	12,142
Consumption (dry equivalent)	6,901	9,548	10,074	[r]11,810	12,051
World: Production	[r]88,173	[r]91,891	98,357	[p]105,695	[e]109,118

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Excludes calcined bauxite. Includes bauxite imported to the U.S. Virgin Islands.

raw ore shipped to its Andersonville, GA, facility for the production of refractory products.

Alcoa indicated that it had closed its Arkansas bauxite mining operation and 340,000-ton-per-year production capacity refining plant because of depleted ore reserves. The mining operation had supplied metallurgical-grade bauxite for aluminum metal production over tha major portion of the mine's history. The company's Arkansas mining facilities, opened in 1899, were the last mining operations in the United States capable of producing bauxite for smelter-grade alumina production. In recent years, however, mine output was primarily utilized as feed for the manufacture of proppants used in the petroleum industry and the production of a wide range of specialty alumina chemicals. It was reported that the production of alumina chemical products would be continued at the Bauxite, AR, location employing alumina feedstocks supplied from other Alcoa facilities.

Clarendon Ltd., an aluminum trading group based in Switzerland, reopened the 635,000-ton-per-year alumina plant on the Island of St. Croix within the U.S. Virgin Islands in early 1990 through its subsidiary Virgin Islands Alumina (VIALCO). The refinery had been idle since 1985 and was purchased from the previous owner, Martin Marietta Corp., in April 1989. Bauxite feedstock for the refinery reportedly was supplied from sources in Brazil and Guyana.

The net domestic capacity to produce alumina approached almost 5.62 million tons per year in 1990, with the reopening of the St. Croix, VI, plant and the closure of the Bauxite, AR, plant. Apparent refinery capacity utilization in the United States for the year was approximately 93%.

In 1990, it was announced that the American Capital and Research Corp. subsidiary, ICF Kaiser Engineers, entered a 3-year contract with Kaiser Aluminum and Chemical Corp. involving engineering work on Kaiser's Gramercy alumina plant in Louisiana and affiliated Kaiser operations in Jamaica.

Consumption and Uses

A continued firm requirement for smelter-grade alumina moved the consumption of crude and dried metallurgical-grade bauxite to a level slightly above that of 1989. The majority of this increase was supplied from imports. Consumption of bauxite by the abrasive industries remained essentially unchanged throughout 1990, while consumption within the chemical and refractory industries decreased by modest amounts for the year. Approximately 90% of the bauxite consumed in the United States during 1990 was refined to alumina, and an estimated average of 2.21 tons of dried bauxite was required to produce 1 ton of calcined alumina. Twenty-two of the 23 active primary aluminum smelters reported to the U.S. Bureau of Mines a consumption of 7.6 million tons of calcined alumina in 1990, down slightly from the consumption level reported for 1989. This lower level of consumption, coupled with the high U.S. alumina production rates, resulted in the development of a modest oversupply of smelter-grade alumina on the domestic alumina market. An estimated 92% of the alumina shipped by U.S. refineries went to domestic primary smelters for metal production. Consumption in various forms by the abrasives, chemicals, refractories, and specialties industries accounted for the balance of the alumina usage.

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 1990, the U.S. Bureau of Mines estimated the average value of domestic crude bauxite shipments, f.o.b. mine or plant, to be $16 per ton. The average value of calcined domestic bauxite was estimated to be $175 per ton. Base prices quoted by Industrial Minerals magazine and independent sources for imported calcined refractory-grade bauxite were as follows: Chinese, typical 85% alumina (Al_2O_3), f.o.b. barge, Burnside, LA, $85 to $125 per ton; and Guyanese, f.o.b. railcar, 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

TABLE 25

MINE PRODUCTION OF BAUXITE AND SHIPMENTS FROM MINES AND PROCESSING PLANTS TO CONSUMERS IN THE UNITED STATES

(Thousand metric tons and thousand dollars)

Year	Mine production			Shipments from mines and processing plants to consumers[1]		
	Crude	Dry equivalent	Value[2]	As shipped	Dry equivalent	Value[2]
1988	714	588	$10,566	770	688	$24,703
1989	W	W	W	W	W	W
1990	W	W	W	W	W	W

W Withheld to avoid disclosing company proprietary data.
[1]May exclude some bauxite mixed in clay products.
[2]Computed from values assigned by producers and from estimates of the U.S. Bureau of Mines.

TABLE 26

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]				
1986	2,570	r755	4,320	3,105
1987	3,555	830	4,385	4,150
1988	r4,185	r810	4,995	r4,770
1989	4,580	r605	r5,180	r5,000
1990	4,775	655	5,430	5,230
Shipments:[e]				
1986	2,590	740	3,330	3,120
1987	3,530	845	4,375	4,135
1988	r4,945	r815	5,760	r5,535
1989	4,665	605	5,270	r5,090
1990	4,750	575	5,325	5,150

[e]Estimated. rRevised.
[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.

high levels established during the previous 2 years. The average value of domestic calcined alumina shipments was estimated to be $260 per ton. Trade data released by the Bureau of the Census indicated the average value of imported calcined alumina was $305 per ton, f.a.s. port of shipment, and $332 per ton, c.i.f. U.S. ports. Beyond these current prices, medium-term projections support a reasonably buoyant market outlook for alumina toward the mid-1990's.

For 1990, the International Bauxite Association (IBA) recommended that its members set their minimum c.i.f. price for metallurgical-grade bauxite at between 2% and 2.5% of the composite reference price for primary aluminum ingot and, for metallurgical-grade alumina, between 13.5% and 15% of the composite reference price for primary aluminum ingot. The IBA members account for approximately 86% of the bauxite output from the market economy countries and about 56% of the alumina production.

Foreign Trade

Dried bauxite exports from the United States totaled 32,300 tons in 1990, a marked increase over the 1989 total of 18,900 tons. Canada received 30,400 tons and Mexico, 1,500 tons. U.S. exports of calcined refractory-grade bauxite totaled 13,700 tons for 1990. Mexico received 10,600 tons and Canada, 2,800 tons. Exports of all other grades of calcined bauxite (chiefly abrasive-grade) amounted to 7,000 tons for the year. Mexico received 4,500 tons and Venezuela, 1,200 tons. Specialty aluminum compounds exported included 6,800 tons of aluminum sulfate, 13,700 tons of aluminum oxide abrasives, and 13,900 tons of various fluoride-base compounds of aluminum, including synthetic cryolite and aluminum fluoride.

Imports for consumption of crude and dried bauxite increased from 1989 receipts, and the three primary suppliers were Jamaica, Guinea, and Brazil, in order of shipments. Brazil's shipments to the United States continued to increase during the year, and Brazil displaced Australia from the third place position on the list of countries that supplied bauxite to U.S. markets in 1990.

World Review

World production of bauxite and alumina remained on the upward trends that commenced following the aluminum industry slowdown of the mid-1980's. Twenty-seven countries reportedly mined bauxite in 1990, and the total world production of bauxite reached a record 109 million tons, an increase of 3% above 1989 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 increased to 40 million tons, also a new production record, and was 3% higher than the 1989 production level. The traditional, principal producing countries, Australia, the U.S.S.R., and the United States, once again supplied almost 50% of the total world production.

Capacity.—A moderate increase in the annual rated capacity of plants producing alumina resulted in the development of a modest surplus of alumina stocks on

TABLE 27

CAPACITIES OF DOMESTIC ALUMINA PLANTS,[1] DECEMBER 31

(Thousand metric tons per year)

Company and plant	1988	1989	1990
Aluminum Co. of America:			
Bauxite, AR	340	340	—
Point Comfort, TX	1,735	1,735	1,735
Total	2,075	2,075	1,735
Kaiser Aluminum & Chemical Corp.: Gramercy, LA	795	795	1,000
Ormet Corp.: Burnside, LA	545	545	545
Reynolds Metals Co.: Corpus Christi, TX	1,700	1,700	1,700
Virgin Islands Alumina: St. Croix, VI	—	—	635
Grand total	5,115	5,115	5,615

[1]Capacity may vary depending on the bauxite used.

TABLE 28

U.S. CONSUMPTION OF BAUXITE, BY INDUSTRY

(Thousand metric tons, dry equivalent)

Industry	Domestic	Foreign	Total
1989:			
Alumina	W	[1]10,538	10,782
Abrasive[2]	W	W	275
Chemical	W	W	223
Refractory	W	[r,3]732	[r]407
Other	W	W	123
Total	540	[r]11,270	[r]11,810
1990:			
Alumina	W	[1]10,757	11,064
Abrasive[2]	W	W	276
Chemical	W	W	212
Refractory	W	[3]688	396
Other	W	W	103
Total	606	11,445	12,051

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Includes "Abrasive."
[2]Includes consumption by Canadian abrasive industry.
[3]Includes "Chemical" and "Other."

world markets in 1990. Apparent worldwide refinery capacity utilization for 1990 was estimated at approximately 92%. The 1990 world annual alumina plant capacity was rated at 2% above the previous record level that was posted in 1984. Any further increases in smelter-grade alumina production capacity are expected primarily to develop 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 capital investment.

Australia.—In 1990, the world's largest bauxite- and alumina-producing country achieved new production records for the eighth consecutive year.

Alcan Aluminium announced that its South Pacific Ltd. subsidiary would conduct a joint feasibility study with Comalco for the installation of a new alumina plant in northern Australia. The refinery was projected to have an initial capacity of approximately 1 million tons per year and would be built near bauxite reserves owned by both companies on the Cape York Peninsula of northern Queensland, where Alcan holds rights to the Wenlock River deposit and Comalco operates the Weipa bauxite mine. The initial cost estimates for the proposed refinery were indicated to be approximately $1 billion.

Comalco reported that its 1990 production and shipments of bauxite from the Weipa mining operation were the highest in the mine's history, with beneficiated bauxite production at 11.0 million tons and metal-grade bauxite shipments at 10.5 million tons. The company attributed the increases to new markets in Eastern Europe, as well as higher demand from the Queensland Alumina Ltd. plant at Gladstone, which also enjoyed a record year, with alumina production more than 3 million tons. A continuing program for the upgrading of this plant was expected to result in the alumina production capacity of this facility being raised to the 3.3-million-ton-per-year level, a 400,000-ton-per-year increase in refinery capacity.

The current expansion program of the Worsley Alumina Pty. Ltd. (50% Reynolds Metals, 37.5% Shell, and 12.5% Kobe/Nissho-Iwai) refinery in Western Australia was expected to be completed in early 1991 and would raise the capacity of this alumina plant to 1.5 million tons per year.

Alcoa of Australia reported that construction had begun on the previously announced $250 million expansion of its Wagerup alumina plant in Western Australia. The expansion, expected to be completed in early 1993, would lift the refinery's capacity by 630,000 tons to 1.48 million tons per year. For 1990, Alcoa of Australia's three alumina plants (Kwinana, Pinjarra, and Wagerup) reportedly produced just under 5.5 million tons of alumina.

Nabalco Pty. Ltd. (70% Alusuisse-Lonza, 30% Gove Aluminium Ltd.) released plans to spend about $109 million to upgrade its bauxite and alumina operations at Gove in the Northern Territory of

TABLE 29

U.S. CONSUMPTION OF CRUDE AND PROCESSED BAUXITE

(Thousand metric tons, dry equivalent)

Type	Domestic origin	Foreign origin	Total
1989:			
Crude and dried	W	W	11,104
Calcined and activated	W	W	r706
Total	540	r11,270	r11,810
1990:			
Crude and dried	W	W	11,357
Calcined and activated	W	W	694
Total	606	11,445	12,051

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Total."

TABLE 30

PRODUCTION AND SHIPMENTS OF SELECTED ALUMINUM SALTS IN THE UNITED STATES IN 1989

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)	76	1,128	1,040	$122,561
Iron-free (17% Al_2O_3)	23	115	113	14,246
Aluminum chloride:				
Liquid and crystal	3	W	W	W
Anhydrous (100% $AlCl_3$)	3	W	W	W
Aluminum fluoride, technical	2	W	W	W
Aluminum hydroxide, trihydrate (100% $Al_2O_3 \cdot 3H_2O$)	8	615	634	196,221
Aluminates	15	68	65	20,493
Other aluminum compounds[1]	NA	NA	NA	NA

NA Not available. W Withheld to avoid disclosing company proprietary data.
[1]Includes light aluminum hydroxide, cryolite, etc.

Source: Data are based on Bureau of the Census 1989 Current Industrial Reports, Series MA-28A, "Inorganic Chemicals."

TABLE 31

STOCKS OF BAUXITE IN THE UNITED STATES,[1] DECEMBER 31

(Thousand metric tons, dry equivalent)

Sector	1989	1990
Producers, processors, and consumers	r2,521	2,321
Government	18,474	18,477
Total	r20,995	20,798

rRevised.
[1]Domestic and foreign bauxite; crude, dried, calcined, activated; all grades.

TABLE 32

STOCKS OF ALUMINA IN THE UNITED STATES,[1] DECEMBER 31

(Thousand metric tons, calcined equivalent)

Sector	1989	1990
Producers	623	e679
Primary aluminum plants	1,346	1,419
Total	1,969	e2,098

eEstimated.
[1]Excludes consumers' stocks other than those at primary aluminum plants.

Australia. When completed in early 1992, the company would be producing an additional 1 million tons per year of bauxite, raising total mine output to approximately 6 million tons per year, and the related alumina production would be increased from the present 1.4 million tons per year to 1.6 million tons per year. Late in 1990, this Gove joint-venture company secured the right to export 40 million tons of bauxite during the next 20 years through an extension of an agreement with the government of Australia's Northern Territory that had been due to expire in 1991.

Alcoa of Australia was honored in June by the United Nations Environmental Program (UNEP) for rehabilitating and reforesting four bauxite mining areas in Western Australia during the past 20 years. This was the first mining operation ever to win environmental honors from the UNEP as part of the agency's Global 500 Roll of Honor. Alcoa of Australia reportedly spends $9.24 million per year on rehabilitation planning, operations, and research for its mined-out areas.

Brazil.—Alto Brasil Mineração (ABM), a joint-venture company of Alcoa Alumínio and Billiton Metais, received an environmental license from the Brazilian Government to open a bauxite mine at Cruz Alta within the Trombetas River area of Brazil's Amazon region. It was estimated that the initial capacity of the mining operation would be 2.25 million tons per year; capacity may be expanded to 4.5 million tons per year at a later date. Investment in the first phase was projected to be $150 million, and it was expected that construction would begin in 1991. ABM was reported to hold rights for bauxite ore reserves of 230 million tons within the Trombetas area.

Mineração Rio do Norte S.A. (MRN) reportedly produced 8.0 million tons of bauxite at its Trombetas mining operation in Pará State 31% above 1989 production levels. Its reported sales of 7.8 million tons were 22% above those of the previous year. The MNR bauxite exports totaled 5.6 million tons, and domestic sales amounted to 2.2 million tons. These new production and sales records were achieved in part because of the completion of a $40 million mine expansion and modernization program. In addition, MRN announced that because of increased competition from other bauxite mines, it had initiated an ambitious cost

TABLE 33

AVERAGE VALUE OF U.S. IMPORTS OF CRUDE AND DRIED BAUXITE[1]

(Per metric ton)

Country	1989[r]		1990	
	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.)
To U.S.:				
Australia	$15.93	$25.37	$16.31	$27.14
Brazil	31.22	40.58	32.48	41.17
Guinea	30.71	38.45	33.08	40.25
Guyana	30.15	42.06	29.20	39.34
Jamaica	26.22	30.81	25.07	29.67
Weighted average	26.84	35.45	27.23	35.51

[r]Revised.
[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 34

MARKET QUOTATIONS ON ALUMINA AND ALUMINUM COMPOUNDS

(Per metric ton, in bags, carlots, freight equalized)

Compound	Dec. 29, 1989	Dec. 28, 1990
Alumina, calcined	$418.88	$418.88
Alumina, hydrated, bulk	278.88	278.88
Alumina, activated, granular, works	905.00	904.99
Aluminum sulfate, commercial, ground, (17% Al_2O_3)	253.53	253.53
Aluminum sulfate, iron-free, dry (17% Al_2O_3)	358.25	358.25

Source: Chemical Marketing Reporter.

TABLE 35

U.S. EXPORTS OF ALUMINA,[1] BY COUNTRY

(Thousand metric tons, calcined equivalent, and thousand dollars)

Country	1988		1989		1990	
	Quantity	Value	Quantity	Value	Quantity	Value
Argentina	1	$740	1	$849	(2)	$440
Belgium	3	2,955	5	5,292	5	5,365
Brazil	115	19,780	20	6,966	103	27,089
Canada	509	91,337	942	257,466	709	197,889
France	1	1,422	3	2,225	1	3,523
Germany, Federal Republic of	2	3,372	2	7,216	3	12,702
Ghana	183	27,854	125	22,579	83	12,443
Japan	20	7,491	23	19,842	12	23,900
Mexico	175	35,341	150	56,280	170	66,215
Netherlands	3	3,520	8	9,709	18	9,972
Norway	—	—	—	—	27	8,521
Sweden	(2)	323	27	5,634	62	18,553
United Kingdom	6	3,448	2	4,471	2	4,249
Venezuela	4	3,028	3	2,008	3	2,789
Other	15	15,495	17	19,388	43	27,706
Total[3]	1,036	216,107	1,328	419,924	1,243	421,356

[1]Includes exports of aluminum hydroxide (calcined equivalent) as follows: 1988—15,656 tons; 1989—33,316 tons; and 1990—34,124 tons.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

control program that had resulted in a reduction of almost 20% of its total work force by the end of 1990.

The long stalemated Alumina do Norte do Brasil S.A. (Alunorte) refinery project near Belém remained on hold in 1990 pending Cia. Vale do Rio Doce and Nippon Amazon Aluminium Co. arranging further financial support for the project.

China.—Chinese geologists reported the discovery of a large bauxite deposit in central Guizhou Province, China. It was thought to be one of the largest bauxite deposits to have been found in the country, and its total resources were estimated at 200 million tons. A 1.2-million-ton-per-year mining operation was proposed to exploit the currently identified 70-million-ton reserve base of the deposit.

Dominican Republic.—Government officials announced that Alcoa had entered a $6.3 million agreement to purchase 350,000 tons of bauxite in 1990. Ideal Dominicana, S.A., a subsidiary of the U.S. firm Holnam Inc., continued to manage and operate the Cabo Rojo-Pedernales area bauxite mining operations for the Government. It was believed that approximately 300 new jobs would be created, directly and indirectly, as a result of the resumption of bauxite mining activities at this operation, previously owned by Alcoa. It was expected that the majority of the bauxite covered by this purchase agreement would be shipped to Alcoa's subsidiary in Suriname.

Egypt.—Billiton International Metals BV and Marc Rich & Co. AG (RICHCO) secured contracts to supply 350,000 tons per year of alumina to Egyptalum, the state-owned Egyptian aluminum smelter at Nag Hammâdi. The supply agreements were reportedly such that Billiton would deliver 200,000 tons per year for the next 5 years, and RICHCO 150,000 tons per year. The first shipments were expected to commence in 1991.

Ghana.—It was announced that the Ghana Bauxite Co. (55% Government and 45% British Alcan Aluminium Co. Ltd.) had commenced a 5-year mine rehabilitation program that was expected to cost $7 million and return bauxite output to within the range of production levels experienced in the 1970's. This modernization program at the Ichiniso Mine in the Awaso area of western Ghana would

include major improvements in the mining operation's infrastructure and processing facilities.

Greece.—It was reported, despite various accounts of problems in arranging project financing, that the Hellenic Alumina Industry S.A. (ELVA) alumina plant under construction at Thisvi, in Boeotia, was expected to be completed in late 1993 and start continuous alumina production at the 600,000-ton-per-year level within the second quarter of 1994.

Aluminium de Grèce S.A. reportedly lost approximately 8,000 tons of scheduled alumina production because of labor strikes in 1990. Supervisory staff handled plant operations during five 24-hour general strikes called by Greece's trade union federation.

Guinea.—It was announced that Halco (Mining), Inc., a consortium of western aluminum companies that are partners with the Government of Guinea in the joint venture Compagnie des Bauxites de Guinée (CBG), had agreed on a formula by which CBG would expand its mining operations to the Bidikoum bauxite deposit, adjacent to the current Sangaredi mine. The Bidikoum ore body has a lower alumina content than that of the Sangaredi deposit, but placing it into production before the Sangaredi ore reserves are depleted would allow blending of the two ore types and thereby provide an extension of the overall mine life for the CBG mining operation.

Guyana.—Bauxite shipments commenced in late 1990 from the new mining operations developed in the Berbice region of Guyana by the Aroaima Mining Co., a 50-50 joint venture of Reynolds Metals and the Government of Guyana. The consortium, which was working a deposit with known reserves of 25 million tons, reportedly expected to ship 1.5 million tons of bauxite in its first year of operation and to phase production up to 2 million tons per year by 1994.

India.—It was announced that India's State-owned National Aluminium Co. Ltd. (NALCO) planned to commence a 4-year program to increase alumina production to 1.35 million tons and bauxite

TABLE 36

U.S. IMPORTS FOR CONSUMPTION OF BAUXITE, CRUDE AND DRIED,[1] BY COUNTRY

(Thousand metric tons)

Country	1988	1989	1990
Australia	1,612	1,535	1,430
Brazil	792	1,373	1,812
China	20	69	47
Dominican Republic[2]	33	—	—
Guinea	4,526	r3,504	3,669
Guyana	225	379	546
Indonesia	39	306	413
Jamaica[2]	2,654	3,330	3,886
Malaysia	12	r172	129
Sierra Leone	29	167	159
Suriname	3	—	—
Other	—	58	51
Total[3]	9,944	r10,893	12,142

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: 1988—10,498,913 tons; 1989—11,346,182 tons; and 1990—12,628,163 tons.

Source: Bureau of the Census and Jamaica Bauxite Institute.

TABLE 37

U.S. IMPORTS FOR CONSUMPTION OF CALCINED BAUXITE, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1989				1990			
	Refractory grade		Other grade		Refractory grade		Other grade	
	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]
Australia	—	—	8	$570	—	—	15	$1,100
China	176	$10,044	147	8,218	126	$8,097	173	10,089
Guinea	—	—	—	—	—	—	78	3,066
Guyana	74	10,871	96	3,449	84	9,273	52	2,372
Malaysia	—	—	—	—	—	—	2	479
Other	5	292	26	1,233	(2)	9	28	1,079
Total[3]	254	21,207	r277	r13,470	210	17,379	348	18,185

rRevised.
[1]Value at foreign port of shipment as reported to U.S. Customs Service.
[2]Less than 1/2 unit.
[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 38

U.S. IMPORTS FOR CONSUMPTION OF ALUMINA,[1] BY COUNTRY

(Thousand metric tons, calcined equivalent, and thousand dollars)

Country	1988		1989		1990	
	Quantity	Value[2]	Quantity	Value[2]	Quantity	Value[2]
Australia	3,532	$562,479	3,603	$915,113	3,413	$949,280
Brazil	65	15,574	44	21,465	87	26,515
Canada	91	39,241	154	69,711	123	56,021
France	6	14,740	5	13,369	5	13,428
Germany, Federal Republic of	20	27,328	20	30,576	23	37,550
India	79	1,761	36	8,916	(3)	15
Italy	(3)	783	(3)	386	(3)	531
Jamaica	201	47,890	217	92,144	173	100,762
Japan	7	8,503	8	13,109	8	13,424
Suriname	417	77,124	209	52,124	173	45,424
Venezuela	207	34,286	1	136	1	382
Other	8	22,142	, 15	11,075	64	25,640
Total[4]	4,634	851,851	4,311	1,228,123	4,070	1,268,973

[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.

production to 3.6 million tons within the context of an overall aluminum industry expansion program.

It was reported that the Bharat Aluminium Co. (BALCO), also State-owned, had been granted a 30-year lease for bauxite mining within the Khurkhuridadar area in the Mandla District of Madhya Pradesh. In a related effort, to secure bauxite resources for its Korba refinery, BALCO had also reportedly sought the right to open an additional bauxite mine within the Hazaridadar area of the Mandla region. Because the company's bauxite mines at Phutkapahar and Amarkantak in Madhya Pradesh are approaching depletion and because the Government of India has shelved the Gandhamardhan bauxite mining project in western Orissa on environmental grounds, BALCO has been compelled to rely on outside sources for its bauxite requirements. In this regard, under agreements currently in effect, NALCO would provide 250,000 tons of bauxite from its 2.4-million-ton-per-year Panchapatmali Mine in Orissa as feedstock to BALCO through the period 1991-92, with the possibility of increasing the amount supplied to 450,000 tons after 1992.

It was announced that NALCO had passed a major commercial milestone during 1990, as its total cumulative alumina exports passed the 1-million-ton level. In August 1990, with shipments to Egypt and Indonesia, the company's aggregate export total reached 1.03 million tons.

Ireland.—The 3-year and $50 million expansion plan that began in 1989 at the Aughinish Alumina Ltd. refinery, near Limerick, was expected to increase alumina production at the plant from its previously rated 800,000-ton-per-year capacity to 1 million tons per year by 1991.

With respect to setting records, a significant milestone was attained by the Aughinish refinery in August when it produced the five millionth ton of alumina generated since the plant startup in September 1983.

Italy.—It was reported that the Euralumina SpA refinery at Portoscuso, Sardinia, achieved a record alumina production with an output of more than 750,000 tons. This increased level of alumina output was accomplished through a capacity expansion and upgrading program that was scheduled for final completion in 1992.

Jamaica.—According to provisional statistics released by the Jamaica Bauxite Institute, Jamaica recorded its highest alumina shipments on record in 1990. Jamaican exports reached a total of 2.9 million tons of alumina during 1990, surpassing the previous high of 2.8 million tons set in 1974. The 1990 alumina shipments amounted to a 34.6% increase over the 2.1 million tons shipped from Jamaica in 1989 and were valued at approximately $611.2 million. A major portion of this improvement in alumina export levels may be attributed to the 1989 reopening of the Alumina Partners of Jamaica (Alpart) alumina plant, which had been closed since the mid-1980's.

A Memorandum of Understanding, embodying the commercial relationships on bauxite and alumina, was developed between Jamaica and the U.S.S.R. during contract discussions held in October 1990. The accord covered the requirements for settlement of outstanding payments on bauxite shipments to the U.S.S.R. and arrangements to deal with shortfalls in bauxite shipments under the existing contract, through which Jamaica had supplied the Soviets with 1 million tons of bauxite per year, or about 250,000 tons per quarter, for the past 7 years. During these contract negotiations, Jamaican officials explored the feasibility of possible Soviet involvement in rehabilitating and

reopening the bauxite mine at Lydford, St. Ann Parish, on the northern coast of Jamaica, that had been operated by Reynolds Metals and closed in 1984.

In 1990, Alpart, owned by Kaiser Aluminum (65%) and Hydro Aluminium (35%), indicated that it had a program underway to expand the annual rated capacity of its alumina plant at Nain, St. Elizabeth Parish, from 1.00 to 1.45 million tons per year. For 1990, it was reported that the refinery operated above its nominal capacity and produced approximately 1.2 million tons of alumina.

In late 1990, Alcan Aluminium provided the Jamaican Government with the results of a prefeasiblity study for a 1-million-ton-per-year greenfield alumina plant. It was reported that a full feasibility study was contingent upon participation by other industrial investors and clarification of the Government's environmental policy.

Suriname.—Suriname Aluminium Co. (Suralco) announced that it intended to import 200,000 tons of bauxite from the Dominican Republic in mid-1990 to rebuild stocks at its Paranam refinery. The ore would replace bauxite stocks used during a 2-month mine shutdown caused by clashes between rebel insurgents and Government forces at Suralco's Moengo operations, in eastern Suriname.

In 1990, Billiton Maatschappij Suriname (BMS) announced that it had invested $30 million in new mining equipment for its Suriname mining operations. This investment included a new bucket wheel excavator and auxiliary equipment that reportedly would be used to remove overburden at the new Accaribo bauxite mine near Paranam, a joint-venture operation between BMS (76%) and Suralco (24%). It was estimated that this new mine would come on-stream in early 1992 and would produce 1 million tons of bauxite per year when fully operational.

In further mining developments, Suralco reported that mine preparation was continuing at Coermotibo, a new site 10 to 15 kilometers east of Moengo. Suralco planned to commence bauxite production at the location in 1991, with this new mining area gradually taking over from its current Moengo operations, where ore reserves reportedly were nearing depletion.

Venezuela.—It was announced that Venezuela and Yugoslavia had signed a letter of intent to construct and operate a 1-million-ton-per-year alumina plant in conjunction with an associated primary aluminum smelter within Bolívar State.

C.V.G.-Interamericana de Alúmina, C.A. (INTERALUMINA) was reportedly in the process of expanding the capacity of its alumina plant at Puerto Ordaz, Bolívar State. Present plans were to increase production capacity at the facility from the current 1.3 million tons per year to 2.0 million tons per year by the end of 1991.

Current Research

In 1990, the U.S. Bureau of Mines reported on research designed to remove or lower the organic matter levels in bauxite, plus the associated leach liquor of the Bayer process, without impairing the leachability of these aluminum-bearing materials. During Bayer processing, humates and lignins within bauxite undergo degradation to oxalate that builds up to equilibrium concentrations and remains in the recycled Bayer liquor of an alumina plant, causing undesired alumina precipitation as fine particles, reduced mud settling rate, foaming, loss of caustic, and a discolored alumina trihydrate product. To help overcome these problems, the Bureau investigated a method of reducing the amount of organic matter in these feedstock and processing materials by pretreatment of bauxite with oxygen or air at temperatures up to 440° C.[7] The results of this work indicated that processing at temperatures above 160° C progressively diminished the bauxite's content of organic carbon. It was further determined that the bauxite's leachability was not impaired by high-temperature treatments, except at temperatures higher than 300° C.

In related research, involved with seeking improvements to the Bayer process, the Bureau demonstrated that treatment of bauxite with hydrogen under pressure at temperatures from 250° to 450° C partially reduced the ferric iron in Jamaican bauxite to magnetite, Fe_3O_4, as well as partially volatilized the contained organic carbon.[8] This largely fulfilled the investigation's twin objectives of eliminating the organic carbon contaminants from the bauxite and making the leached residue, known as red or brown mud, susceptible to liquid-solid separation by magnetic filtration methods. It was established, however, that tradeoffs were required in choosing the ultimate operating conditions because optimum carbon destruction and development of magnetic properties occurred at pretreatment temperatures of more than 340° C, while optimum aluminum extraction required leaching bauxite that had been pretreated at temperatures below 300° C.

Research conducted jointly by Alcan Aluminium, Carleton University, and Energy, Mines and Resources Canada successfully developed a laboratory procedure for the decomposition of sodium oxalate by microbial metabolism.[9] Sodium oxalate, a byproduct of the Bayer process, is a hazardous toxic substance that, when removed from a Bayer circuit, must be disposed of in an environmentally safe manner. This experimental work determined that the disposal of Bayer sodium oxalate by a microbial method was a feasible economic option that resulted in complete degradation of oxalate into environmentally acceptable CO_2 gas and an innocuous biomass.

Alcoa of Australia Ltd. announced that it had developed a family of tracer substances that may be used to assist in detailed efficiency studies of Bayer-process operations.[10] The flow behavior of solutions within continuous processes, such as the Bayer process, exert an enormous impact upon the efficiency of alumina plant operations. In the Bayer process, the use of tracers to study liquor flow patterns and residence-time distributions has been severely constrained due to the inherently aggressive chemical environment and the very high concentration of interfering substances. The Alcoa of Australia research work established that a number of halogenated organic acids could be successfully utilized as liquor tracers within alumina plant environments. These halogenated carboxylic acids are very similar to some naturally occurring Bayer-liquor organics and, therefore, they were found to be very stable within the harsh Bayer-process regime.

During 1990, the U.S. Geological Survey (USGS) published a compilation of reference information on the geology and worldwide distribution of nonbauxite aluminum resources (excluding alunite), plus the associated methods of extracting alumina from these alternative resources.[11] This was the third, and last, of a series of recent research reports prepared by the USGS on the resources of aluminum.

TABLE 39

BAUXITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
Albania	NA	NA	38	35	[2]26
Australia	32,384	34,102	36,192	38,583	[2]40,697
Brazil	6,544	6,567	8,083	8,665	8,750
China[e]	1,650	2,400	3,500	4,000	4,000
Dominican Republic[3]	—	[r]187	168	151	150
France	1,379	1,271	978	720	560
Germany, Federal Republic of:					
Western states	([4])	—	—	—	—
Ghana	[r]204	[r]196	285	347	[2]381
Greece	2,230	2,472	2,533	2,576	2,700
Guinea[e 5]	13,300	13,500	[r]15,619	[2]16,523	16,500
Guyana[3]	2,074	2,785	1,774	1,321	1,600
Hungary	3,022	3,101	2,593	2,644	2,600
India	[r]2,662	[r]2,779	3,961	4,768	5,000
Indonesia	650	635	513	862	[2]1,206
Italy	—	17	17	12	12
Jamaica[3 6]	[r]6,930	[r]7,802	7,305	9,601	[2]10,921
Malaysia	566	482	361	355	[2]398
Mozambique	4	5	7	6	[2]7
Pakistan	3	3	2	2	2
Romania[e]	600	600	600	[2]313	300
Sierra Leone	1,246	1,390	1,379	1,562	1,600
Spain	3	1	3	[e]3	3
Suriname	[r]3,847	2,522	3,434	3,530	[2]3,267
Turkey	280	[r]259	269	562	515
U.S.S.R.[e 7]	4,600	4,600	4,600	4,600	4,200
United States[3]	510	576	588	W	W
Venezuela	—	[r]245	522	702	[2]771
Yugoslavia	3,459	3,394	3,034	3,252	[2]2,952
Zimbabwe	24	—	—	—	—
Total	[r]88,173	[r]91,891	98,357	105,695	109,118

[e]Estimated. [p]Preliminary. [r]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]Table includes data available through June 14, 1991.

[2]Reported figure.

[3]Dry bauxite equivalent of crude ore.

[4]Less than 1/2 unit.

[5]Dry bauxite equivalent of ore processed by drying plant.

[6]Bauxite processed for conversion to alumina in Jamaica plus kiln-dried ore prepared for export.

[7]In addition to the bauxite reported in the body of the table, the U.S.S.R. produces nepheline syenite concentrates and alunite ore as sources of aluminum. Nepheline syenite concentrate production was as follows, in thousand metric tons: 1986—1,638; 1987—1,660; 1988—1,639 (revised); 1989—1,697; and 1990—1,650 (estimated). Estimated alunite ore production was as as follows, in thousand metric tons: 1986—620; 1987—625; 1988—625; 1989—600; and 1990—550. 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.

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 appear to become economically more attractive. Alternatively, high fuel prices tend to make nonbauxitic materials less competitive because the processes for treating substitute materials require considerably more energy than Bayer-processed bauxite.

TABLE 40

WORLD ANNUAL ALUMINA CAPACITY, BY COUNTRY

(Thousand metric tons, yearend)

Country	1987[r]	1988	1989	1990
Australia	10,000	10,000	10,850	11,700
Brazil	1,150	1,150	1,555	1,555
Canada	1,225	1,225	1,140	1,140
China	1,300	[r]1,500	1,500	1,700
Czechoslovakia	100	[r]210	[r]210	210
France	1,040	1,040	700	700
Germany, Federal Republic of:				
Eastern states	60	60	60	—
Western states	1,745	1,745	1,380	1,170
Greece	500	500	600	600
Guinea	700	700	700	700
Guyana	355	355	300	—
Hungary	920	920	920	920
India	1,000	1,000	1,580	1,580
Ireland	800	800	900	1,000
Italy	720	720	720	820
Jamaica	3,100	3,100	2,950	2,950
Japan	550	550	500	500
Romania	540	540	540	540
Spain	800	800	1,000	1,000
Suriname	1,350	1,350	1,400	1,500
Turkey	200	200	200	200
U.S.S.R.	4,600	4,600	4,600	4,600
United Kingdom	120	120	120	120
United States	4,570	5,115	5,115	5,615
Venezuela	1,300	1,300	1,300	1,300
Yugoslavia	1,635	1,635	1,570	1,570
Total	40,380	[r]41,235	[r]42,410	43,690

[r]Revised.

TABLE 41

ALUMINA: WORLD PRODUCTION,[1] BY COUNTRY[2]

(Thousand metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
Australia	9,423	10,109	10,511	10,800	[3]11,231
Brazil	1,258	1,326	1,488	1,632	1,600
Canada	1,015	953	993	1,048	1,087
China[e]	825	1,200	1,500	[r]1,500	1,500
Czechoslovakia	139	134	138	[r e]170	200
France	740	711	563	480	664
Germany, Federal Republic of:					
Eastern states	46	51	64	[e]60	50
Western states	1,560	1,313	1,163	1,174	1,175
Greece	[r]307	518	515	521	[3]566
Guinea	556	543	589	619	[3]631
Hungary	856	858	803	882	[3]826
India	586	650	1,188	1,419	1,455

See footnotes at end of table.

TABLE 41—Continued

ALUMINA: WORLD PRODUCTION,[1] BY COUNTRY[2]

(Thousand metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
Ireland	686	784	843	891	885
Italy[4]	618	700	708	722	752
Jamaica	1,586	1,572	1,522	2,221	[3]2,869
Japan[5]	607	358	415	466	[3]459
Romania	555	584	620	611	400
Spain[4]	748	801	881	949	900
Suriname[4]	1,471	1,363	1,632	1,567	[3]1,532
Turkey	144	95	182	201	185
U.S.S.R.[e]	3,500	3,500	3,500	3,500	3,300
United Kingdom	110	110	114	116	115
United States[e]	3,105	4,150	[r]4,770	[r]5,000	5,230
Venezuela	1,269	[r]1,360	1,284	1,212	[3]1,293
Yugoslavia	1,117	1,113	1,051	1,168	1,200
Total[6]	[r]32,827	[r]34,856	37,034	38,929	40,105

[e]Estimated. [p]Preliminary. [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 14, 1991.

[3]Reported figure.

[4]Hydrate.

[5]Data presented are for metallurgical-grade alumina. Gross weight of aluminum hydrate for all uses was as follows, in thousand metric tons: 1986—956; 1988—778; 1989—863; and 1990—890.

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

It, therefore, seems evident that nonbauxitic sources of aluminum would become viable only within the context of a prolonged national emergency or international embargo extending over a period of several years. Imports of primary aluminum metal from countries with low electrical energy costs and secondary production from recycled aluminum appear likely to be used in ever-increasing proportions to meet the domestic demand for aluminum.

In addition, the political revolution that swept Eastern Europe in the last months of 1989 was followed by the current economic revolution that has changed, for the coming years, the style and structure of the aluminum industry within that part of Europe. The basic industries of these countries had been established primarily on the principle of national self-sufficiency and not on the basis of return on capital. The emphasis had been on production, rather than on costs or profit. Within the framework of a global economy, the Eastern European bauxite mines appear to be marginal operations, with the only economically sound mines in Yugoslavia. In the future, this economic restructuring would seem to provide substantially increased market opportunities for the firmly established bauxite-producing countries of the world.

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ANTIMONY

By Thomas O. Llewellyn

Mr. Llewellyn, a physical scientist with the Branch of Industrial Minerals, has been the commodity specialist for antimony since 1987. Domestic survey data were prepared by Elsie Isaac, mineral data assistant, Section of Nonferrous Metals Data; and international data were prepared by Virginia Woodson, international data coordinator, Section of International Data.

Reported consumption of primary antimony declined about 5% in 1990 from that of 1989. Production of primary antimony, however, increased slightly compared with that of the previous year. Secondary smelter production totaled 20,380 tons, up from 19,501 tons produced in 1989. Total imports of antimony products increased considerably. The principal supplying country continued to be China, which accounted for about 61% of all antimony imported into the United States in 1990. Effective June 20, 1990, the National Defense Stockpile (NDS) goal for antimony was increased from 32,659 metric tons to 80,287 metric tons.

TABLE 1

SALIENT ANTIMONY STATISTICS

(Metric tons of antimony content unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Production:					
Primary:					
Mine (recoverable antimony)	W	—	W	W	W
Smelter	r15,691	r17,930	17,616	18,954	19,717
Secondary	14,081	15,833	16,172	r19,501	20,380
Exports of metal, alloys, waste and scrap	540	795	624	293	588
Exports of antimony oxide	526	705	1,227	1,850	7,139
Imports for consumption	23,043	24,248	30,027	25,165	29,403
Reported industrial consumption, primary antimony	9,935	r10,373	12,067	13,424	12,739
Stocks: Primary antimony, all classes, Dec. 31	r5,487	r6,093	6,498	r6,270	8,185
Price: Average, cents per pound[1]	121.9	110.6	103.9	94.3	81.8
World: Mine production	r59,677	r69,955	r70,547	r66,283	e62,004

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.

DOMESTIC DATA COVERAGE

Domestic production data for antimony are developed by the U.S. Bureau of Mines from two voluntary surveys of U.S. operations. Typical of these surveys is the "Primary Antimony" survey. Of the six operations to which a survey request was sent, all responded, representing 100% of the primary smelter production shown in table 1 and 100% of the total antimony content of primary antimony production by class shown in table 2.

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 tallic antimony indicates that 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 with 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.

Products for Trade and Industry

The commercial products are generally semicircular-shaped ingots, broken pieces, granules, and cast cake. Other forms are powder, ingot, shot, and single crystals.

Industry Structure

Antimony was produced from ores and as a byproduct of the smelting of base metals ores in about 23 countries. China, the world's leading producer, accounted for about 48% of the total world estimated mine production during 1990. China, together with the other four major producing countries, Bolivia, Mexico, the Republic of South Africa, and the U.S.S.R., accounted for about 89% of the total world antimony production. In 1990, antimony production from domestic source materials was largely derived from recycling of lead-antimony batteries. Recycling plus U.S. 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 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 of them purchase raw materials from mine and smelter operations either directly or through dealers.

Resources

Estimates of the abundance of antimony in the Earth's crust range from 0.2 to 0.5 parts per million. Antimony is chalcophile, occurring with sulfur and the heavy metals copper, lead, and silver. More than 100 minerals of antimony are found in nature. Stibnite (Sb_2S_3) is the predominant ore mineral of antimony.

Simple antimony deposits consist principally of stibnite, or rarely, native antimony in a siliceous gangue, commonly with some pyrite, and in places a little gold and small amounts of other metal sulfides, principally silver and mercury. Antimony ores commonly are associated with igneous activity and have common genetic association with such intrusives as granite, diorites, and monzonites. The mineralogy of the veins and their almost invariably shallow depth suggest a low temperature of formation at near-surface positions, possibly related to the configuration of the water table at the time of deposition. Most of these geologically simple stibnite deposits do not individually contain more than several thousand tons of ore. Deposits of this type are found in the world's most productive antimony districts, including those of Bolivia, China, Mexico, and the Republic of South Africa.

Complex antimony deposits consist of stibnite associated with pyrite, arsenopyrite, cinnabar, or scheelite, or of antimony sulfosalts with varying amounts of copper, lead, and silver, as well as common sulfides of these metals and zinc. Ores of the complex deposits generally are mined primarily for gold, lead, silver, tungsten, or zinc.

Most of the antimony produced in the United States is from complex deposits. The tetrahedrite ores found in the Coeur d'Alene district of Idaho are outstanding examples of complex deposits.[1]

Principal identified world antimony resources, at about 5 million tons, are in Bolivia, China, Mexico, the Republic of South Africa, and the U.S.S.R. U.S. resources are mainly in Alaska, Idaho, Montana, and Nevada.

Technology

Antimony deposits are seldom explored in advance of actual mining because the deposits are generally small, irregular, and difficult to appraise.

Many of the typically small mines contain irregular and scattered ore bodies that cannot be readily exploited by large-scale mining methods. Mining methods used in mines that recover metalliferous ores, of which antimony is a minor constituent, are designed for producing the principal metals such as lead, silver, or gold.

The antimony content of ores determines the method of recovery. In general, the lowest grades of sulfide ores, 5% to 25% antimony, are roasted; 25% to 40% antimony ores are smelted in a blast furnace; and 45% to 60% antimony ores are liquated. At some mines in Bolivia and the Republic of South Africa, the high-grade sulfide ore is concentrated by hand-cobbing and sold as lump sulfide ore, 60% antimony content. As higher grade deposits have become depleted, increasing emphasis has been placed on upgrading low-grade ores by flotation.

Roasting of the ore to yield a volatile trioxide or the stable nonvolatile tetroxide is the only pyrometallurgical procedure suitable for low-grade ores (5% to 25% antimony content). The sulfur is oxidized and removed from waste gases, and the volatilized antimony oxide is recovered in flues, condensing pipes, a baghouse, precipitators, or a combination of the above. The temperature and quantity of available oxygen determine the kind and quantity of the oxide produced. The oxide produced by this method is generally impure and can be reduced to metal. Careful control of volatilization conditions, however, produces 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 briquet 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 1990, 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 end on December 31, 1991.

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 both 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, for non-MFN, a statutory duty of 4.4 cents per kilogram was imposed.

Operating Factors

Environmental and ecological problems associated with the treatment of antimony metal and ores are minimal because emissions and affluents are controlled at the processing plant.

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 200 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

The Environmental Protection Agency (EPA) denied a petition submitted by Synthetics Products Co. (SPC) requesting removal of antimony tris (iso-octyl mercaptoacetate), ATOM, from the list of toxic chemicals under section 313 of the Emergency Planning and Community Right-to-Know Act of 1986. The petition was based on SPC's contention that ATOM does not meet the criteria for human health effects under the section 313 listing. EPA's decision to deny the petition was based on human health concerns for antimony and antimony compounds. ATOM degrades in the environment yielding antimony and antimony oxide.[4]

According to section 3301 of the National Defense Authorization Act for Fiscal Years 1990 and 1991 (Public Law 101-189, November 29, 1989), the Assistant Secretary of Defense determined that, effective June 20, 1990, the NDS goal for antimony was increased from 32,659 metric tons to 80,287 metric tons, where it remained at yearend.[5]

Strategic Considerations

Antimony was included in the NDS because of its strategic uses in flame-retardant compounds, friction bearings, and batteries. No inventory acquisitions or sales were made during the year. As of December 31, 1990, the stockpile inventory was 32,658 metric tons of antimony metal.

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.**—In March 1990, Laurel Industries and Empresa Metalurgica de Vinto (ENAF), the state-owned smelting and refining company of Bolivia, entered into an agreement to produce crude antimony oxide at the Vinto smelter. Under the terms of the agreement, Laurel will provide technical assistance to the antimony smelter to produce sulfur-free crude antimony trioxide. In return, the entire ENAF crude antimony trioxide production will be shipped to Laurel's refining plant in La Porte, TX. The first shipment of sulfur-free crude antimony trioxide from Bolivia was received at Laurel's refining plant in December.

The producers of primary antimony metal and oxide products were ASARCO Incorporated, Omaha, NE; Amspec Chemical Corp., Gloucester City, NJ; Anzon America, 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.

TABLE 2

PRIMARY ANTIMONY PRODUCED OR GENERATED IN THE UNITED STATES

(Metric tons of antimony content)

Year	Class of material produced or generated			
	Metal	Oxide	Residues	Total
1986	343	r15,280	68	r15,691
1987	W	r17,892	38	r17,930
1988	W	17,150	466	17,616
1989	W	18,720	234	18,954
1990	W	19,085	632	19,717

rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

TABLE 3

SECONDARY ANTIMONY PRODUCED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons of antimony content unless otherwise specified)

	1989r	1990
KIND OF SCRAP		
New scrap: Lead- and tin-base	1,254	1,178
Old scrap: Lead- and tin-base	18,247	19,202
Total	19,501	20,380
FORM OF RECOVERY		
In antimonial lead	18,914	19,786
In other lead- and tin-base alloys	587	594
Total	19,501	20,380
Value (millions)	$41	$42

rRevised.

TABLE 4

REPORTED INDUSTRIAL CONSUMPTION OF PRIMARY ANTIMONY IN THE UNITED STATES

(Metric tons of antimony content)

Year	Class of material consumed				
	Metal	Oxide	Sulfide	Residues	Total
1986	2,211	7,629	27	68	9,935
1987	2,248	r8,048	39	38	r10,373
1988	2,121	9,438	42	466	12,067
1989	2,523	10,640	27	234	13,424
1990	2,130	9,952	25	632	12,739

rRevised.

Consumption and Uses

Decreased reported domestic consumption of primary antimony, compared with that of 1989, reflected the continued national economic slowdown. Lead-antimony alloys were used in starting-lighting-ignition (SLI) batteries, ammunition, corrosion resistant pumps and pipes, tank linings, roofing sheets, solder, cable sheaths, and antifriction bearings. In 1990, the Battery Council International reported a 1.2% increase in the total shipments of replacement automotive SLI batteries in the United States compared with those of 1989. Antimony compounds were used in plastics, both as stabilizers and as flame retardant. Antimony trioxide in an organic solvent was used to make textiles, plastics, and other combustibles flame retardant. Antimony was used as a decolorizing and refining agent in some forms of glass, such as special optical glass. The estimated distribution of antimony uses were flame retardants, 70%; transportation, including batteries, 10%; chemicals, 10%; ceramics and glass, 4%; and other, 6%.

Markets and Prices

The New York dealer price range for antimony metal, published by Metals Week, started 1990 at $0.81 to $0.84 per pound. The price range showed minor fluctuations throughout the first 10 months, decreased to a range of $0.78 to $0.80 per pound by November 29, where it held steady until the end of December.

The price range for high-tint antimony trioxide was $1.45 per pound at the beginning of the year, decreased to a range of $1.10 to $1.20 per pound by March 1, and remained constant for the rest of 1990.

The European price range quotation for clean antimony sulfide concentrate (60% antimony content), published by Metal Bulletin (London), which was $15.50 to $18.00 per metric ton unit at the beginning of 1990, decreased to a range of $15.00 to $17.00 per metric ton unit at the end of the first quarter and remained constant for the rest of the year. The European price range quotation for lump antimony sulfide ore (60% antimony content), which was listed at $16.50 to $18.00 per metric ton unit at the beginning of 1990, also decreased during the first quarter and closed the year at a range of $15.50 to $17.50 per metric ton unit.

TABLE 5

REPORTED INDUSTRIAL CONSUMPTION OF PRIMARY ANTIMONY IN THE UNITED STATES, BY PRODUCT

(Metric tons of antimony content)

Product	1986	1987	1988	1989	1990
Metal products:					
Ammunition	W	W	W	521	602
Antimonial lead	r549	1,102	1,538	r1,871	1,995
Bearing metal and bearings	139	187	178	129	90
Cable covering	62	W	W	W	W
Castings	11	8	13	8	8
Collapsible tubes and foil	W	W	—	—	—
Sheet and pipe	36	76	181	157	123
Solder	r253	347	256	245	208
Type metal	8	8	6	4	3
Other	379	584	609	80	104
Total	r1,437	r2,312	2,781	r3,015	3,133
Nonmetal products:					
Ammunition primers	21	32	34	20	23
Ceramics and glass	932	1,122	1,221	1,050	991
Fireworks	4	r2	4	5	3
Pigments	r226	279	179	196	246
Plastics	885	750	916	1,141	1,148
Rubber products	37	W	29	97	27
Other	147	r199	147	159	151
Total	2,252	r2,384	2,530	2,668	2,589
Flame-retardants:					
Adhesives	154	315	251	219	189
Paper	1	W	W	W	W
Pigments	13	30	104	926	502
Plastics	4,517	4,139	5,469	5,842	5,668
Rubber	398	r387	282	174	181
Textiles	1,163	800	643	558	460
Other	—	r6	7	r22	17
Total	6,246	r5,677	6,756	r7,741	7,017
Grand total	9,935	r10,373	12,067	13,424	12,739

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

TABLE 6

INDUSTRY STOCKS OF PRIMARY ANTIMONY IN THE UNITED STATES, DECEMBER 31

(Metric tons of antimony content)

Stocks	1986	1987	1988	1989	1990
Metal	868	822	2,360	1,873	2,936
Ore and concentrate	934	1,148	W	W	W
Oxide	r3,572	r4,018	3,840	r4,079	4,388
Residues	96	83	274	302	844
Sulfide	17	r22	24	16	17
Total	r5,487	r6,093	6,498	r6,270	8,185

rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

TABLE 7

ANTIMONY PRICE RANGES IN 1990, BY TYPE

Type	Price per pound
Domestic metal[1]	$1.25-$1.40
Foreign metal[2]	.78- .88
Antimony trioxide[3]	1.10- 1.20

[1]Based on antimony in alloy.
[2]Duty-paid delivery, New York.
[3]Producer price, published by ASARCO Incorporated, for high-tint antimony trioxide.

Foreign Trade

Exports of antimony oxide increased dramatically in 1990 and reached their highest level in 23 years.

Total imports of antimony products increased significantly compared with those of 1989. China, Mexico, and the Republic of South Africa, in descending order of shipments, accounted for approximately 82% of the total U.S. antimony imports in 1990.

World Review

Capacity.—The data in table 12 represent rated annual production capacity for mines and refineries on December 31, 1990. Rated capacity was defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable, long-term operating rate, based on the physical equipment of the plant and routine operating procedures for labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Mines and refineries rated capacity of antimony was estimated based on discussions with some officials from private industry, past and present production rate, and published capacity data.

Bolivia.—In May 1990, Bolivian officials withdrew their participation in the joint Bolivian-Chinese quarterly producer price for antimony concentrates, published by Metal Bulletin of London. Reportedly, the published producer price failed to achieve its objective of coordinating the policies on antimony production and trade between the two countries.

TABLE 8

U.S. EXPORTS OF ANTIMONY METAL, ALLOYS, WASTE AND SCRAP, BY COUNTRY

Country	1989		1990	
	Gross weight (metric tons)	Value (thousands)	Gross weight (metric tons)	Value (thousands)
Belgium	38	$45	299	$345
Canada	7	53	66	188
Colombia	33	101	17	38
Germany, Federal Republic of	1	15	(1)	3
Jamaica	19	23	(1)	4
Japan	44	102	—	—
Mexico	10	29	23	74
Netherlands	1	5	—	—
United Kingdom	56	91	133	269
Venezuela	77	197	40	121
Other	6	32	9	102
Total[2]	293	694	588	1,143

[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 ANTIMONY OXIDE, BY COUNTRY

Country	1989			1990		
	Gross weight (metric tons)	Antimony content[1] (metric tons)	Value (thousands)	Gross weight (metric tons)	Antimony content[1] (metric tons)	Value (thousands)
Australia	2	2	$8	—	—	—
Belgium	14	12	70	5	4	$21
Brazil	9	7	44	15	12	71
Canada	505	419	1,564	768	637	2,324
Chile	—	—	—	17	14	55
Colombia	41	34	94	35	29	111
Dominican Republic	111	92	90	18	15	18
France	109	90	161	21	17	60
Germany, Federal Republic of	68	56	276	58	48	257
Hong Kong	3	2	9	—	—	—
India	10	8	23	7	6	34
Israel	58	48	154	36	30	98
Italy	294	244	1,042	1,063	882	1,676
Japan	51	42	220	220	183	598
Korea, Republic of	11	9	27	21	17	65
Mexico	637	529	1,218	5,791	4,807	6,954
Netherlands	29	24	140	179	149	843
Singapore	28	23	246	186	154	303
Spain	52	43	147	51	42	131
Switzerland	18	15	56	—	—	—
Taiwan	40	33	127	34	28	136
United Kingdom	39	32	150	17	14	65
Venezuela	22	18	51	15	12	50
Other	76	63	185	48	39	95
Total[2]	2,229	1,850	6,106	8,605	7,139	13,962

[1]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 10

U.S. IMPORTS FOR CONSUMPTION OF ANTIMONY, BY CLASS AND COUNTRY

Country	1989			1990		
	Gross weight (metric tons)	Antimony content[1] (metric tons)	Value (thousands)	Gross weight (metric tons)	Antimony content[1] (metric tons)	Value (thousands)
Antimony ore and concentrate:						
Bolivia	1,259	737	$1,823	1,045	608	$869
Canada	—	—	—	47	42	41
Chile	60	47	102	66	48	98
China	1,689	1,198	3,022	2,759	1,844	2,610
Guatemala	1,108	665	286	480	269	141
Honduras	6	3	21	28	11	13
Hong Kong	448	290	674	192	121	233
Japan	38	38	67	(2)	(2)	2
Mexico	3,734	1,412	1,927	914	361	604
Peru	—	—	—	150	149	225
Thailand	269	161	540	—	—	—
Total[3]	8,613	4,550	8,462	5,680	3,454	4,835
Antimony oxide:						
Belgium	779	647	2,367	573	476	1,654
Bolivia	729	605	1,371	658	546	1,152
China	5,091	4,226	9,752	5,049	4,191	7,837
Colombia	20	17	16	—	—	—
Denmark	(2)	(2)	22	(2)	(2)	7
France	605	502	1,640	494	410	1,245
Germany, Federal Republic of	89	74	855	90	74	909
Honduras	59	49	22	—	—	—
Hong Kong	442	367	913	511	424	801
Italy	—	—	—	100	83	180
Japan	20	17	76	(2)	(2)	25
Korea, Republic of	—	—	—	4	44	183
Macao	—	—	—	40	33	71
Mexico	929	771	1,076	4,179	3,469	4,224
Netherlands	33	27	119	53	3	18
South Africa, Republic of	3,107	2,579	1,080	2,657	2,205	913
Taiwan	57	47	102	—	—	—
United Kingdom	80	66	358	62	51	354
Total[3]	12,041	9,994	19,770	14,472	12,009	19,574

[1]Antimony ore and concentrate content reported by Bureau of the Census. Antimony oxide content estimated by the U.S. Bureau of Mines.
[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 ANTIMONY METAL, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Belgium	1	$4	—	—
Bolivia	93	163	130	$191
Canada	2	133	1	198
Chile	114	187	74	110
China	9,742	18,756	11,862	19,584
Germany, Federal Republic of	20	208	1	171
Hong Kong	286	485	162	253
Japan	—	—	91	640
Korea, Republic of	—	—	1	6
Mexico	81	31	185	163
Netherlands	(1)	32	(1)	1
Taiwan	13	104	112	309
Thailand	219	396	1,054	1,580
United Kingdom	—	—	268	174
Other	51	644	—	—
Total[2]	10,621	21,143	13,940	23,380

[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

WORLD ANNUAL ANTIMONY PRODUCTION CAPACITY, DECEMBER 31, 1990

(Metric tons, antimony content)

	Mine	Smelter[1]
North and Central America:		
United States	3,000	31,000
Other	10,000	5,000
Total	13,000	36,000
South America	17,000	11,000
Europe[2]	16,000	28,000
Africa	15,000	5,000
Asia[3]	50,000	40,000
Oceania: Australia	2,000	—
World total	113,000	120,000

[1]Includes antimony oxide plants.
[2]Includes estimates for U.S.S.R. and other centrally planned economies.
[3]Includes estimates for China.

Japan.—Antimony trioxide production, mainly from imported materials, was 10,994 tons, an increase of about 6% compared with 1989 production. Antimony metal production also increased from 173 tons in 1989 to 216 tons in 1990.[6]

Current Research

The Roskill organization issued its 1990 antimony report. This comprehensive report discusses and analyzes world production of antimony by country and individual company. It also contains information on end-use markets, international trade patterns, and trends in prices.[7]

OUTLOOK

Mining, beneficiation, and metallurgical procedures for antimony have changed little in the past 30 years. No new technological developments that would affect productivity are foreseen for the near future.

The oversupply of antimony products from China that have saturated the market in the past 2 years will continue during 1991. Unless China's policy of offering discounts from the world market price for antimony products shows signs of changing, the prospects for Western antimony trioxide producers are not good.

[1]Miller, M. H. Antimony. Ch. in United States Mineral Resources. U.S. Geol. Surv. Prof. Paper 820, 1973, pp. 45–50.
[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. Environmental Protection Agency. Antimony Tris (Iso-Octyl Mercaptoacetate); Toxic Chemical Release Reporting; Community Right-to-Know. V. 55, No. 30, Feb. 13, 1990, pp. 5030–5032.
[5]———. Department of Defense. Office of the Secretary. Determination. V. 55, No. 123, June 26, 1990, p. 25993.
[6]Japan Metal Journal. V. 21, No. 11, Mar. 18, 1991, pp. 7–8.
[7]Roskill Information Services Ltd. The Economics of Antimony 1990. London, England, 7th ed., Oct. 1990, 279 pp. and Appendices A, B, and C.

TABLE 13

ANTIMONY: WORLD MINE PRODUCTION BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989	1990[e]
Australia[2]	1,131	1,231	r1,320	r1,360	1,300
Austria	514	322	228	r350	350
Bolivia	10,243	10,635	9,943	r8,533	8,300
Canada[3]	3,805	3,706	3,171	r2,818	4653
China[e]	15,000	27,000	30,000	30,000	30,000
Czechoslovakia[e]	1,000	1,000	4,2,921	r600	500
Guatemala	1,839	1,881	921	r1,343	1,200
Honduras	50	28	19	e30	25
Italy	r305	r86	r24	—	—
Malaysia (Sarawak)	—	129	—	—	—
Mexico[5]	3,337	2,839	2,185	r1,906	1,800
Morocco (content of concentrate)	617	444	r250	r142	140
Namibia (content of sodium antimonate)	—	r24	r73	r34	30
Pakistan	—	7	—	8	6
Peru (recoverable)	e670	590	420	r519	500
South Africa, Republic of (content of concentrate)	6,816	6,673	r6,240	r6,167	6,000
Spain[e]	4,45	20	20	20	—
Thailand	1,019	409	445	r495	500
Turkey	2,752	2,344	r1,877	re1,350	1,100
U.S.S.R.[e]	9,500	9,600	9,600	9,600	9,000
United States	W	—	W	W	W
Yugoslavia	859	834	725	r798	400
Zimbabwe (content of concentrate)	175	153	165	r210	200
Total	r59,677	r69,955	r70,547	r66,283	62,004

[e]Estimated. [p]Preliminary. [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 17, 1991.
[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]Antimony content of ores for export plus antimony content of antimonial lead and other smelter products produced.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Antimony. Ch. in Mineral Commodity Summaries, annual.
Antimony. Ch. in Mineral Facts and Problems, 1985 ed.

Other Sources

American Metal Market.
Chemical Abstracts.
Engineering and Mining Journal.
Metal Bulletin (London).
Metals Week.
Mining Journal (London).

ARSENIC

By J. Roger Loebenstein

Mr. Loebenstein, a physical scientist with 16 years industry and U.S. Bureau of Mines experience, has been the commodity specialist for arsenic since 1987. Domestic survey data were prepared by Evangeline Hemphill, mineral data assistant; and international data tables were prepared by Harold Willis, international data coordinator.

Small amounts of arsenic trioxide were shipped in 1990 from remaining stocks at ASARCO Incorporated's closed plant at Tacoma, WA.

The price of metallurgical-grade arsenic metal shot up from $0.60 per pound in December 1989 to $5.30 to $6.00 per pound by February 1990 because of a disruption in the supply from China that began at yearend 1989 and did not completely end until October 1990. By October, the price had declined to about $1.00 per pound.

ANNUAL REVIEW

Legislation and Government Programs

The Environmental Protection Agency (EPA) proposed to revoke tolerances for calcium arsenate and lead arsenate, which were used as insecticides on various agricultural commodities. EPA had canceled the registrations for the food uses of these arsenicals several years ago. EPA proposed to revoke the tolerances because no companies were manufacturing calcium and lead arsenate and because most of the stocks of these chemicals had been depleted.[1]

Issues

The problem of arsenic contamination of the environment is an unfortunate recurring theme near some nonferrous smelters. In the 1970's, Asarco sold slag from its copper smelter (now closed) in Tacoma, WA, to log yards and others. The log yards mixed the smelter slag with wood waste and used the material as pavement. Over time, rainwater weathered the pavement and leached arsenic, lead, zinc, and other toxins into Commencement Bay. The EPA is involved in the massive cleanup effort, but it appears that it will be many years before the litigation between Asarco and the log yards will be settled.[2]

Consumption

All arsenic consumed in the United States was derived from imported sources. Apparent demand declined in 1990, as shown in table 1. The industrial chemical sector, specifically the wood preservative industry, accounted for about 70% of domestic demand. The wood preservative industry converted imported arsenic trioxide to arsenic acid, an intermediate used in the production of the wood preservative chromated copper arsenate (CCA).

In the wood industry, Hickson Corp. operated wood preservative plants in Conley, GA, Hickory Grove, SC, Valparaiso, IN, and Kalama, WA. LaPorte PLC, United Kingdom, produced arsenical wood preservatives through its U.S. subsidiary, CSI. CSI operated wood preservative plants at Valdosta, GA, Harrisburg, NC, Gilmer, TX, and Laramie, WY. Another company, Osmose Corp., produced wood preservatives at plants in Memphis, TN, Tangent, OR, and Rock Hill, SC. Hickson, CSI, and Osmose accounted for most of the arsenical wood preserving industry.

The major agricultural chemical use for arsenic was as the herbicides monosodium methanearsonate (MSMA) and disodium methanearsonate (DSMA). Arsenic acid was used as a cotton leaf desiccant. The major producer of DSMA and MSMA was Fermenta ASC Corp., Mentor, OH. Atochem Corp., Bryan, TX, was a major producer of arsenic acid for use by cotton growers and wood preservative companies.

The glass industry used arsenic acid as a fining agent. The wood preservative industry supplied some of the arsenic acid used by the glass industry.

A zinc producer in Illinois used arsenic trioxide as a flotation reagent to separate zinc from cobalt, copper, and nickel. This was the only zinc producer known to use arsenic in its process.

Commercial-grade arsenic metal, 99% pure, was used in lead- and copper-base alloys as a minor additive (about 0.01% to 0.5%) to increase strength in the posts and grids of lead-acid storage batteries and to improve the corrosion resistance and tensile strength in copper alloys. China is the only country in the world that produces arsenic metal for use in nonferrous alloys.

Relatively small quantities of high-purity arsenic metal, 99.99% pure or greater, were used in electronics. Arsenic metal was used in gallium arsenide for a variety of electronic devices and in selenium-base xerography. Gallium arsenide crystals are grown in a highly controlled process that eventually results in gallium arsenide cylinders, generally from 2 inches to 4 inches in diameter. The cylinders are doped, sawed into wafers, and polished to create semiconductor devices used in optoelectronic devices.

Prices

Prices for arsenic trioxide and arsenic metal are shown in table 2. The average price for Mexican arsenic trioxide declined again in 1990. At $0.23 per pound, arsenic trioxide was only worth about one-half of what it was in 1987.

Prices for arsenic trioxide are not readily available from published sources, although historical prices from 1955 to 1990 are published in the Chemical Economics Handbook published by SRI International, Menlo Park, CA. Normally, producers quote two prices, one for high-grade (minimum 99%) arsenic trioxide and one for low-grade (minimum 95%) arsenic trioxide. There is a spread of $0.08 to $0.12 per pound between the prices of the two grades.

TABLE 1

ARSENIC SUPPLY-DEMAND RELATIONSHIPS

(Metric tons, arsenic content)

	1985	1986	1987	1988	1989[r]	1990
U.S. supply:						
Refinery production	1,700	—	—	—	—	—
Imports, metal	400	400	600	600	900	800
Imports, compounds	13,600	20,200	21,100	21,700	21,500	19,900
Industry stocks, Jan. 1	3,300	900	400	200	100	100
Total	19,000	21,500	22,100	22,500	22,500	20,800
Distribution of U.S. supply:						
Industry stocks, Dec. 31	900	400	200	100	100	100
Apparent demand	18,100	21,100	21,900	22,400	22,400	20,700
Estimated U.S. demand pattern:						
Agricultural chemicals	4,500	5,300	5,000	5,200	4,900	4,600
Glass	700	800	900	900	900	800
Industrial chemicals	12,100	14,100	15,100	15,500	15,700	14,500
Nonferrous alloys and electronics	400	400	400	400	700	600
Other	400	500	500	400	200	200
Total	18,100	21,100	21,900	22,400	22,400	20,700

[r]Revised.

The price of Chinese arsenic metal rebounded from an extremely low level in 1989. In December 1989, Chinese producers stopped delivering arsenic metal to lead alloyers, causing the intermerchant price of arsenic (as quoted by Metal Bulletin) to rise from $0.60 per pound to $1.50 per pound in 1 week. By early February, the price had risen to $5.30 to $6.00 per pound, and several companies were involved in a legal battle over canceled contracts. However, by October, supply of metal from China had been replenished, and the intermerchant price had decreased to $0.95 to $1.10 per pound. The average price for the year was $1.80 per pound.

World Review

Arsenic was recovered as arsenic trioxide from the smelting or roasting of nonferrous metal ores or concentrates in about 20 countries. Annual arsenic trioxide refinery production capacities for the three leading countries were as follows: Sweden, 11,000 metric tons; France, 10,000 metric tons; and the U.S.S.R., 10,000 metric tons. Arsenic metal, which accounts for only 3% of world demand for arsenic, was produced by the reduction of arsenic trioxide. Commercial-grade arsenic metal, 99% pure, which accounted for the majority of arsenic metal production, was produced only in China. High-purity arsenic, 99.99% pure or greater, for use in the semiconductor industry was produced by about 10 companies. Furukawa Electric Co. Ltd. in Japan and Preussag AG in the Federal Republic of Germany were believed to be the world's largest producers, with reported capacities of 30 and 15 metric tons per year, respectively. Other high-purity arsenic producers included Johnson Matthey Electronics in Canada, Mitsubishi Metal Corp. and Rasa Industries Ltd. in Japan, and Johnson Matthey Ltd. and MCP Electronic Materials Ltd. in the United Kingdom.

TABLE 2

AVERAGE ARSENIC PRICE QUOTATIONS

(Cents per pound)

	1988	1989	1990
Trioxide, Mexican	33	27	23
Metal, Chinese	73	47	180

Source: Calculated from Bureau of the Census import data.

Johnson Matthey Ltd. announced the relocation of its research and development facility for gallium arsenide from Trail, British Columbia, to Victoria, British Columbia. Johnson Matthey's subsidiary, Crystar Research, produced gallium arsenide. The closing of the Trail facility was part of a move to restructure Johnson Matthey's electronics business, which it had purchased from Cominco Ltd. in 1988. The decision to close the Trail facility was due in part to stiff price competition in the gallium arsenide industry from Japanese producers.

Current Research

The U.S. Bureau of Mines developed porous beads containing immobilized biological materials for removing metal contaminants from wastewaters. The beads, designated as BIO-FIX beads, are prepared by blending biomass, such as sphagnum peat moss or algae, into a polymer solution. Porous polysulfone beads containing nonliving biomass were successfully used to remove metal contaminants, such as arsenic, cadmium, copper, and lead, from acidic mine wastewaters. After treatment with BIO-FIX beads, effluents met the federally mandated National Drinking Water Standards.[3]

OUTLOOK

World production of arsenic trioxide is expected to decline by about 20% in 1991 because the Swedish producer, Boliden, decided to stop production in early 1991 (see table 4). Historically, Boliden has been a major producer of arsenic trioxide, as a byproduct of lead and copper. The absence of Boliden from the market could create some shortages for arsenic trioxide in 1991 and 1992, although supply was plentiful in 1990.

The major market for arsenic is its use in wood preservatives. The future for arsenic consumption is therefore tied to new housing starts, where wood decks containing arsenical preservatives have become almost standard items in recent years. People adding decks to existing houses also use treated wood. During the next 5 years, the growth of wood preservatives is expected to average 1% to 2%

TABLE 3

U.S. IMPORTS FOR CONSUMPTION OF ARSENICALS, BY CLASS AND COUNTRY

Class and country	1988		1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Arsenic trioxide:						
Australia	—	—	—	—	90	$221
Belgium	1,563	$1,241	1,425	$881	1,714	1,032
Canada	2,068	1,589	1,771	799	—	—
Chile	6,709	2,648	5,057	1,926	6,052	2,511
China	18	8	—	—	1,132	450
Finland	—	—	414	191	963	442
France	6,909	3,664	7,059	2,977	5,399	2,485
Germany, Federal Republic of	16	13	17	28	147	49
Hong Kong	54	42	18	9	70	33
Japan	1	3	—	—	—	—
Mexico	4,187	3,064	4,008	2,361	5,486	2,841
Philippines	1,850	792	2,727	979	2,542	944
South Africa, Republic of	1,017	559	94	53	380	191
Sweden	3,664	2,836	5,676	3,262	2,281	1,371
Switzerland	—	—	77	50	—	—
United Kingdom	(1)	2	5	10	—	—
Total[2]	28,056	16,461	28,348	13,526	26,256	12,570
Arsenic acid:						
British Virgin Islands	7	9	—	—	—	—
Canada	—	—	15	17	1	2
Germany, Federal Republic of	—	—	—	—	3	10
Netherlands	(1)	1	—	—	—	—
United Kingdom	181	161	33	50	17	19
Total	188	171	48	67	21	31
Arsenic sulfide:						
Canada	12	2	—	—	—	—
Germany, Federal Republic of	15	29	—	—	—	—
Taiwan	—	—	2	19	—	—
Total	27	31	2	19	NA	NA
Arsenic metal:						
Canada	19	899	85	658	7	755
China	421	675	627	649	660	2,184
France	—	—	1	1	(1)	3
Germany, Federal Republic of	1	162	3	136	2	220
Hong Kong	75	139	124	129	94	276
Japan	5	613	74	508	8	465
Mexico	78	137	—	—	—	—
Netherlands	—	—	—	—	2	4
Taiwan	—	—	—	—	10	113
United Kingdom	(1)	17	14	69	13	71
Total[2]	600	2,642	928	2,150	796	4,091

NA Not available.
[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 4

ARSENIC TRIOXIDE:[1] WORLD PRODUCTION, BY COUNTRY[2]

(Metric tons)

Country[3]	1986	1987	1988	1989	1990[e]
Belgium[e]	3,000	3,500	3,500	3,500	3,500
Bolivia	241	132	191	[r]338	280
Canada[e]	3,000	2,000	2,000	2,000	2,000
Chile	[e]4,000	3,616	3,207	[e]3,400	3,400
France[e]	10,000	10,000	10,000	[r]7,000	7,000
Germany, Federal Republic of:					
Western states[e]	360	360	360	360	360
Japan[e]	500	500	500	500	500
Mexico	5,315	5,304	5,164	[r]5,551	4,900
Namibia[4]	2,208	1,864	2,983	[r]2,399	2,000
Peru[5]	1,273	1,757	828	[r]563	600
Philippines	[r]4,123	[r]6,286	[r]5,046	[r]4,652	[6]5,092
Portugal	176	218	214	[r]199	200
Sweden[e 7]	10,000	10,000	10,000	10,000	10,000
U.S.S.R.[e]	8,100	8,100	8,100	8,100	7,800
Total	[r]52,296	[r]53,637	[r]52,093	[r]48,562	47,632

[e]Estimated. [r]Revised.

[1]Including calculated arsenic trioxide equivalent of output of elemental arsenic and arsenic compounds other than arsenic trioxide where inclusion of such materials would not duplicate reported arsenic trioxide production.

[2]Table includes data available through May 29, 1991.

[3]Austria, China, Czechoslovakia, the Eastern states of the Federal Republic of Germany, Hungary, the Republic of Korea, Spain, the United Kingdom, and Yugoslavia have produced arsenic and/or arsenic compounds in previous years, but information is inadequate to make reliable estimates of output levels, if any.

[4]Output of Tsumeb Corp. Ltd. only.

[5]Output of Empresa Minera del Centro del Peru (Centromin Peru) as reported by the Ministerio de Energia y Mines.

[6]Reported figure.

[7]Based on arsenic trioxide exported plus the arsenic trioxide equivalent of the output of metallic arsenic exported.

per year because of the recession in the housing industry. No major environmental problems associated with the use of arsenicals in wood preservatives are anticipated because of the small amounts of arsenic used and the fact that arsenic does not readily leach from treated wood.

The use of arsenic in agricultural chemicals has been under close scrutiny by EPA for many years. Many pesticide uses for arsenical chemicals have been banned by EPA. The use of the arsenicals DSMA, MSMA, arsenic acid, and cacodylic acid on cotton is not expected to grow and could even decline during the next 5 years.

Gallium arsenide components compete with silicon components in electronic applications. Gallium arsenide components are faster, but silicon components are cheaper. Advances in computer technology have led to the move from linear to parallel arrangement of processors, thus minimizing the relative slowness of silicon. For this reason, it is unlikely that gallium arsenide will replace silicon in most electronic applications, despite growth in gallium arsenide production capacity.

[1]Federal Register. Calcium Arsenate and Lead Arsenate; Revocation of Tolerances. V. 55, No. 158, Aug. 15, 1990, pp. 33332-33335.

[2]Spokane Spokesman Review. Jury Considers Who Must Take On Massive Slag Cleanup in Tacoma. Nov. 2, 1990.

[3]Jeffers, T. H., C. R. Ferguson, and P. G. Bennett. Biosorption of Metal Contaminants Using Immobilized Biomass—A Laboratory Study. BuMines RI 9340, 1991, 9 pp.

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ASBESTOS

By Robert L. Virta

Mr. Virta, a physical scientist with 15 years of U.S. Bureau of Mines experience, has been the commodity specialist for asbestos since 1986. Domestic survey data were prepared by Joseph Daniels, mineral data assistant; and international data tables were prepared by Harold Willis, international data assistant.

The first stage of a regulation enacted by the Environmental Protection Agency (EPA) that phases out the use of asbestos went into effect on August 27, 1990. Health and liability issues continued to be a major factor in determining the economic stability of several former producers of asbestos products. The number of firms that produce asbestos-containing products continued to decline in response to these issues. Domestic asbestos production increased slightly from that of 1989, but consumption decreased 25%, from 55,306 to 41,348 tons. Asbestos was consumed domestically for roofing products, 37%; friction products, 26%; asbestos-cement pipe, 15%; packing and gaskets, 8%; and other, 14%.

DOMESTIC DATA COVERAGE

Domestic production data for asbestos are developed by the U.S. Bureau of Mines by means of a voluntary industry survey. Of the two canvassed operations to which a survey request was sent, both responded, representing 100% of the total production data shown in table 1.

ANNUAL REVIEW

Legislation and Government Programs

The first stage of the EPA rule banning the manufacture, importation, processing, and distribution of most asbestos-containing products was implemented on August 27, 1990. The first stage banned the production of asbestos-containing flooring and roofing felt, pipeline wrap, asbestos-cement corrugated and flat sheet, vinyl asbestos floor tile, and asbestos clothing. Sales of these materials are banned after August 25, 1992.[1] The validity of the regulation was contested in legal briefs filed on behalf of the Asbestos Information Association of North America, Asbestos-Cement Pipe Producers Association, the Asbestos Institute, and several other organizations and trade associations.[2]

The EPA issued revisions to the national emission standards for hazardous air pollutants under the Clean Air Act for asbestos. The revisions require daily monitoring of visible emissions

TABLE 1

SALIENT ASBESTOS STATISTICS

		1986	1987	1988	1989	1990
United States:						
Production (sales):						
Quantity	metric tons	51,437	50,600	18,233	17,427	W
Value[1]	thousands	$17,367	$17,198	W	W	W
Exports and reexports (unmanufactured):						
Quantity	metric tons	47,281	60,084	31,544	27,004	27,965
Value	thousands	$14,520	$16,149	$8,468	$7,690	$7,964
Exports and reexports of asbestos products:						
Value	do.	$163,896	$180,602	$194,858	$153,081	$120,328
Imports for consumption (unmanufactured):						
Quantity	metric tons	108,352	93,763	85,326	55,306	41,348
Value	thousands	$26,537	$22,022	$21,528	$14,031	$10,773
Consumption, apparent[2]	metric tons	119,627	84,279	71,354	55,306	41,348
World: Production	do.	r4,029,364	r4,235,458	r4,316,443	r4,242,973	3 e3,979,500

e Estimated. r Revised. W Withheld to avoid disclosing company proprietary data.

[1] F.o.b. mine.

[2] Production plus imports minus exports plus adjustments in Government and industry stocks.

[3] Does not include U.S. production.

for milling, manufacturing, and fabricating operations; weekly inspection of air cleaning devices; and recordkeeping. Notification requirements for demolitions and renovations are revised, and recordkeeping is required for asbestos waste disposal.[3]

The EPA published a summary of information submitted by manufacturers and processors of certain asbestos products in accordance with the Asbestos Information Act of 1988. The summary provided the names and addresses of the manufacturer, the type of materials produced, the years in which the materials were manufactured, and identifying characteristics of these materials.[4]

The Mine Safety and Health Administration (MSHA) issued a proposed rule to establish a hazard communication standard. The standard would require mine operators to assess the hazards of chemicals they produce or use and provide information to their employees concerning chemical hazards, including asbestos. Employers also would have to establish a hazard communication program, label containers, provide access to material safety data sheets, and provide employee training. Mixtures containing more than 0.1% of a carcinogen would be assumed to present a carcinogenic hazard.[5]

The MSHA continued reviewing its proposed revisions to existing standards for air quality and chemical substances, including the lowering of permissible exposure levels to asbestos from 2.0 fibers per cubic centimeter to 0.2 fibers per cubic centimeters.[6]

The Occupational Safety and Health Administration (OSHA) conducted public hearings on the regulation governing exposure to the nonasbestiform varieties of actinolite, anthophyllite, and tremolite. An administrative stay was extended through August 31, 1991, on the regulation while it continued to review submissions to the docket.[7] OSHA revised that section of the rule covering asbestos to reduce the short-term exposure limit to 1 fiber per cubic centimeter, to expand its ban on smoking in the workplace, and to increase worker risk awareness training.[8] OSHA proposed to reduce the personal exposure limit from 0.2 fiber cubic centimeters to 0.1 fiber cubic centimeters, to require modified work practices to reduce exposures in certain occupations, to require additional warning of asbestos risks to owners and occupants of buildings prior to asbestos abatement operations, and to require oversight of all abatement work.[9]

The National Institute for Occupational Safety and Health (NIOSH) issued a request for information on synthetic and natural mineral fibers, including asbestos, nonasbestiform amphiboles, glass fibers, mineral wool, and refractory and aluminosilicate ceramic fibers. The type of information that NIOSH requested covered the types of operations that mine, produce, or process these fibers; the number of workers in these occupations; and exposure data to these fibers. Other information requested included the results of medical and epidemiological studies of persons exposed to these fibers, the results of experimental animal studies in which these fibers were used, and criteria for defining fibers.[10]

The EPA continued to review proposed changes in the national primary and secondary drinking water regulations. The proposal covers 30 organic chemicals and 8 inorganic chemicals, including asbestos. The proposed maximum contaminant level goal for asbestos is 7 million fibers (longer than 10 micrometers) per liter.[11]

Strategic Considerations

A wide variety of asbestos-containing civilian products also have military applications. Examples include friction materials (brakes and clutches), electrical and thermal insulations, packings and gaskets, and asbestos-reinforced plastics for use on military vehicles, ships, rockets, missiles, and in military construction. During World War II and the Korean War, strict controls were placed on the export of asbestos because the United States was dependent on foreign sources for about 90% of its requirements of all grades of asbestos. The United States was totally dependent on foreign sources for low-iron, spinning-grade chrysotile. Since that time, equipment components have been redesigned, new products have been introduced, and substitutes for asbestos are being used more frequently. Many of the asbestos-containing civilian products that are used by the military will be eliminated because of the EPA-mandated phaseout of asbestos. Because of the trend toward lower asbestos consumption, the Department of Defense has authorized the disposal of 6,155 tons of chrysotile, 33,844 tons of amosite, and 33 tons of crocidolite from the National Defense Stockpile.

Issues

Environmental and liability issues continued to affect the asbestos industry. The first stage of the EPA regulation that phases out the use of asbestos went into effect in August 1990. The second and third phases become effective in 1993 and 1996, respectively. Most uses of asbestos will be banned after 1997. The EPA phaseout of asbestos is based on the assumption that there is no threshold level of exposure beyond which there is no reasonable risk. Industry representatives and many health scientists maintain that available data do not support this assumption and have challenged the legality of the regulation in court. A decision by the courts is expected in late 1991.

Production

Asbestos was produced in the United States by two companies, KCAC Inc., San Benito County, CA, and Vermont Asbestos Group Inc. (VAG), Orleans County, VT. Domestic production was limited to chrysotile, one of six commercial varieties of asbestos. KCAC operated a mine in a highly sheared serpentinite composed of matted short fiber chrysotile and unfractured serpentinite (also referred to as a mass fiber deposit). The ore was stripped, and wet processing was used to beneficiate the fiber. VAG operated an open pit mine in a serpentinite containing cross-fiber veins of chrysotile. Dry milling was used to process the fiber. While the California company produced only short fiber chrysotile, the Vermont company produced a wide range of chrysotile grades.

Domestic production increased slightly from that of 1989. While domestic markets for asbestos continued to weaken, foreign markets remained strong.

Consumption and Uses

Asbestos was used in a wide variety of products because of its high tensile strength, chemical and thermal stability, high flexibility, low electrical conductivity, and large surface area. Products made from asbestos were more heat resistant (and often incombustible), more resistant to chemical attack (particularly for alkalis), stronger (as-

bestos acted as a physical reinforcer), and less conductive (asbestos had a low dielectric constant). Products were also more viscose (asbestos stiffened compounds and coatings), faster setting (asbestos hastened water drainage in asbestos-cement pipe production), and more cost efficient than many nonasbestos products.

Asbestos cement is composed of 10% to 15% asbestos in a portland cement matrix. This mixture is widely used in the construction industry to produce corrugated and flat sheet, slates, and low- and high-pressure pipe. The main advantage of asbestos-cement products is that they are inexpensive, incombustible, corrosion resistant, and can be produced locally. Markets in North America and Western Europe have declined owing to maturing markets and environmental concerns. However, markets grew in South America, Southeast Asia, the Middle East, and Eastern Europe because of the demands of infrastructure development.[12]

U.S. consumption of asbestos decreased 25% in 1990. Approximately 83% of the asbestos consumed domestically was chrysotile, 2% was crocidolite, and 15% was an unspecified fiber type, most likely chrysotile. Approximately 76% of the chrysotile consumed in the United States was grade 7, followed by grades 4, 6, 5, and 3.

The construction industry is the major consumer of asbestos fiber in the form of asbestos-cement pipe and asbestos-cement sheet, coatings, compounds, packings, and roofing products. These end uses accounted for 70% of the asbestos consumed in the United States.

Apparent consumption has declined dramatically from 800,962 tons in 1973 to 41,348 tons in 1990 in response to environmental and liability issues. There is a continuing interest among manufacturers of both organic and inorganic fibers in acquiring portions of the asbestos market. Product manufacturers gradually have been replacing asbestos with substitute materials, redesigning old products to eliminate the need for asbestos, or designing new products that require neither asbestos nor asbestos substitutes. Economic, manufacturing, performance, and/or technical difficulties were considered before asbestos was replaced by a substitute material or product.

Examples of materials substituted for asbestos include aramid fiber, calcium silicate, carbon fiber, cellulose fiber, ceramic fiber, fibrous glass, graphite flake and fiber, several varieties of organic fiber, steel fibers, and wollastonite. Examples of alternative products include aluminum, vinyl, and wood siding; aluminum and fiberglass sheet; asphalt coatings; ductile iron pipe; polyvinylchloride pipe; prestressed and reinforced concrete pipe; and semimetallic brakes.

Markets and Prices

The average unit value of domestically produced asbestos increased slightly from that of 1989. Unit values for imported asbestos ranged from $130 per ton to $1,629 per ton and averaged $261 per ton. Unit values for exported asbes-

TABLE 2

U.S. ASBESTOS CONSUMPTION, BY END USE, GRADE, AND TYPE

(Thousand metric tons)

End use	Chrysotile[1]							Amosite	Crocidolite	Other[3]	Total asbestos[4]
	Grades 1 and 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Total[2]				
1989	0.1	0.1	5.7	3.8	3.4	38.3	51.5	(5)	0.6	3.2	52.1
1990:											
Asbestos-cement pipe	—	—	3.2	.5	.9	—	4.6	—	.8	—	5.4
Asbestos-cement sheet	—	—	—	—	.9	.9	1.8	—	—	—	1.8
Coatings and compounds	—	—	—	—	—	1.7	1.7	—	—	—	1.7
Flooring products	—	—	—	—	—	—	—	—	—	—	—
Friction products	—	—	—	1.0	.5	7.9	9.3	—	—	—	9.3
Insulation:											
Electrical	—	—	—	—	—	—	—	—	—	—	—
Thermal	—	—	—	—	—	—	—	—	—	—	—
Packing and gaskets	—	—	(5)	.7	.1	1.8	2.7	—	—	—	2.7
Paper	—	—	—	—	—	.2	.2	—	—	—	.2
Plastics	—	—	—	—	—	.3	.3	—	—	—	.3
Roofing products	—	—	—	—	—	12.9	12.9	—	—	—	12.9
Textiles	—	—	—	—	—	—	—	—	—	—	—
Other	—	.1	.4	(5)	—	.4	.9	—	—	—	.9
Total[2]	—	.1	3.6	2.1	2.4	26.0	34.3	—	.8	6.2	35.1

[1] Estimated distribution based upon data provided by the Asbestos Institute, Montreal, Canada, and the Bureau of Mines asbestos producer survey.
[2] Data may not add to totals shown because of independent rounding.
[3] Source: Bureau of the Census. "Other" category contains unspecified fiber type and end use.
[4] Does not include "Amosite" and "Other" category in total.
[5] Less than 1/10 unit.

tos ranged from $128 per ton to $2,158 per ton and averaged $285 per ton. Customs unit values of imported crude chrysotile increased significantly because high-valued crude chrysotile from Canada and Zimbabwe was imported under this import category in 1990. The unit value of imported spinning chrysotile decreased 25% because lower valued chrysotile fiber was included under the "chrysotile, spinning" category. Approximate equivalents, in dollars per metric ton, of price ranges quoted in Industrial Minerals (London), December 31, 1990, for Canadian chrysotile, f.o.b. mine, were $1,320 to $2,125 for Group 3, $918 to $1,275 for Group 4, $604 to $714 for Group 5, $442 for Group 6, and $136 to $264 for Group 7.

TABLE 3

CUSTOMS UNIT VALUES OF IMPORTED ASBESTOS

(Dollars per metric ton)

	1986	1987	1988	1989	1990
Canada:					
Chrysotile:					
Crude	547	610	635	167	782
Spinning	507	598	756	387	291
Other	229	218	227	227	259
South Africa, Republic of:					
Amosite	—	—	—	3,728	—
Crocidolite	582	572	609	631	651

Source: Bureau of the Census.

Foreign Trade

The total value of asbestos fibers and asbestos products exported and reexported from the United States was $128,292,000. This is a 20% decrease from that of 1989. Exports and reexports of brake linings and disk pads accounted for 77% of the value of all manufactured asbestos products. Canada remained the largest importer of unmanufactured fibers and manufactured products, followed by Japan, the United Kingdom, Mexico, and the Federal Republic of Germany.

Canada provided approximately 98% of the asbestos imported into the United States, and the Republic of South Africa provided 2%. Zimbabwe supplied the remaining amount. Approximately 98% of the asbestos fiber imports was chrysotile.

World Review

Canada continued to be the largest market economy producer of asbestos, followed by Brazil, Zimbabwe, and the Republic of South Africa. The U.S.S.R. was the world's largest producer of asbestos. Canada and the U.S.S.R. accounted for 77% of the world production. Canada continued to be the largest exporter of asbestos.

Australia.—Woodsreef Mines continued to await governmental approval to rehabilitate its mine site. The site, consisting of an open pit mine and dry

TABLE 4

COUNTRIES IMPORTING U.S. ASBESTOS FIBERS AND PRODUCTS

(Thousand dollars)

Country	1989			1990		
	Unmanufactured fiber	Manufactured products	Total[1]	Unmanufactured fiber	Manufactured products	Total[1]
Australia	18	1,734	1,752	12	1,851	1,863
Brazil	785	4,203	4,988	534	4,171	4,705
Canada	884	98,974	99,859	472	58,458	58,930
Germany, Federal Republic of	93	3,801	3,894	63	5,479	5,542
Japan	3,314	7,211	10,526	4,119	10,938	15,057
Korea, Republic of	145	953	1,097	107	1,477	1,584
Kuwait	—	574	574	—	189	189
Mexico	370	5,797	6,166	529	5,822	6,350
Saudia Arabia	105	1,394	1,499	14	1,047	1,061
Thailand	10	167	177	81	280	360
Turkey	—	304	304	—	92	92
United Kingdom	75	4,841	4,916	134	6,517	6,650
Venezuela	50	709	759	13	712	725
Other	1,841	22,417	24,259	1,888	23,295	25,185
Total[1]	7,690	153,081	160,771	7,964	120,328	128,292

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

Source: Bureau of the Census.

TABLE 5

U.S. EXPORTS AND REEXPORTS OF ASBESTOS AND ASBESTOS PRODUCTS

		Quantity	Value (thousands)
1989:			
Unmanufactured:			
Asbestos[1]	metric tons	27,004	$7,690
Manufactured:			
Asbestos fibers	do.	r104	382
Brake linings and disk brake pads[2]		NA	127,182
Clutch facings and linings[3]	metric tons	NA	3,868
Clothing, cord, fabric, and yarn		NA	1,363
Gaskets, packing and seals	metric tons	NA	6,206
Panel, sheet, title, and tube[4]	do.	NA	4,773
Paper and millboard		NA	1,188
Other articles[5]		NA	8,119
Total		XX	153,081
1990:			
Unmanufactured:			
Asbestos[1]	metric tons	27,965	7,964
Manufactured:			
Asbestos fibers	do.	81	684
Brake linings and disk brake pads[2]		NA	93,125
Clutch facings and linings[3]	metric tons	NA	7,242
Clothing, cord, fabric, and yarn		NA	1,376
Gaskets, packing and seals	metric tons	NA	4,565
Panel, sheet, title, and tube[4]	do.	NA	4,109
Paper and millboard		NA	885
Other articles[5]		NA	8,341
Total[6]		XX	120,328

r Revised. NA Not available. XX Not applicable.
[1] Includes crudes, fibers, stucco, sand, refuse.
[2] Includes asbestos and cellulose fiber brakes and similar materials.
[3] Includes clutches and other friction materials, excluding brakes and brake pads.
[4] Includes asbestos-cement and cellulose fiber cement products.
[5] Includes asbestos and cellulose fiber products.
[6] Data may not add to totals shown because of independent rounding.

processing facility, closed in 1983. Woodsreef Mine and ICI Australia constructed a prototype wet milling facility in 1982 to demonstrate its ability to improve fiber recovery. The prototype mill achieved a recovery of 90% compared to 67% recovery with dry processing.[13]

Canada.—Baie Verte Mines completed construction and began operation of its wet-process plant in Newfoundland. The operation initially will process tailings from its dry mill plant. Later, it will be used to process stockpiled tailings. Fiber recovery is expected to approach 95%. The process permitted the company to manufacture a pelletized open fiber product that was easier to handle, generated less dust during handling, and was of higher and more consistent quality.[14]

Italy.—Amiantifera di Balangero SpA closed its asbestos mine at San Vittore. The company produced asbestos for use in cement, gaskets, brakes, paint, and insulation products.[15]

Current Research

A new application under study is the use of preimpregnated asbestos-containing products. An asbestos textile would be impregnated with a resin and heated sufficiently to partially polymerize the resin. At a later time, the impregnated fabric would be placed in a mold and heated to completely polymerize the resin and form the shaped part. Preimpregnation would reduce dust during handling by encapsulating the fiber, provide excellent resin-to-fiber bonding, provide a faster molding cycle, and permit a wide variation of performance characteristics by using different resins and resin-to-fiber ratios. Examples of potential applications include rocket blast pipe, electrical and thermal insulating panels, rocket fins, and clutch disks.[16]

OUTLOOK

Domestic markets will decline as each stage of the EPA phaseout of asbestos becomes effective and consumer demand for asbestos substitutes continues. Foreign markets for asbestos fiber should remain strong for several years because of the high demand in developing countries for proven, low-cost construction materials. The prospects for the domestic asbestos manufacturing industry are poor because of the EPA-mandated phaseout of asbestos.

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[14] Stewart, P., G. French, and D. Anthony. Baie Verte Wet Process Plant. Ind. Miner., No. 273, June 1990, pp. 51-55.

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TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF ASBESTOS FIBERS, BY TYPE, ORIGIN, AND VALUE

Type	Canada		South Africa, Republic of		Other		Total[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1988	79,690	$18,336	4,288	$2,516	1,348	$676	85,326	$21,528
1989:								
Amosite	—	—	—	—	2	7	2	7
Chrysotile:								
Crude	205	34	—	—	—	—	205	34
Spinning fibers	5,214	1,877	39	46	130	161	5,383	2,084
All other	45,816	10,378	—	—	110	56	45,926	10,433
Crocidolite (blue)	19	16	574	359	—	—	593	374
Other (unspecified asbestos type)	2,318	656	427	224	452	218	3,197	1,098
Total[1]	53,572	12,961	1,040	628	694	442	55,306	14,031
1990:								
Chrysotile:								
Crude	188	137	—	—	17	23	205	160
Spinning fibers	840	185	—	—	58	77	898	261
All other	33,164	8,542	—	—	58	77	33,222	8,619
Crocidolite (blue)	—	—	835	544	—	—	835	544
Other (unspecified asbestos type)	6,188	1,188	—	—	—	—	6,188	1,188
Total[1]	40,380	10,052	835	544	133	177	41,348	10,773

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

Source: Bureau of the Census.

TABLE 7

ASBESTOS: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989	1990[e]
Argentina	1,697	332	2,328	r225	300
Brazil[3]	204,460	212,807	227,653	r206,195	210,000
Bulgaria	300	400	e400	e400	400
Canada (shipments)	662,381	664,546	r710,357	r701,227	682,200
China	150,712	144,673	157,478	e160,000	160,000
Colombia[e 4]	6,500	6,600	7,600	r7,900	8,000
Cyprus	13,011	18,070	14,585	—	—
Egypt	476	209	166	r312	300
Greece	51,355	r60,134	r e71,000	r e72,500	72,500
India	25,236	29,110	r31,123	r36,502	37,000
Iran (concentrate)[e]	3,000	3,300	r3,400	r3,500	3,500
Italy	115,208	r118,352	94,549	r54,500	20,000
Japan	3,593	3,143	e3,000	e3,000	3,500
Korea, Republic of	2,983	2,518	2,428	r2,361	2,300
South Africa, Republic of	138,862	135,074	145,678	r155,462	147,500
Swaziland	r24,475	25,925	22,804	r27,291	35,000
Turkey	1,098	r806	r e50	(5)	—
U.S.S.R.[e]	2,400,000	6 2,554,600	2,600,000	2,600,000	2,400,000
United States (sold or used by producers)	51,437	50,600	18,233	17,427	W
Yugoslavia	8,596	10,964	17,030	r7,105	7,000
Zimbabwe	163,984	r193,295	186,581	r187,066	190,000
Total	r4,029,364	r4,235,458	r4,316,443	r4,242,973	3,979,500

[e] Estimated. r Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

[1] Marketable fiber production. Table includes data available through Apr. 15, 1991.

[2] In addition to the countries listed, Afghanistan, Czechoslovakia, North Korea, and Romania also produce asbestos, but output is not officially reported, and available general information is inadequate for the formulation of reliable estimates of output levels.

[3] Excludes direct sales of run-of-mine material of 2,060 metric tons in 1986, zero in 1987-88, and estimated zero in 1989-90.

[4] Estimated fiber production based on reported crude production, in metric tons, of: 1986—129,155; 1987—132,723; 1988—152,896; 1989—158,149; and 1990—160,000 (estimated).

[5] Revised to zero.

[6] Reported figure.

BARITE

By Joyce A. Ober

Mrs. Ober, a physical scientist with 13 years of industry and U.S. Bureau of Mines experience, is the acting commodity specialist for barite. Domestic survey data were prepared by Rosa L. McGee, supervisory mineral data assistant; and the international production table was prepared by Virginia A. Woodson, international data coordinator.

Domestic production of barite increased more than 53% to 445,000 metric tons, while the value increased about 20% to $15.9 million. Barite production has remained relatively stable for the past 4 years except for a marked decrease in production in 1989. Although imports remained greater than domestic production, domestic barite comprised a larger share of total U. S. consumption than had been the case for several years. Production from Nevada, the leading producing State, increased about 62%. Imports for consumption of crude barite remained about the same, and ground barite imports increased 22%. Imports of barite exceeded domestic production for the ninth consecutive year, but the import figure of 988,000 tons for 1990 was about 1.1 million tons below the record-high tonnage of 1982. Ground barite imports, except for the drilling boom years of the late 1970's and early 1980's, have been negligible. The principal use for barite, as a weighting agent in oil- and gas-well-drilling fluids (muds), accounted for more than 92% of U.S. consumption. Chemical, glass, and filler and/or extender uses accounted for the remainder.

The Iraqi invasion of Kuwait on August 2, 1990, caused oil prices to rise within days of the invasion. Concern over a stable oil supply prompted U.S. oil companies to increase drilling activity. Total world supplies were not significantly effected because of increased oil production in Saudi Arabia. Oil prices decreased after the initial spike with the stabilization of supply, but did not return to the lower preinvasion prices.

TABLE 1

SALIENT BARITE AND BARIUM CHEMICAL STATISTICS

(Thousand metric tons and thousand dollars)

	1986	1987	1988	1989	1990
United States:					
Barite, primary:					
Sold or used by producers	269	406	404	290	445
Value	$12,326	$15,810	$15,512	$12,625	$15,853
Exports	7	9	(1)	10	9
Value	$1,021	$716	$353	$1,622	$1,675
Imports for consumption (crude)	676	748	1,132	987	988
Consumption (apparent)[2]	939	1,147	1,536	1,271	1,424
Crushed and ground (sold or used by processors)[3]	1,103	1,301	1,612	1,277	1,434
Value	$75,965	$108,759	$127,373	$103,759	$123,836
Barium chemicals (sold or used by processors)	25	28	27	e30	W
Value	$16,871	$16,466	$15,284	e17,000	W
World: Production	r4,688	r4,712	r5,472	r5,577	e5,577

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.

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 65 operations to which a survey request was sent, all responded, representing 100% of the total 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. 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."

Specifications for barite vary according to different uses. Material for weighting 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.

TABLE 2

PRODUCERS OF BARIUM MATERIALS IN 1990

Company	Plant location	Material
BARITE		
American Minerals Inc.	Camden, NJ	Filler amd well drilling.
Do.	Rosiclare, IL	Do.
Baroid Drilling Fluids Inc.	Fountain Farm, MO	Do.
Do.	Lake Charles, LA	Do.
Do.	New Orleans, LA	Do.
Circle A Construction Co. Inc.	Wells, NV	Primary and filler.
Custom Milling & Supply Co.	Salt Lake City, UT	Well drilling.
Cyprus Industrial Minerals Co.	Cartersville, GA	Primary and ground.
De Soto Mining Co. Inc.	Richwoods, MO	Primary
Extender Products Ltd.	Mineral Point, MO	Filler.
General Barite Co.	Washington, MO	Primary.
GEO International Inc.	Florin, CA	Do.
International Drilling Fluids	Amelia, TX	Well drilling.
J. M. Huber Corp.	Quincy, IL	Do.
M I Drilling Fluids	Battle Mountain, NV	Do.
Do.	Brownsville, TX	Well drilling and filler.
Do.	Galveston, TX	Well drilling.
Do.	Lander, NV	Primary and ground.
Do.	New Orleans, LA	Well drilling.
Do.	West Lake Charles, LA	Well drilling and filler.
Do.	Ross, NV	Primary
Milpark Drilling Fluids	Argenta, NV	Primary and ground.
Do.	Corpus Christi, TX	Do.
Do.	Galveston, TX	Do.
Do.	New Orleans, LA	Do.
The Milwhite Co. Inc.	Brownsville, TX	Well drilling and filler.
Do.	Bryant, AK	Do.
Do.	Houston, TX	Well drilling.
Harcros Pigment Inc.	East St. Louis, IL	Filler.
Mountain Minerals Co., Ltd.	Missoula, MT	Primary and ground.
New Riverside Ochre Co.	Cartersville, GA	Primary.
Old Soldiers Minerals Ltd.	Abbeville, LA	Well drilling.
Do.	Elk City, OK	Do.
Ozark-Mahoning Co.	Rosiclare, IL	Primary.
Standard Industrial Minerals	Laws, CA	Filler.
Standard Slag Inc.	Nye, NV	Do.
A.J. Smith Mines Co.	McMinn, TN	Primary
BARIUM COMPOUNDS		
J.T. Baker Chemical Co.	Phillipsburg, NJ	Chemicals.
Chemical Products Corp.	Cartersville, GA	Do.

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.

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 minus 30 to plus 140 mesh. Fine-ground barite can be substituted when crushed material is not available.

Products for Trade and Industry

The principal use for barite, as a weighting material in well-drilling muds, accounted for more than 92% of total U.S. consumption in 1990. Drilling muds have five main functions: (1) to transport drill cuttings to the surface, (2) to control formation pressures, (3) to maintain borehole stability, (4) to protect producing zones, and (5) to cool and lubricate the bit and drill string. The principal function of the barite constituent is as a weighting agent to suppress high formation pressures and prevent blowouts. As the well is drilled, the bit passes through various formations, each with different characteristics. The deeper the hole, the more barite is needed as a percentage of the total mud mix.

The use of barite as a filler or extender and other uses accounted for about 7% of total U.S. consumption in 1990. Barite has a high specific gravity, low oil absorption, easy wettability by oils, and good sanding qualities. Unbleached barite may be substituted for bleached barite when brightness is not a factor. In painting automobiles, barite is used as a filler for the primer coats. The barite contributes to the gloss of the topcoat. When the primers are applied by the electrodeposition process, the body structure is dipped into a tank containing water and paint primer. The method eliminates one of the primary coats, thus reducing the quantity of barite used.

Barite is also used as a filler or extender in some plastic and rubber products. Processors of polyurethane foam use barite in manufacturing such products as floormats and carpet-backings to increase density 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 flux 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.

Minor uses include ballast for ships, heavy concrete aggregate for radiation shielding and pipe-weighting in low-lying areas, and applications in foundries.

Barite is also a raw material for barium chemical manufacturing. The major barium chemicals are the carbonate, chloride, oxide, hydroxide, nitrate, peroxide, and sulfate.

The most important barium chemical is precipitated barium carbonate, which is a raw material for production of many of the other compounds. It is also used in brick and tile manufacturing to control scum caused by gypsum or magnesium sulfate in the clay and to diminish porosity and prevent discoloration in brick. Other uses are in television picture tubes, optical glass, ceramic glazes, porcelain enamel, ferrites, and miscellaneous ceramic products.

Blanc fixe, chemically precipitated barium sulfate, is used as a white filler in paints, rubber, inks, and other materials where a degree of purity higher than natural barite is required. Lithopone (a white pigment composed of a mixture of barium sulfate, zinc sulfide, and zinc oxide), formerly manufactured in large tonnages for use as a white pigment in paints, has been largely replaced by titanium dioxide.

Barium chloride is used in case-hardening and heat-treating baths, in leather and cloth, in making magnesium metal, in preventing scum on brick, in water treatment, and as a laboratory reagent. Fused barium chloride may be electrolyzed to produce barium metal.

Barium metal is also produced by reduction of barium oxide. The metal is used as a "getter" to remove traces of gas from vacuum tubes or in alloys for spark plugs and electronic emission elements in electronic tubes.

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 prevents scumming in ceramics and is used in lubricating oils and to recover sugar from molasses by the barium saccharate process. Barium titanate finds use in miniature electronic and communication equipment.

Industry Structure

Domestic barite production began in 1845 in Fauquier County, VA. About 5 years later, production began in Missouri. In 1880, Tennessee became the third barite-producing State, and 1901 and 1903 saw Georgia and Kentucky, respectively, become producers. California began producing in 1914, Nevada in 1916, and Arkansas in 1941.

Barite was first used as a filler in white paints; however, in 1842, with the advent of the domestic lithopone industry, a second important market opened. In 1908, Chicago Copper Refining Co. (now Chicago Copper & Chemical Co.) began manufacturing barium chemicals at Blue Island, IL. The first washers and jigs used in the industry were installed in Georgia and Tennessee in 1914-16 and in Missouri in 1923–24. A fourth market for barite came into existence in 1916 when a patent was obtained on the use of barite as a weighting agent in rotary drilling muds; today this is the largest consumer of barite. In 1941, the deposit of barite at Malvern, AK, was opened when Magnet Cove Barium Corp. successfully separated barite from associated minerals by flotation. In 1977, IMCO Services Co. completed a multimillion dollar plant at Mountain Springs, NV, that produced barite concentrate using jigs, concentration tables, and flotation. This combination of beneficiating methods was unique in the barite industry.

Geology

Barite is the only commercial source of barium and barium compounds. 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 the weathering of preexisting deposits. The principal residual deposits are found in southeastern Missouri; the Appalachian region; Sweetwater, TN; Cartersville, GA; and in the Rio Grande area of Texas. A concentration of at least 100 to 300 pounds of barite per cubic yard is required in a commercial deposit. In Washington County, MO, the residuum is 10- to 15-feet thick, while in Cartersville, GA, the ore is 150-feet thick in some spots. This form of deposit has been of considerable economic significance.

The most important commercial deposits are of bedded barite. These are principally in Arkansas, California, and Nevada.[1] The barite in these areas is generally dark gray to black and has a characteristic fetid odor when struck with a hammer. The beds, which vary in thickness from several inches to more than 50 feet, occur interbedded with dark chert and siliceous siltstone and shale. In most of the deposits, the barite is laminated. In some areas, barite nodules and rosettes make up a large part of the beds. Many of the beds contain 50% to 95% barite. Originally it was thought that these deposits were the result of the replacement of carbonate rocks; however, current thought is that the deposits are of sedimentary origin. The actual environment of deposition has not been established, but theories range from submarine volcanic emissions to hydrothermal solutions to recycling of barite from preexisting rocks.

Technology

Exploration.—In the past two decades, geological exploration has led to the discovery of bedded barite deposits in

Canada, India, Mexico, and the United States. Bedded deposits have not been sought in many parts of the world. As the search for barite expands in the coming years, it is likely that more bedded deposits will be discovered.

Mining.—Residual deposits of barite are generally mined by draglines in open pits after removal of overburden by conventional methods using elevating scrapers, trucks, dumpers, bulldozers, and front-end loaders. The ore is then beneficiated in washer plants equipped with rotary breakers, log washers, trommel screens, and jigs to separate barite from other material. Fine barite in the overflow from the log washers is recovered by tabling and flotation, while the jig concentrate is magnetically separated.

Bedded and vein deposits may be mined by open pit or underground methods depending on local conditions. The bedded deposits of Arkansas have been mined by both methods. The ore is crushed and ground for beneficiation by flotation. Bedded barite in Nevada is mined by open pit methods using a combination of bulldozers with ripping teeth and conventional blasting. The ore is picked up by front-end loaders and hauled in dump trucks to a processing plant. In some deposits, the ore is of sufficient grade to be either screened and direct shipped or washed, crushed, screened, and shipped to a grinding plant; however, much of the ore requires beneficiation by jigging or flotation.

Quantities of barite have been recovered by underwater mining off Castle Island near Petersburg in southeastern Alaska. The ore is blasted, recovered by a crane equipped with a special digging bucket, and loaded into barges.

Processing.—Barite grinding is usually accomplished by heated airswept Raymond mills, a type of roller mill; however, ball mills are used when iron contamination is not important, as in drilling muds. Barite is ground either wet or dry. For use in well drilling, barite is ground dry; if it requires upgrading by flotation, it is ground wet. Barite 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.

Barite is converted into an intermediate soluble form before its use in the manufacture of lithopone. 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.[2] By adding zinc sulfate to the leach liquor, an intimate mixture of barium sulfate and zinc sulfide called lithopone is precipitated.

The leach liquor is also a precursor of a number of barium chemicals. Addition of sodium sulfate precipitates 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

Production

Run-of-mine barite, the lowest cost primary barite sold or used by producers, representing 70% of total production, increased more than 140% in 1990. The remainder was flotation concentrate and other beneficiated material. The lower cost crude barite and jigged beneficiated materials were used chiefly in drilling muds; the higher valued floated and other beneficiated material was used mostly in chemical and glass manufacturing and in filler applications.

Reported primary production increased approximately 53% from 290,000 in 1989 to 445,000 tons. Nevada and Georgia remained the two leading barite-producing States. Other producing States, in descending order, were Missouri, California, Tennessee, Illinois, and Montana. Illinois production was as a coproduct of fluorspar mining and milling; in all other States, barite is the primary product.

The leading domestic barite producers were M-I Drilling Fluids Co. with mines in Nevada, a Dresser-Halliburton Co.; Milpark Drilling Fluids, a Baker Hughes Inc. company also with mines in Nevada; and Baroid Drilling Fluids Inc., a division of NL Petroleum Services Inc., with mines in Missouri and Nevada.

TABLE 3

U.S. PRIMARY BARITE SOLD OR USED BY PRODUCERS, BY STATE

State	Number of operations	Run of mine		Beneficiated material		Total	
		Quantity (thousand metric tons)	Value (thousands)	Quantity (thousand metric tons)	Value (thousands)	Quantity (thousand metric tons)	Value (thousands)
1989:							
Nevada	5	122	$1,869	87	$1,603	209	$3,473
Other States	8	3	177	78	8,975	81	9,152
Total	13	125	2,046	165	10,578	290	[1]12,625
1990:							
Nevada	6	294	5,116	44	768	338	5,884
Other States	8	17	1,056	91	8,913	108	9,969
Total	14	311	6,172	135	9,681	[1]445	15,853

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

TABLE 4

CRUSHED AND GROUND BARITE[1] SOLD OR USED BY PROCESSORS IN THE UNITED STATES, BY STATE

State	1989			1990		
	Number of plants	Quantity (thousand metric tons)	Value (thousands)	Number of plants	Quantity (thousand metric tons)	Value (thousands)
Louisiana	7	700	$50,533	7	700	$56,895
Missouri	1	W	W	2	W	W
Nevada	3	97	6,208	3	144	9,680
Oklahoma	2	W	W	1	W	W
Texas	4	313	27,288	7	388	33,905
Other[2]	14	167	19,730	19	202	23,356
Total	31	1,277	103,759	39	1,434	123,836

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Includes imports.
[2]Includes Arkansas, California, Georgia, Illinois, New Jersey, and Utah.

Oil prices remained volatile throughout the year, but trends were to higher prices even before the Iraqi invasion of Kuwait. Drilling activity had risen somewhat before the invasion, and the higher prices experienced after the invasion prompted even more domestic drilling and an increase in demand for barite. Oil prices are expected to remain higher than they had been prior to the evasion after the problems in that part of the world are resolved. The invasion renewed concern over the U.S. energy dependence, leading to additional oil exploration and renewed interest in the development of alternative fuels.

Consumption and Uses

Consumption of crushed and ground barite increased about 11%, from 1.3 million tons in 1989 to 1.4 million tons in 1990. The oil- and gas-well-drilling industry completed more than 22,000 wells and drilled nearly 113 million feet of hole;[3] these figures were 8% and 11% higher, respectively, than those in 1989. The relationship between barite production, consumption, and well drilling is illustrated in figure 1.

Total drilling footage exceeded 6 million feet in four States: Texas, 42.1 million feet; Oklahoma, 12.7 million; Louisiana, 9.1 million; and Kansas, 7.1 million. Generally, the deeper a hole is drilled, the more barite is used per foot of drilling. Among the four leading States, Louisiana had the highest average well depth, about 7,100 feet, and Kansas the shallowest, about 3,500 feet. Wyoming, absent from the top States this year in well footage drilled and the perennial leader in the highest average well depth, recorded an average well depth of about 7,200 feet. The U.S. average increased slightly to about 5,000 feet. Barite consumption increased accordingly with the 8% increase in the number of wells drilled as well as the slight increase in average well depth. There was little change in the amount of barite used per foot of drilling, from 11.52 kilograms in 1989 to 11.76 kilograms in 1990.

Another barometer of drilling activity, the Baker Hughes rig count, showed the average number of operating domestic rigs in 1990 increased about 17% to 1,010.[4]

Prices

Price quotations in trade publications for barite remained unchanged. These prices may serve as a general guide, but do not reflect actual transactions.

The reported average value per ton of domestic barite, based on reported value of direct-ship, beneficiated, and floated material, decreased about 18%, f.o.b. plant, from $43.53 per ton in 1989 to $35.63. This decrease in value for domestic concentrate is attributed to a larger percentage of lower valued drilling-mud-grade material in the total. The average value of ground barite, sold or used by producers, was $86.36 per ton, a 6% increase from the $81.25 per ton reported in 1989. The average customs value of exported barite was $181.53 per ton.

Foreign Trade

Exports of natural barium sulfate or barite decreased about 5%, from about 9,700 tons to about 9,200 tons. Exports were still significantly lower than the record high of 109,000 tons in 1979. Export and import data provided by the Bureau of the Census did not indicate the grades of barite traded; however, based only on the value of individual shipments, from about $75 to about $5,000 per ton, drilling-, pharmaceutical-, chemical-, filler-, and glass-grade were all exported. Historically, barite exports were predominantly ground drilling-mud-grade material with less than 5% of the tonnage specialty ground barites. Canada and Mexico have been traditionally either first or second among export recipients of U.S. ground barite; these two major oil-producing countries accounted for about 75% of the total exports.

Imports for consumption of crude barite remained about the same as they were in 1989, at about 1 million tons. The 1990 barite import figure was approximately 50% below the record high of 2.32 million tons set in 1982. The c.i.f. value of this material averaged $41.61 ton, slightly higher than that in 1989. The principal source countries, in descending order, were China, with an average value of $41.33; India, $34.94; and Peru, $37.08. The higher priced material was chiefly crude filler and extender-quality barite. High-quality barite, generally material with a specific gravity greater than 4.2, is usually blended during grinding with lower

FIGURE 1

BARITE CONSUMPTION AND NUMBER OF OIL AND GAS WELLS DRILLED

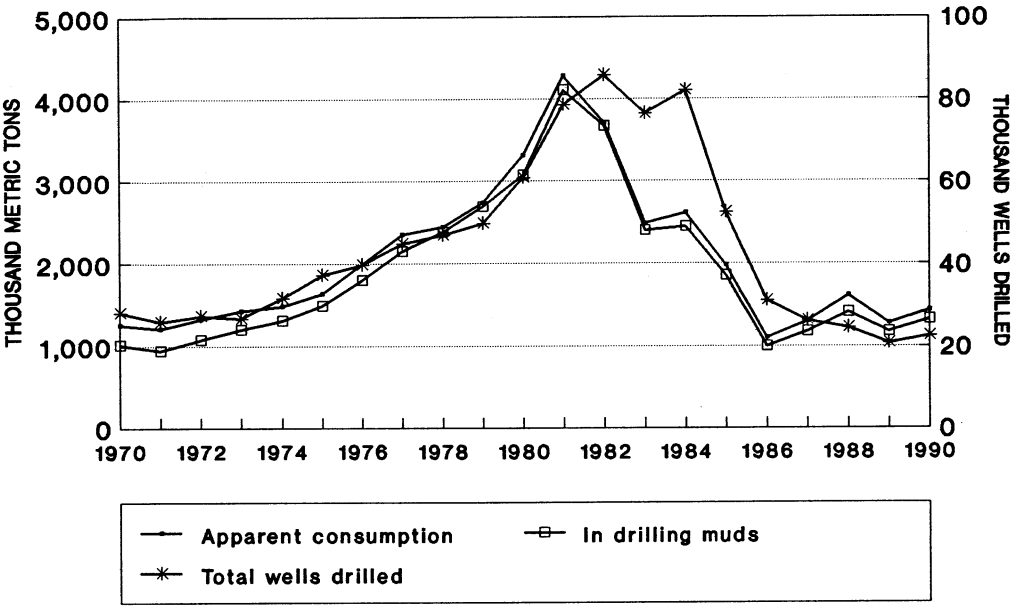

TABLE 5

CRUSHED AND GROUND BARITE[1] SOLD OR USED BY PROCESSORS IN THE UNITED STATES, BY USE

(Thousand metric tons and thousand dollars)

Use	1989		1990	
	Quantity	Value	Quantity	Value
Barium chemicals, filler and/or extender, glass	140	19,470	105	16,758
Well drilling	1,137	84,289	1,329	107,078
Total	1,277	103,759	1,434	123,836

[1]Includes imports.

grade ore, foreign or domestic, to meet American Petroleum Institute specifications for 4.2 drilling-mud-grade barite. Most of the crude barite entered through customs districts along the gulf coast for delivery to grinding plants in the area. The import distribution by customs districts in 1989 (1988) was New Orleans, LA, 73% (65%) and Houston, TX, 24% (31%). Small amounts were also received, in decreasing order, in Laredo, TX; Portland, ME; Pembina, ND; Detroit, MI; Savannah, GA; and Buffalo, NY.

Imports of ground barite increased to about 57,000 tons from about 47,000 tons in 1989; of this, Canada (16%), China (5%), Mexico (65%), and Morroco (13%) supplied almost all of the total. Prior to 1984, ground barite imports had been limited to premium-quality pharmaceutical grades, which were unavailable domestically. In recent years, this market has been dwindling because certain medical X-ray diagnostic procedures employing barium compounds have been largely replaced with computer-assisted tomography (CAT) scanners or imaging techniques. Sources of medical-grade barite were Canada, the Federal Republic of Germany, Japan, and the Netherlands. The average c.i.f. value of lower grade imports ranged from $36 to $309 per ton, suggesting that most of this ground barite is probably destined for the domestic filler and/or extender markets that usually are supplied by U.S. producers. The continued imports of ground filler- and extender-grade barite into this mature market will probably cause concern among domestic producers. Imports

TABLE 6

U.S. HYDROCARBON WELL DRILLING AND BARITE CONSUMPTION

Year	Barite used for well drilling (metric tons)	Wells drilled (thousands)[1]				Successful wells (percent)	Average depth per well (feet)	Average barite per well (metric tons)
		Oil	Gas	Dry holes	Total			
1970	1,015	13.02	3.84	11.26	28.12	60.0	4,952	39.79
1971	947	11.86	3.83	10.16	25.85	60.7	4,806	40.39
1972	1,073	11.31	4.93	11.06	27.30	59.5	4,932	43.33
1973	1,203	9.90	6.39	10.31	26.60	61.2	5,129	49.85
1974	1,306	12.78	7.24	11.67	31.69	63.2	4,750	45.44
1975	1,486	16.41	7.58	13.25	37.24	64.4	4,685	43.98
1976	1,802	17.06	9.09	13.62	39.77	65.7	4,571	49.94
1977	2,152	18.91	11.38	14.69	44.98	67.3	4,687	52.73
1978	2,388	17.76	12.93	16.25	46.94	65.4	4,829	56.07
1979	2,692	19.38	14.68	15.75	49.81	68.4	4,791	59.57
1980	3,071	26.99	15.74	18.09	60.82	70.3	4,675	55.66
1981	4,106	37.67	17.89	22.97	78.53	70.8	4,602	57.63
1982	3,672	40.30	18.95	26.55	85.80	69.1	4,616	47.18
1983	2,402	37.21	15.63	23.49	76.33	69.2	4,268	34.69
1984	2,445	41.10	15.71	25.23	82.04	69.5	4,246	32.85
1985	1,852	26.24	10.15	15.97	52.36	69.5	4,658	39.00
1986	995	15.27	5.53	10.28	31.08	66.9	4,716	35.30
1987	1,174	12.13	4.97	9.04	26.14	65.4	4,779	49.50
1988	1,401	10.54	5.54	8.42	24.50	65.6	5,072	63.02
1989	1,175	7.73	6.16	6.89	20.78	66.8	4,889	36.08
1990	1,329	8.67	7.17	6.59	22.44	70.6	5,021	59.22

[1]Includes exploratory and development wells; excludes service wells, stratigraphic tests, and core tests.

Source: American Petroleum Institute.

TABLE 7

U.S. BARITE MATERIALS IMPORT RATES OF DUTY

Tariff item	January 1, 1991			LDDC[2]	Non-MFN[3] January 1, 1991
	HTSUS[1]	General	Special		
Barite other (crude)	2511.10.50	1.25 dollars per metric ton	Free (A, CA, E, IL)	Free	3.94 dollars per metric ton.
Barite, ground	2511.10.10	3.20 dollars per metric ton	Free (A, CA, E, IL)	Free	7.38 dollars per metric ton.
Barium carbonate	2836.60.00	0.9 cents per kilogram	Free (A, E, IL), 0.5 cents (CA) ad valorem	Free	3.3 cents per kilogram.
Barium chloride	2827.38.00	4.2% ad valorem	Free (A, E, IL) 2.5% (CA) ad valorem	Free	28.5% ad valorem.
Barium hydroxide, oxide and peroxide	2816.30.00	2% ad valorem	Free (A, E, IL), 0.2 cents (CA) ad valorem	Free	10.5% ad valorem.
Barium nitrate	2834.29.50	3.5% ad valorem	Free (A, E, IL) 2.1 (CA) ad valorem	Free	10% ad valorem.
Barium sulfate (blanc fixe/precipitated)	2833.27.00	0.4 cents per kilogram	Free (A, E, IL), 0.2 cents (CA) ad valorem	Free	2.8 cents per kilogram.
Witherite, crude ground	2511.20.00	3.0% ad valorem	Free (CA, E, IL)	Free	30% ad valorem.
Barium metal	2805.22.20	Free	Free	Free	25% ad valorem.

[1]Harmonized Tariff Schedule of the United States.
[2]Least developed developing countries.
[3]Most favored nation.
A-Generalized System of Preferences.
CA-U.S.-Canada Free-Trade Agreement.
E-Carribean Basin Economic Recovery Act.
IL-United States-Israel Free-Trade Area.

TABLE 8

U.S. EXPORTS OF NATURAL BARIUM SULFATE (BARITE), BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	23	$11	51	$80
Barbados	708	63	1,373	166
Canada	1,735	347	3,837	588
Chile	57	120	—	—
Colombia	1,868	248	27	13
Guinea-Bissau	945	109	447	135
Italy	31	202	7	18
Japan	97	25	71	18
Mexico	258	100	3,180	392
Netherlands	20	55	—	—
Senegal	400	50	—	—
United Kingdom	18	28	—	—
Venezuela	3,490	184	6	11
Other[1]	59	78	228	255
Total[2]	9,709	1,622	9,227	1,675

[1]Includes Dominican Republic, Philippines, Saudi Arabia, and Republic of South Africa.
[2]Data do not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF BARITE, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Crude barite:				
Canada	11,281	$337	488	$52
Chile	28,110	935	—	—
China	622,232	25,417	849,963	35,131
India	270,838	10,907	101,649	3,552
Japan	30	6	—	—
Mexico	11,331	440	7,167	276
Morocco	1,228	172	—	—
Peru	42,380	1,541	28,234	1,047
Other	23	13	42	45
Total[2]	987,452	39,768	987,543	40,103
Ground barite:				
Belgium-Luxembourg	38	22	—	—
Canada	7,802	2,455	9,293	2,693
China	—	—	3,000	398
Czechoslovakia	20	3	—	—
France	575	172	—	—
Germany, Federal Republic of	277	138	94	45
Japan	7	5	270	218
Mexico	37,509	1,931	36,655	2,375
Morocco	—	—	7,165	357
Netherlands	394	185	247	108
Total[2]	46,622	4,911	56,724	6,197

[1]C.i.f. value.
[2]Data does not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF BARIUM CHEMICALS

Year	Blanc fixe (precipitated barium sulfate)		Barium chloride		Barium oxide, hydroxide, and peroxide	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
1986	9,479	$8,530	1,741	$733	4,468	$3,960
1987	10,405	8,586	1,795	775	4,760	4,147
1988	23,326	8,754	4,188	834	8,558	4,109
1989	10,638	8,945	1,477	702	4,644	5,335
1990	10,354	8,675	1,510	783	4,186	5,275

	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)
1986	1,037	$504	10,310	$4,809	1,635	$3,197
1987	1,324	579	11,658	5,485	8,566	2,500
1988	2,754	567	19,209	4,803	2,165	3,439
1989	1,477	1,012	14,401	8,047	—	—
1990	1,178	1,394	11,201	6,038	—	—

[1]C.i.f. value.

Source: Bureau of the Census.

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF WITHERITE[1]

Year	Quantity (metric tons)	Value[2] (thousands)
1986	133	$78
1987	396	144
1988	1,213	253
1989	76	30
1990	34	23

[1]Barium carbonate.
[2]C.i.f value.

Source: Bureau of the Census. The Bureau no longer reports crude and ground witherite separately.

TABLE 12

WORLD BARITE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990

(Thousand metric tons)

Country	Rated capacity[1]
Afghanistan	3
Algeria	109
Argentina	64
Australia	23
Austria	1
Belgium	41
Bolivia	2

TABLE 12—Continued

WORLD BARITE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990

(Thousand metric tons)

Country	Rated capacity[1]
Brazil	154
Burma	9
Canada	73
Chile	109
China	1,633
Colombia	5
Czechoslovakia	64
Egypt	5
France	154
Finland	11
German Federal Republic of:	
Western states	204
Eastern states	36
Greece	9
Guatemala	4
India	590
Iran	181
Ireland	181
Italy	136
Japan	64
Kenya	5
Korea, North	91

TABLE 12—Continued

WORLD BARITE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990

(Thousand metric tons)

Country	Rated capacity[1]
Korea, Republic of	4
Malaysia	45
Mexico	544
Morocco	544
Pakistan	36
Peru	91
Philippines	5
Poland	100
Portugal	1
Romania	82
South Africa, Republic of	9
Spain	8
Thailand	181
Tunisia	23
Turkey	408
U.S.S.R.	544
United Kingdom	91
United States	1,451
Yugoslavia	45
Zimbabwe	1
Total	8,174

[1]Includes capacity at operating plants as well as at plants on stand-by basis.

for consumption of barium chemicals decreased slightly.

World Review

The data in table 13 are rated capacity for mines as of December 31, 1990. Rated capacity is defined as the maximum quantity of product that can be produced on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period with minimum capital expenditure.

Mine capacity for domestic barite production was aggregated from data voluntarily supplied by the producers. The rated capacity data for the foreign mines were estimated from the previous year's production in cooperation with the Division of International Minerals.

OUTLOOK

Prior to the Iraqi invasion of Kuwait, domestic demand for barite was expected to increase slowly at an annual rate of between 1% and 2% through 1995. Primary barite production was expected to approach 500,000 tons per year by 1995, and the apparent consumption of barite in this period was expected to be in the vicinity of 2.0 million tons. With the increased domestic drilling activity resulting from the situation in the Persian Gulf area, demand may grow quicker than previously had been anticipated.

Although oil supplies have experienced no significant disruptions, attention has focused on the U.S. dependence on foreign oil. Exploration activities requiring additional barite supplies are expected in the short term. Long-term investigations may lead to development of alternative energy sources, ultimately resulting in a decreased demand for barite as oil and gas are replaced. It is anticipated that acceptance of alternate fuels, such as alcohol and nuclear power systems, will be challenged by a belatedly introduced newer and cleaner generation of petroleum products by the major oil companies. These two systems, if left to competitive market forces, will probably be resolved to the advantage of the new generation

TABLE 13

BARITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989	1990[e]
Afghanistan[e 3]	2,000	2,000	2,000	2,000	2,000
Algeria[e]	[4]60,000	60,000	60,000	60,000	60,000
Argentina	58,617	33,462	[r]48,972	[r]57,558	50,000
Australia	5,818	10,363	10,970	[e]10,000	11,000
Belgium[e]	40,000	40,000	35,000	40,000	40,000
Bolivia	129	1,337	—	[r,(5)]	600
Brazil	[r]105,489	[r]158,197	[r]58,278	[r]51,407	65,000
Burma[6]	[r]11,578	[r]17,243	[r]12,678	[r]9,144	9,000
Canada	40,000	42,000	51,000	[r]39,000	[4]48,000
Chile	53,121	52,109	43,135	[r]59,873	[4]3,037
China[e]	1,000,000	1,250,000	1,500,000	1,750,000	1,750,000
Colombia	4,198	4,189	[e]4,000	[r]5,460	5,400
Czechoslovakia[e]	60,000	60,000	[r,4]60,794	60,000	60,000
Egypt	[e]4,500	4,116	5,651	[r]7,295	7,000
Finland	6,969	11,000	[r]10,993	[r]1,614	1,500
France	116,400	104,050	[e]100,000	[e]100,000	100,000
Germany, Federal Republic of:					
Western states	201,565	173,356	[r]165,317	[r]144,106	144,000
Eastern states[e]	34,000	32,000	32,000	30,000	27,000
Greece[7]	2,305	2,227	2,300	[r]1,180	1,150
Guatemala	750	—	2,415	[r]3,995	4,000
India	344,000	247,000	[r]445,604	[r]548,103	475,000
Iran[3]	[r]42,430	[r]44,309	[r]59,660	[r]45,000	45,000
Ireland	127,500	70,000	83,000	[r]82,000	85,000
Italy	114,132	81,643	85,650	[r]75,640	75,500

See footnotes at end of table.

TABLE 13—Continued

BARITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989	1990[e]
Japan	52,848	31,625	—	—	—
Kenya	420	50	48	r210	200
Korea, Republic of	3,778	2,942	2,573	r3,735	3,800
Malaysia	17,677	38,935	38,766	r36,526	47,000
Mexico	321,186	401,336	534,954	r324,739	332,000
Morocco	189,881	143,503	321,562	r370,000	370,000
Pakistan	39,047	10,031	22,198	r29,718	30,000
Peru	9,945	8,354	8,500	e8,400	8,400
Philippines	—	—	349	r348	500
Poland	77,100	73,100	r63,100	r65,000	65,000
Portugal	120	660	r1,740	r1,729	1,600
Romania[e]	75,000	72,000	72,000	70,000	65,000
South Africa, Republic of	8,653	8,617	8,735	r8,570	4,2490
Spain	49,100	33,761	r6,585	r6,600	7,000
Thailand	142,232	33,370	40,587	r76,422	80,000
Tunisia	e20,000	14,412	r18,868	r33,104	33,000
Turkey	r330,758	r291,913	r405,017	r434,664	430,000
U.S.S.R.[e]	540,000	540,000	540,000	540,000	500,000
United Kingdom	86,754	81,360	r76,253	r70,026	70,000
United States[8]	269,000	406,000	404,000	290,000	4439,000
Yugoslavia	18,250	19,270	23,350	e22,000	21,000
Zimbabwe	298	191	3,400	r1,900	1,800
Total	r4,687,548	r4,712,031	r5,472,002	r5,577,066	5,576,977

[e]Estimated. [r]Revised.
[1]Table includes data available through May 24, 1991.
[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]Revised to zero.
[6]Data are for fiscal year beginning Apr. 1 of that stated.
[7]Barite concentrates.
[8]Sold or used by producers.

of petroleum products, thus ensuring continued demand for barite used in oil drilling.

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BERYLLIUM

By Deborah A. Kramer

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Since its first commercial production in the United States in the early 1920's, beryllium has become an important material in many industrial and defense applications. Properties such as its high strength, light weight, and high thermal conductivity allow beryllium to be used for components in aircraft, satellites, electronic circuits, oil drilling equipment, and consumer goods.

The United States is the only market economy country with an integrated beryllium industry. Bertrandite, mined and processed in Utah, is the primary mineral source for the end products—beryllium metal, beryllium alloys, and beryllium oxide—that are produced in Ohio and Pennsylvania. Imported beryl, mainly from Brazil, supplements domestic mineral supply.

In 1990, U.S. mine production declined slightly, continuing a 3-year trend. Persistent weak demand in the automotive, defense, and telecommunications markets led to a decline in usage of beryllium metal, alloys, and oxide. But the U.S. mine production supplied a greater percentage of the domestic demand, while beryl imports continued to decrease.

Brush Wellman Inc. was the sole U.S. beryllium mine producer with the capability to convert this ore and beryl into beryllium products. In an effort to upgrade the beryllium-containing materials in the National Defense Stockpile (NDS), the company was awarded a contract to recover beryllium metal from some beryl in the NDS.

DOMESTIC DATA COVERAGE

Beryllium data are collected from two voluntary surveys of U.S. operations. In 1990, there were eight responses to the "Beryllium Mineral Concentrate and Beryllium Ore" survey, representing 80% of the total canvassed. These respondents are estimated to have produced 100% of total domestic mine shipments, shown in tables 1 and 9. A small number of unidentified producers may have shipped insignificant quantities of byproduct beryl, which have not been included.

BACKGROUND

Products for Trade and Industry

Beryllium principally is used in one of three forms—beryllium alloys, beryllium metal, and beryllium oxide. The most common products are beryllium-copper alloys, which contain about 2% beryllium and the balance copper. These average about 65% of U.S. beryllium demand and are produced in many shapes, including bar, plate, rod, strip, tube, and wire. Most beryllium-copper alloys are used as current-carrying parts in electronic, telecommunications, and computer equipment. They also are used in oil and gas drilling equipment, as molds for plastic products, and in consumer goods, including golf clubs, stereo systems, and video cassette recorders.

Small quantities of beryllium-aluminum and beryllium-nickel alloys are used in applications such as automotive electronics. Adding small quantities of beryllium to some magnesium alloys inhibits oxidation.

Beryllium metal averages about 20% of annual domestic demand and is used mainly in aerospace and defense applications. Beryllium has been used in guidance systems and as structural components for satellites and deep space probes such as *Galileo* and *Magellan*. It also was used in firing control systems in advanced tactical aircraft. In medical applications, beryllium metal was used for radiation windows in diagnostic X-ray equipment.

The principal use for beryllium oxide is as a substrate for high-density electronic circuits for high-speed computers, automotive ignition systems, lasers, and radar electronic countermeasure systems. Its transparency to microwaves allows beryllium oxide to be used as windows in microwave communications systems.

TABLE 1

SALIENT BERYLLIUM MINERAL STATISTICS

(Metric tons of beryllium metal equivalent unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Beryllium-containing ores:					
Mine shipments	237	220	212	184	182
Imports for consumption, beryl[1]	54	83	35	24	14
Consumption, reported	288	323	243	217	232
Price, approximate, per short ton unit BeO, imported cobbed beryl at port of exportation	$88	$84	$93	$90	$101
Yearend stocks	177	164	158	153	119
World: Production[1]	r356	r345	332	r301	e286

e Estimated. r Revised.

[1] Based on a beryllium metal equivalent of 4% in beryl.

Industry Structure

Although beryllium is a constituent of more than 90 minerals, only 2 are exploited commercially for their beryllium content. Bertrandite ($4BeO \cdot 2SiO_2 \cdot H_2O$) is the principal ore mined in the United States, and beryl ($3BeO \cdot Al_2O_3 \cdot 6SiO_2$) is the principal ore mined in the rest of the world.

Mechanized mining methods are used in the United States, but beryl mining operations in the rest of the world are limited to labor-intensive hand-cobbing of the host rock for beryl crystals. As a result, production from operations outside the United States is sporadic and largely is dependent on the economic and political situations within the individual country.

Little is known about beryl mining operations in China and the U.S.S.R., which are probably the two largest producers outside the United States. Beryl produced in China has been imported into the United States in the past, and China has supplied small quantities of beryllium-copper master alloy to the U.S. market. Little, if any, beryllium products from the U.S.S.R. have surfaced in the United States; it is assumed that the U.S.S.R. has an integrated beryllium industry, and its production is consumed within the country.

Geology

Beryl and bertrandite are the chief ores from which beryllium is commercially recovered. Commercial sources of beryl are heterogeneous granite pegmatites, where the mineral occurs in enriched zones, filled fractures, and replacement bodies. The principal beryl deposits occur in zones that usually contain only a few thousand tons of pegmatite rock; some deposits, however, contain 1 million metric tons or more of rock. When beryl occurs in zoned pegmatites, the largest crystals usually are near the core, and the fine-grained crystals are near the outer zone. Some forms of beryl are regarded as precious or semiprecious gems. Pegmatites normally are not mined solely for their beryl content. The beryl is recovered as a coproduct of mining other pegmatite minerals such as feldspar, mica, and lithium minerals. Bertrandite is found in both pegmatite and nonpegmatite deposits; the deposit currently mined in Utah occurs erratically in altered tuff associated with fluorite, montmorillonite, opal, and chalcedony.

TABLE 2

WORLD ANNUAL BERYL PRODUCTION CAPACITY,[1] DECEMBER 31, 1990

(Metric tons, contained beryllium)

	Capacity
North America: United States[2]	360
South America:	
Argentina	4
Brazil	65
Total	69
Europe:	
Portugal	3
U.S.S.R.	77
Total	80
Africa:	
Madagascar	5
Mozambique	3
Rwanda	3
South Africa, Republic of	3
Zimbabwe	5
Total	19
Asia: China	75
World total	603

[1] Includes capacity at operating plants as well as at plants on standby basis.
[2] Includes bertrandite ore.

ANNUAL REVIEW

Legislation and Government Programs

Brush Wellman received a $25.6 million contract from the Defense Logistics Agency (DLA) to upgrade some beryl in the NDS. The company will convert the beryl into 91,000 pounds of vacuum hot-pressed beryllium billets during a 2-year period. Deliveries of the beryllium billets were expected to begin in early 1991. Included in the contract is an option for DLA to buy an additional 43,000 pounds of beryllium in 1993 for about $13 million. NDS inventories at yearend 1990 are shown in table 3.

The Environmental Protection Agency (EPA) issued final regulations to limit effluent discharge into public waters for several metal manufacturing operations, including beryllium, under the authority of the Clean Water Act. As part of these regulations, EPA set effluent limits for ammonia, beryllium, chromium, copper, cyanide, fluoride, total suspended solids, and pH for wastes from six processing steps that previously were not regulated. EPA also increased the maximum discharge levels for fluoride in the beryllium hydroxide supernatant wastewater and for mass pollutants in the beryllium hydroxide filtrate. These rules supersede the standards in effect since September 1985.[1]

TABLE 3

STOCKPILE STATUS, DECEMBER 31, 1990

(Metric tons, beryllium content)

Material	Goal	Inventory
Beryllium ore	653	653
Beryllium-copper master alloy	287	268
Beryllium metal	363	290

Issues

The health effects of airborne beryllium particles continue to be assessed by both the Federal Government and industry. The U.S. Department of Energy planned to implement a complete study of its workers with potential exposure to beryllium. The Agency also expected to review studies on beryllium exposure that were conducted at the National Jewish Center for Immunology and Respiratory Medicine, the University of Colorado Medical School, and the National Institute of Occupational Safety and Health.[2] Brush Wellman also assembled a study group to examine the health and safety concerns of beryllium users. In addition, the company sponsored publication of a book that details current techniques for safe handling of beryllium.[3]

Although both Federal and State environmental and health and safety regulations exist for beryllium, discharge of and exposure to the metal remain an issue. NGK Metals Corp. reportedly was fined $300,000 by the State of Pennsylvania for illegal storage and disposal of chemical wastes. One of the company's employees also was charged with submitting monthly reports to the

State that underreported the number of instances that the company violated its discharge limitations for beryllium and copper. NGK pleaded no contest to one felony violation of the Solid Waste Management Act, two misdemeanor violations of the Act, one count of unsworn falsification, one count of pollution of water, and one violation of the Clean Streams Act.[4]

The Occupational Safety and Health Administration (OSHA) issued citations against Alloy Research Inc., a New Madrid, MO, casting foundry that produces beryllium-copper alloy billets and slabs, for alleged violations of Federal health and safety standards. Molten metal and steam explosions at the facility spurred OSHA to conduct inspections; the Agency found that some employees were exposed to airborne beryllium levels that were higher than the Permissible Exposure Limit. OSHA's citations included 16 willful violations, 31 serious, and 10 other-than-serious and carry a total proposed penalty of $170,480.

Production

Mine production declined slightly in 1990, and inventories were drawn down to meet part of the worldwide demand. Beryllium metal production increased by about 18%, but this increase was used mainly to fill the NDS requirements. Production of beryllium-copper master alloy increased slightly, and there was a significant drop in U.S. production of beryllium oxide. In addition, beryllium-nickel alloy production declined, and beryllium-aluminum alloy production increased sharply.

Brush Wellman was the only integrated producer of beryllium in the United States. The company mined bertrandite at its open pit near Delta, UT, and processed this ore, imported beryl, and small quantities of domestically produced byproduct beryl into beryllium hydroxide at its facility in Delta. Beryllium hydroxide was shipped to Brush Wellman's plant in Elmore, OH, where it was manufactured into beryllium metal, beryllium alloys, and beryllium oxide. NGK Metals also produced beryllium alloys at its plant in Reading, PA, from beryllium hydroxide supplied by Brush Wellman.

A joint venture between Beryllium International Corp. and Inspiration Gold, a subsidiary of Inspiration Resources Inc., planned to develop a beryllium mining and milling operation in Utah. Inspiration Gold owns 51% of the joint venture, which it purchased from Cominco American Resources, a division of Cominco Ltd., in mid-1990. Cominco had completed a project feasibility study on this property and decided not to go ahead with beryllium production. The joint venture expected to mine beryllium from property next to Brush Wellman's and has set up a temporary office in Delta, UT, to handle early stages of project development. After obtaining Federal and State permits, the companies expect to begin plant construction in 1991.

Consumption and Uses

Reduced demand in the U.S. automotive, defense, and telecommunications markets led to a decrease in beryllium oxide ceramic usage. A decline in beryllium alloy demand in computer-related applications partially was offset by an increase in automotive electronics and oil and gas drilling equipment.

Hughes Aircraft Co. ordered 110 beryllium blanks from Brush Wellman to be machined into mirrors for the firing systems of the South Korean K-1 Main Battle tank. This is the second order from the Government of the Republic of Korea, which took delivery of 170 tanks in 1989. The 2.2-pound mirrors originally were developed for the European Leopard II tank and were used to aim the tank's gun. Beryllium mirrors also have potential use in an upgraded version of the U.S. M-1 tank; if beryllium is chosen for this application, another 5,000 blanks may be required.

In January, Brush Wellman announced the purchase of Electrofusion Corp., a manufacturer of electron-beam welded, brazed, and diffusion-bonded beryllium components, to give Brush Wellman more value added products. Electrofusion supplied the aerospace, defense, medical, and scientific markets.

During 1990, the Defense Reutilization and Marketing Service was a major source of beryllium scrap, primarily in worn aircraft brake disks and other components of aircraft brake assemblies. A total of 30,073 kilograms of beryllium-base scrap was offered for sale during the year, and Brush Wellman was the principal purchaser.

Markets and Prices

Yearend prices for beryllium ore, alloy, metal, and oxide are shown in table 4. Beryllium-copper strip, rod, bar, and wire prices increased about 4% from those at yearend 1989. Although the quoted price for beryllium powder appears to have increased significantly from that of yearend 1989 when it was quoted at $196 per pound, revised prices for 1986–89 show that the price increase between 1989 and 1990 was about 3%. Revisions to the beryllium powder price since yearend 1986 are as follows, in dollars per pound: 1986—$204; 1987—$229; 1988—$244; and 1989—$261.

Foreign Trade

The Bureau of the Census does not separately identify imports and exports of beryllium-copper alloys; these data are combined with data for other cop-

TABLE 4

YEAREND BERYLLIUM PRICES

(Dollars per pound unless otherwise specified)

Material		Price
Beryl ore	short ton unit of contained BeO	$75 -$85
Beryllium vacuum-cast ingot, 98.5% pure		225
Beryllium metal powder, in 1,000- to 4,999-pound lots and 98.5% pure		268.83
Beryllium-copper master alloy	pound of contained Be	160
Beryllium-copper casting alloy		5.52- 6.30
Beryllium-copper in rod, bar, wire		10.24
Beryllium-copper in strip		9.25
Beryllium-aluminum alloy, in 100,000-pound lots		260
Beryllium oxide powder		72.50

Sources: American Metal Market and Metals Week.

per alloys. The Journal of Commerce Port Import/Export Reporting Service (PIERS) provides some data covering beryllium-copper alloy trade, but only on materials that are transported by ship, so the data may not represent U.S. totals. According to PIERS, the United States exported 430 tons (gross weight) of beryllium-copper alloys, with about 50% of the material shipped to Japan and 37% shipped to France. In addition, 21 tons (gross weight) of beryllium-copper master alloy was exported; 87% was shipped to France, and 13% was shipped to Brazil. Imports of beryllium-copper alloys were 154 tons (gross weight), of which 39 tons was scrap. Japan was the source of 50% of the beryllium-copper alloy imports.

Current Research

Nuclear Metals Inc. was awarded a contract by Oak Ridge National Laboratory to use the company's plasma-rotating-electrode process to produce spherical, high-purity beryllium powder for optical applications. Beryllium powder produced by this process is expected to enhance properties needed for producing near-net-shape parts, particularly mirrors, by hot-isostatic pressing (HIP). The plasma-rotating-electrode process essentially involves rapid longitudinal spinning of a high-purity beryllium bar and melting one end with a plasma torch. Liquid beryllium droplets are ejected from the end of the bar by centrifugal force and solidify into spheres. Because this is done in an inert atmosphere, the powder has little chance to oxidize and pick up other contaminants.

Brush Wellman also investigated new processing techniques to improve the properties of metallic beryllium parts and reduce their cost. In particular, its efforts were directed at improving near-net-shape processing techniques. Using HIP, the company developed a new grade of beryllium, Grade O-50, for mirrors in reconnaissance satellites and tactical optical systems. HIP also was used to develop new families of beryllium products, including beryllide intermetallic compounds for rocket nozzles and high-temperature applications, metal-matrix components for hypersonic aircraft applications, and aluminum alloys containing as much as 40% beryllium. Brush Wellman also produced a prototype of a lower cost beryllium foam, which is a potential substitute for honeycomb materials in a variety of applications. In addition, the company developed a laboratory-scale, inert-gas atomization method to produce spherical beryllium particles.

Research personnel at Los Alamos National Laboratories worked on developing methods to produce beryllium alloys by rapid solidification. The researchers modified an existing technique, but this was the first time this type of process was applied to beryllium. Test beryllium compounds were made with a centrifugal atomizer, in which molten metal is cooled at up to 1 million degrees per second. This rapid cooling produces spherical rather than

TABLE 5

U.S. EXPORTS OF BERYLLIUM ALLOYS, WROUGHT OR UNWROUGHT, AND WASTE AND SCRAP,[1] BY COUNTRY

Country	1989		1990	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Angola	31	$9	31	$9
Australia	72	9	16	5
Belgium	277	40	—	—
Brazil	—	—	51	9
Canada	3,415	524	29,557	859
China	37	50	—	—
France	1,954	784	810	430
Germany, Federal Republic of	910	353	1,624	1,220
Ireland	80	9	—	—
Israel	200	156	—	—
Italy	353	55	33	4
Japan	716	285	475	180
Korea, Republic of	79	12	960	133
Mexico	1,014	14	439	40
Netherlands	7,741	190	1,968	228
Sweden	46	7	—	—
Switzerland	937	248	354	114
Taiwan	138	27	28	12
Tanzania	8,825	11	—	—
United Kingdom	7,435	1,062	8,852	1,565
Other	1	2	29	23
Total	34,261	3,847	45,227	4,831

[1] Consisting of beryllium lumps, single crystals, powder; beryllium-base alloy powder; and beryllium rods, sheets, and wire.

Source: Bureau of the Census.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF BERYL, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Brazil	526	$572	342	$418
China	35	44	—	—
Morocco	22	20	—	—
Zimbabwe	18	19	—	—
Total	601	655	342	418

Source: Bureau of the Census.

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF BERYLLIUM METAL AND COMPOUNDS

Year	Beryllium-copper master alloy		Beryllium, unwrought and waste and scrap		Beryllium oxide and hydroxide	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
1989	19,000	$216	14,395	$344	13,546	$40
1990	99,614	871	10,982	132	589	28

Source: Bureau of the Census.

TABLE 8

U.S. IMPORT DUTIES

Tariff item	HTS No.	Most favored nation (MFN) Jan. 1, 1990	Non-MFN Jan. 1, 1990
Ore and concentrate	2617.90.0030	Free	Free.
Unwrought beryllium	8112.11.6000	8.5% ad valorem	25.0% ad valorem.
Beryllium, wrought	8112.19.0000	5.5% ad valorem	45.0% ad valorem.
Beryllium waste and scrap	8112.11.3000	Free	Free.
Beryllium-copper master alloy	7405.00.6030	6.0% ad valorem	28.0% ad valorem.
Beryllium oxide or hydroxide	2825.90.1000	3.7% ad valorem	25.0% ad valorem.

TABLE 9

BERYL: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989	1990[e]
Argentina	50	46	39	r89	85
Brazil	r907	r1,000	913	r800	850
Madagascar[3]	e(4)	(4)	(4)	(4)	(4)
Mozambique	1	—	—	—	—
Nepal	(4)	(4)	(4)	r1	1
Portugal	—	4	4	e4	4
South Africa, Republic of	3	(4)	(4)	e—	—
U.S.S.R.[e]	1,900	2,000	2,000	2,000	1,600
United States[5] (mine shipments)	5,927	5,499	5,313	4,592	6 4,548
Zimbabwe (concentrate, gross weight)	103	83	33	r46	50
Total	r8,891	r8,632	8,302	r7,532	7,138

[e] Estimated. [r] Revised.

[1] Table includes data available through Apr. 26, 1991.

[2] In addition to the countries listed, China produced beryl and Bolivia and Namibia may also have produced beryl, but available information is inadequate to formulate reliable estimates of production.

[3] Includes ornamental and industrial products.

[4] Less than 1/2 unit of measure; for Madagascar, production was, in kilograms: 1986—50 (revised); 1987—35; 1988—3; 1989—154; and 1990—150 (estimated); for Nepal, production for 1988 was 400 kilograms; and for the Republic of South Africa, production for 1987 and 1988 was 135 kilograms and 72 kilograms, respectively.

[5] Includes bertrandite ore, calculated as equivalent to beryl containing 11% BeO.

[6] Reported figure.

angular beryllium particles. The test compounds used unique alloying elements such as titanium, vanadium, yttrium, and zirconium. Beryllium alloys with a 2% yttrium content were shown to be thermodynamically stable, with a melting point of about 1,900° C. Alloys developed by these techniques were expected to be used on the U.S. Government's National Aerospace Plane.

OUTLOOK

In sales volume, the defense market is the largest consumer of beryllium, although the automotive electronics market is the fastest growing sector. Limited production of new defense systems because of declines in Federal funding would decrease the need for beryllium in this market. In addition, because of the perceived health hazards of beryllium, some defense components have been redesigned to use substitute materials. The combination of fewer beryllium components produced and the substitution of other materials for beryllium would lead to a decline in beryllium use in defense applications.

In 1991, U.S. automobile manufacturers plan to produce the fewest quantity of cars since the recession year of 1982. With a decrease in total automobile output, beryllium use in this application is not expected to increase in the near term, even though individually, each car may contain more beryllium components than those in previous years.

Normally, beryllium metal purchases by the NDS result in an increase in U.S. production to supply the additional requirements. But because the metal will be recovered from material that already is in the NDS, additional NDS

metal requirements will not result in increased U.S. mine production.

[1] Federal Register. Environmental Protection Agency. Nonferrous Metals Manufacturing Point Source Category Effluent Limitations Guidelines, Pretreatment Standards and New Source Performance Standards. V. 55, No. 150, Aug. 3, 1990, pp. 31692-31719.

[2] Rossman, M. D., O. P. Preuss, and M. B. Powers (eds.). Beryllium. Biomedical and Environmental Aspects. Williams & Wilkins, 1991, 319 pp.

[3] Abrahamson, P. Beryllium Exposure Study Urged. Am. Met. Mark., v. 98, No. 22, Jan. 31, 1990, pp. 6, 10.

[4] Elson, J. NGK Metals Fined for Waste Dumping. Am. Met. Mark., v. 98, No. 58, Mar. 23, 1990, pp. 5, 10.

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TABLE 10

BERYLLIUM SUPPLY-DEMAND RELATIONSHIPS

(Metric tons of beryllium content)[1]

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
WORLD PRODUCTION											
Mine production:											
United States	270	266	197	242	219	209	237	220	212	184	182
Rest of world	103	119	121	119	141	117	r119	r125	120	r117	e104
Total	373	385	318	361	360	326	r356	r345	332	r301	e286
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mines	270	266	197	242	219	209	237	220	212	184	182
Shipments of Government stockpile excesses	—	—	—	—	—	—	—	—	—	—	—
Imports, metal	W	1	8	8	32	51	19	50	12	14	11
Imports, beryl	62	78	96	80	48	60	54	83	35	24	14
Industry stocks, Jan. 1[2]	W	49	81	185	255	205	181	177	164	158	153
Total U.S. supply	367	394	382	515	554	525	491	530	423	380	360
Distribution of U.S. supply:											
Industry stocks, Dec. 31[2]	49	81	185	255	205	181	177	164	158	153	119
Exports, metal and alloy	26	35	61	17	18	54	36	77	37	34	45
Government accessions	—	—	—	—	28	27	—	—	—	6	21
Industrial demand	292	278	136	243	303	263	278	289	228	187	175
U.S. DEMAND PATTERN											
Nuclear reactors	57	54	29	52	73	65	45	41	18	10	5
Aerospace	53	51	25	46	46	39	41	44	51	44	46
Electrical	109	101	49	87	105	91	108	109	66	36	35
Electronic components	47	46	24	41	53	46	62	68	80	88	79
Other	26	26	9	17	26	22	22	27	13	9	10
Total U.S. demand	292	278	136	243	303	263	278	289	228	187	175

e Estimated. r Revised. W Withheld to avoid disclosing company proprietary data.

[1] Beryllium content of material classified as ores is considered to be 4%.

[2] Beryl ore.

BISMUTH

By Stephen M. Jasinski

Mr. Jasinski is a physical scientist with the Branch of Metals. He has been the U.S. Bureau of Mines bismuth specialist for 3 years. Domestic survey data were prepared by Tony Morris, mineral data assistant; and international data tables were prepared by Harold Willis, international data coordinator.

Domestic consumption of bismuth decreased for the third consecutive year, mainly because of a decline in usage by the chemical and pharmaceutical industries. Bismuth was produced in the United States as a byproduct of lead refining. One company accounted for all primary production. Consumer stocks and imports of bismuth both dropped from those of 1989. The U.S. dealer price, which declined steadily for the first three quarters of the year in response to weak demand, was unchanged in the last 3 months of the year.

DOMESTIC DATA COVERAGE

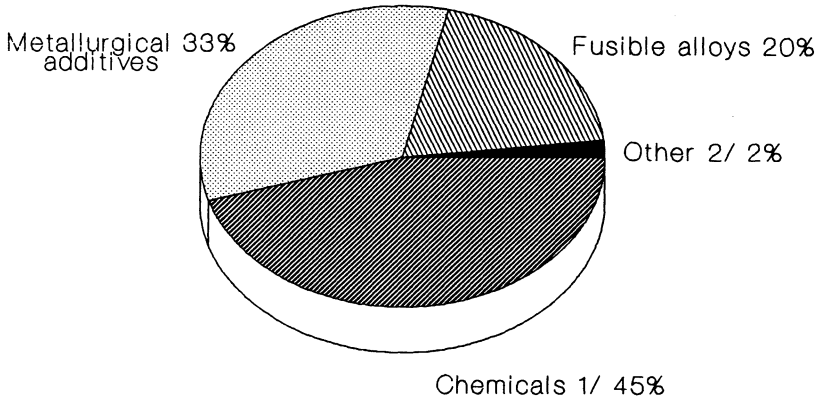
Domestic consumption data are collected through a voluntary survey. Of the 69 firms that received the form, 88% responded. The respondents constituted 94% of the bismuth consumed in the United States. The amount used by the nonrespondents was estimated based upon data reported in the prior year or from other sources.

Legislation and Government Programs

The Defense Logistics Agency (DLA), which maintains the National Defense Stockpile (NDS), sold 58,967 kilograms of bismuth from the NDS in 1990. The DLA began monthly sales of bismuth in August; it awarded 29,484 kilograms in August and the same quantity again in October. The DLA had the authority to dispose of 57,924 kilograms in each of the fiscal years 1990 and 1991. The NDS inventory on December 31, 1990, was 885,119 kilograms, with a goal of 480,808 kilograms.

FIGURE 1

BISMUTH METAL CONSUMED IN THE UNITED STATES IN 1990



1/Includes industrial and laboratory chemicals, cosmetics, and pharmaceuticals.
2/Includes experimental and other alloys.

TABLE 1

SALIENT BISMUTH STATISTICS

(Metric tons unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Consumption	1,324	1,597	1,531	1,352	1,274
Exports[1]	42	38	147	122	122
Imports for consumption	1,129	1,581	1,641	1,880	1,612
Price, average, domestic dealer, per pound	$3.25	$3.65	$5.78	$5.76	$3.56
Stocks, Dec. 31: Consumer	346	294	433	440	344
World:					
Mine production (metal content)[2]	r3,658	r3,173	r3,220	r3,556	e3,200
Refinery production[2]	r4,077	r4,078	r4,098	r4,082	e3,710

eEstimated. pPreliminary. rRevised.
[1]Includes bismuth, bismuth alloys, and waste and scrap.
[2]Excludes the United States.

TABLE 2

BISMUTH METAL CONSUMED IN THE UNITED STATES, BY USE

(Metric tons)

Use	1986	1987	1988	1989	1990
Chemicals[1]	663	748	679	659	577
Fusible alloys	290	334	332	272	249
Metallurgical additives	350	494	493	396	424
Other[2]	21	21	27	25	24
Total	1,324	1,597	1,531	1,352	1,274

[1]Includes industrial and laboratory chemicals, cosmetics, and pharmaceuticals.
[2]Includes other alloys and experimental uses.

TABLE 3

U.S. EXPORTS OF BISMUTH, BISMUTH ALLOYS, AND WASTE AND SCRAP, BY COUNTRY

Country	1989		1990	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Belgium	8,382	$14	—	—
Canada	15,554	263	36,882	$571
Chile	54	2	—	—
France	787	20	425	4
Germany, Federal Republic of	17,914	26	158	19
Hong Kong	18,696	10	2,331	17
India	300	2	—	—
Ireland	—	—	449	8
Israel	1,964	16	—	—
Italy	—	—	1,706	32
Japan	18,755	50	—	—
Korea, Republic of	50	6	108	8
Mexico	121	4	117	9
Singapore	220	11	2,217	26
Sri Lanka	100	4	—	—
Sweden	55	14	—	—
Switzerland	46	2	—	—
Taiwan	1,455	39	1,057	15
United Kingdom	37,278	55	76,227	169
Venezuela	440	4	—	—
Total	122,171	[1]540	121,677	878

[1]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

Production

ASARCO Incorporated was the only domestic producer of primary bismuth. Production of bismuth at the company's Omaha, NE, refinery increased slightly in 1990. Data are not published to avoid disclosing company proprietary data. Several firms recovered small quantities of bismuth from fusible alloys scrap. Secondary production data are not available.

Consumption and Uses

Domestic consumption of bismuth in 1990 dropped 6% from that of 1989. The largest decrease occurred in chemical and pharmaceutical uses, which fell 12% from that of 1989, due to weak demand for bismuth chemicals in the last half of the year. Increased production of free machining aluminum and steel caused the use of bismuth in metallurgical additives to rise 7% from that of 1989.

Markets and Prices

The domestic dealer price for bismuth decreased steadily from a high of $4.40 to $4.50 per pound in January to $2.80 to $2.90 per pound in September, where it remained until the end of the year. The drop was attributed to reduced demand and a plentiful supply of bismuth.

Foreign Trade

U.S. imports for consumption declined 14% from those of 1989 because of consumers using existing stocks to meet their orders and a decrease in bismuth chemical usage. U.S. imports from Belgium dropped 168 tons from those of 1989, but the country remained the largest supplier to the United States. Mexico and Peru were the second and third largest sources, respectively.

Bismuth articles, including waste and scrap (Harmonized Code 8106.00.0000) were imported free from most favored nations (MFN), but subject to a 7.5% ad valorem duty when imported from non-MFN.

World Review

Bismuth was recovered mainly as a byproduct of processing lead and copper ores. Only in Bolivia was bismuth produced as a primary product. Mexico and China were estimated to be the world leaders in mine production of refined bismuth for the fifth consecutive year.

Two Australian companies, Dragon Resources and Austmelt Pty., entered into a joint venture to recover bismuth, copper, and gold from stockpiled flue dust at the Mount Morgan smelter in Queensland, Australia. According to the companies, the 4,740-ton stockpile averages about 5% bismuth. The plant was expected to begin operation in March 1991 and process the entire amount in 7 months. The metals will be recovered using the Sirosmelt process, a method for treating high-value, small-tonnage resources invented by the Commonwealth Scientific and Industrial Research Organization of Australia and licensed to Austmelt. Pilot plant tests have recovered up to 99% of the contained bismuth from the copper flue dust.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF METALLIC BISMUTH, BY COUNTRY

Country	1989		1990	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Belgium	835,675	$9,722	668,071	$5,111
Bolivia	32,001	418	—	—
Canada	23,120	333	130,071	723
China	35,082	500	54,229	382
Germany, Federal Republic of	62,717	897	17,260	207
Hong Kong	700	10	—	—
Japan	1,068	543	339	236
Korea, Republic of	12,000	161	—	—
Mexico	390,815	4,028	404,821	2,471
Netherlands	6,161	115	—	—
Peru	271,444	2,379	262,705	2,095
United Kingdom	209,538	2,481	74,366	522
Total	1,880,321	[1]21,586	1,611,862	11,747

[1]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 5

WORLD ANNUAL BISMUTH PRODUCTION CAPACITY, DECEMBER 31, 1990

(Metric tons)

Country	Mine	Refinery
Australia	1,800	—
Belgium	—	1,100
Bolivia	700	300
Canada	700	300
China[e]	1,000	1,000
Germany, Federal Republic of[e]	—	400
Italy	—	100
Japan	700	1,200
Korea, Republic of	250	250
Mexico	1,100	1,000
Peru	900	800
Romania[e]	100	100
U.S.S.R.[e]	100	100
United Kingdom	—	400
United States	700	500
Yugoslavia[e]	150	150
World total	8,200	7,700

[e]Estimated.

TABLE 6

BISMUTH: WORLD MINE AND REFINERY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	Mine output, metal content					Refined metal				
	1986	1987	1988	1989	1990[e]	1986	1987	1988	1989	1990[e]
Australia[e]	1,000	350	400	r500	400	—	—	—	—	—
Belgium[e]	—	—	—	—	—	1,000	865	r1,000	r800	800
Bolivia	r45	1	13	r41	50	—	—	—	—	—
Canada[3]	153	165	181	164	165	212	218	225	272	280
China[e]	r500	r600	r750	r750	750	r500	r600	r750	r750	750
France	95	e90	e90	r e100	110	—	—	—	—	—
Germany, Federal Republic of	—	—	—	—	—	r e100	r e300	—	—	—
Italy	—	—	—	—	—	66	r43	32	r e30	30
Japan[4]	e190	e165	e160	e150	135	640	546	524	r502	450
Korea, Republic of[4]	e136	e145	r e132	r e96	90	136	145	r132	r96	90
Mexico[5]	r749	r1,012	r958	r883	750	r519	r561	r622	r597	475
Mozambique	(6)	—	—	—	—	—	—	—	—	—
Peru	605	412	r363	r687	585	569	387	r e340	r e650	550
Romania[e]	80	75	65	60	70	80	75	65	60	65
U.S.S.R.[e]	84	85	85	85	80	84	85	85	85	80
United Kingdom[e]	—	—	—	—	—	150	180	r300	r200	125
United States	W	W	W	W	W	W	W	W	W	W
Yugoslavia	e21	e73	23	r40	15	21	73	23	r40	15
Total	r3,658	r3,173	r3,220	r3,556	3,200	r4,077	r4,078	r4,098	r4,082	3,710

[e]Estimated. [P]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

[1]Table includes data available through Apr. 2, 1991. Bismuth is produced primarily as a byproduct of other metals, mostly lead, and only in Bolivia is it mined for itself.

[2]In addition to countries listed, Brazil, Bulgaria, Greece, and Namibia are believed to have mined and/or refined bismuth, but available information is inadequate for formulation of reliable estimates of output levels.

[3]Figures listed under mine output are reported in Canadian sources as production of refined metal and bullion plus recoverable bismuth content of exported concentrate.

[4]Mine output figures have been estimated based on reported metal output figures.

[5]Series revised to show data reported by Consejo de Recursos Minerales.

[6]Less than 1/2 unit.

The Geological Society of Japan revised the bismuth reserve totals for Japan from 57,000 tons to 8,745 tons.[1] The revision was based on an average bismuth content of 0.114% obtained from sampling ores at lead-zinc mines throughout the country. The highest percentages of bismuth were recorded in Kuruko and Skarn deposits, which have been the main source of lead and zinc production, from which bismuth is recovered as a by-product. The new reserve figure confirms reports that the bismuth content of ores in Japan has been declining over the past decade.

Current Research

Glaxo Pharmaceuticals of the United Kingdom patented a new drug, rantidine bismuth citrate, to treat ulcers.[2] The medication was expected to be used to heal duodenal ulcers linked to the Helicobater pylori bacterium. Unlike currently prescribed medications that only suppress the secretion of digestive acids, this new drug also will employ an antibiotic. The company plans to file for a license to manufacture the drug in 1993 or 1994, and the medication reportedly should be available in 1995.[3]

OUTLOOK

Although consumption of bismuth decreased, the outlook for the metal remains optimistic. Bismuth has the advantage of being nontoxic and a potential substitute for lead or cadmium in some metallurgical and pigment uses. Medicinal uses for bismuth are increasing, especially for treating ulcers. World production is still well below capacity and, with bismuth being sold from the NDS, supplies should remain sufficient well into the next century.

[1]Kouda, R., and S. Murao. The Bismuth Resource of Japan: a Modification. (Presented at Meeting for Researchers on Resources of A.I.S.T., Tsukuba, Japan, Nov. 12, 1990). Shigen Kenkyu Sogo Suishinkaigi News, No. 13, p. 9.

[2]Glaxo Group Limited, Ranitidine Derivatives. United Kingdom Pat. 2,220,937A, Jan. 24, 1990.

[3]Metal Bulletin. Bismuth Back in the Ulcer Business. No. 7512, Sept. 3, 1990, p. 13.

BORON

By Phyllis A. Lyday

Mrs. Lyday has covered boron for 12 years. Domestic survey data were prepared by Rosa McGee, mineral data assistant; and international data were prepared by Harold Willis, international data coordinator.

U.S. production and sales of boron minerals and chemicals increased during the year. Domestically, glass fiber insulation was the largest use for borates, followed by sales to distributors, textile-grade glass fibers, and borosilicate glasses.

California was the only domestic source of boron minerals. The United States continued to provide essentially all of its own supply while maintaining a strong position as a source of sodium borate products and boric acid exported to foreign markets.

Supplementary U.S. imports of Turkish calcium borate and calcium-sodium borate ores, borax, and boric acid, primarily for various glass uses, continued.

DOMESTIC DATA COVERAGE

Domestic data for boron are developed by the U.S. Bureau of Mines from two separate, voluntary surveys of U.S. operations. Of the three operations to which a sold and used survey request was sent, all responded, representing 100% of the total boron sold or used shown in tables 1 and 9. A Bureau canvass of the three U.S. producers also collected data on domestic consumption of boron minerals and compounds shown in tables 4 and 5.

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%.

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

TABLE 1

SALIENT STATISTICS OF BORON MINERALS AND COMPOUNDS

(Thousand metric tons and thousand dollars)

	1986	1987	1988	1989	1990
United States:					
Sold or used by producers:					
Quantity:					
Gross weight[1]	1,135	1,256	1,149	1,114	1,094
Boron oxide (B_2O_3) content	571	625	578	562	608
Value	$426,086	$475,092	$429,667	$429,806	$436,176
Exports:					
Boric acid:[2]					
Quantity	38	61	56	42	39
Value	$23,562	$34,180	$35,301	$32,613	$31,679
Sodium borates:					
Quantity[3]	566	552	546	646	585
Value[e]	$161,000	$243,600	$240,800	$361,000	$208,433
Imports for consumption:[4]					
Boric acid:					
Quantity	5	2	3	3	6
Value	$3,824	$2,900	$2,020	$2,197	$3,291
Colemanite:					
Quantity	15	7	17	15	12
Value	$8,770	$2,763	$7,790	$4,202	$3,310
Ulexite:					
Quantity	38	47	31	27	29
Value	$17,766	$20,597	$7,480	$1,552	$7,360
Consumption: Boron oxide (B_2O_3) content	307	335	356	315	319
World: Production	r2,511	r2,684	r2,924	r2,926	e2,906

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] Boron oxide (B_2O_3) content. In addition, borax imports from Turkey were 4,356 tons in 1987, 8,165 tons in 1988, 7,257 tons in 1989, and 5,162 tons in 1990.

TABLE 2

BORON MINERALS OF COMMERCIAL IMPORTANCE[1]

Mineral	Chemical composition	B_2O_3 weight percent
Boracite (stassfurite)	$Mg_6B_{14}O_{26}Cl_2$	62.2
Colemanite	$Ca_2B_6O_{11}\cdot 5H_2O$	50.8
Hydroboracite	$CaMgB_6O_{11}\cdot 6H_2O$	50.5
Kernite (rasorite)	$Na_2B_4O_7\cdot 4H_2O$	51.0
Priceite (pandermite)	$Ca_5B_{12}O_{23}\cdot 9H_2O$	49.8
Probertite (kramerite)	$NaCaB_5O_9$	49.6
Sassolite (natural boric acid)	H_3BO_3	56.4
Szaibelyite (ascharite)	$MgBO_2(OH)$	41.4
Tincal (natural borax)	$Na_2B_4O_7\cdot 10H_2O$	36.5
Tincalconite (mohavite)	$Na_2B_4O\cdot 5H_2O$	47.8
Ulexite (boronatrocalcite)	$NaCaB_5O_9\cdot 8H_2O$	43.0

[1] Parentheses include common names.

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 of compounds are diborane, a gas; pentaborane, a liquid; and decaborane, a solid. These compounds have been studied as fuels that range from 31,220 British thermal units (Btu) per pound for diborane to 27,850 Btu per pound for decaborane. Sodium borohydride is marketed in powder or pellet form and in sodium hydroxide solution.

Boron nitride, a soft, white, highly refractory solid resembling graphite, can withstand significant oxidation 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 22,600° C, is a highly refractory material and one of the hardest substances known. Most commonly used for both abrasive and abrasion-resistant applications as well as nuclear shielding, boron carbide is marketed in technical and high-purity grades.

Byproducts and Coproducts

More than four-fifths of the U.S. production comes from mineral deposits mined only for their boron content. The remainder is produced from lake brines, which also supply sodium carbonate, sodium sulfate, potassium sulfate, and potassium chloride. Turkish colemanite, ulexite, and tincal ores are worked only for their boron content. Most Soviet borates are also mined only for their boron content, but the Gulf of Kara-Bagaz-Gol and the Sivash (lagoon) borates are extracted with coproduct chloromagnesium from brines. South American boron has been mined from ores and also has been produced as a coproduct of nitrate and iodine production.

Economic Factors

Costs.—Energy costs are especially high for producing anhydrous products. The anhydrous products were originally introduced to decrease freight costs per ton of contained boron oxide. Both domestic producers now use cogeneration facilities to reduce the cost of energy for processing and supplying excess electricity for sale.

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 man and other mammals. 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. Ingestion in quantities greater than 20 grams by an adult can cause nausea and skin rashes.

Small quantities of boron are essential for all plant life. Boron is added in trace levels to fertilizers; however, quantities well below concentrations affecting man 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.

TABLE 3

TIME-PRICE RELATIONSHIPS FOR BORAX PENTAHYDRATE[1]

Year	Average annual U.S. producer price, dollars per metric ton
	Actual prices
1971	83
1972	83
1973	88
1974	108
1975	116
1976	121
1977	130
1978	141
1979	184
1980	186
1981	205
1982	222
1983	222
1984	229
1985	236
1986	243
1987	249
1988	249
1989	259
1990	249

[1] Borax pentahydrate, technical, granular, 99.5%, bulk, carlots, works.

ANNUAL REVIEW

Legislation and Government Programs

The Office of Foreign Availability (OFA), Department of Commerce, Bureau of Export Administration, requested comments in the October 23 issue of the Federal Register on the foreign availability of pyrolytic boron nitrite worldwide. On July 30, 1990, OFA accepted for filing a foreign availability submission relating to the decontrol of pyrolytic boron nitride crucibles, boats, furnace tubes, liner, and other specially designed shapes used in the manufacture of semiconductor devices and integrated circuits to controlled countries. The submission period for comments was to close November 23.

The desert tortoise was designated an endangered species by the Fish and Wildlife Service (FWS) of the U.S. Department of the Interior. About 500 plants and animals are now protected by the 1973 Act. By law, FWS looks only at scientific facts as to whether further pressure will lead to extinction.[1] The FWS cited habitat deterioration and loss, disease, and varied human uses of the desert as some of the principal threats facing the tortoise. Energy and mineral development were listed as one of the land uses affecting the tortoise. The listing extends long-term protection to tortoises living north and west of the Colorado River, including eastern California, southern Nevada, northwestern Arizona, and southwestern Utah. The areas listed include boron areas being surface mined and a solution-mining project area. Any change in land use in these areas require consultation with the FWS beforehand.

Congress continued discussion and debate over whether there should be changes to the Mining Law of 1872, better known as the General Mining Law. Sodium borate minerals, which are excluded from the law, are included under the Mineral Leasing Act of 1920, as amended and supplemented.

The Bureau continued two ongoing studies dealing with Federal land availability in the California Desert Conservation Area (CDCA). The CDCA contains all commercial domestic deposits of boron minerals and most of the known reserves. One Bureau study is site specific and the other deals with Federal land availability. The first study will examine in detail about 10 selected known deposits and active mines in the CDCA. In the second study, the Bureau will show how Federal land practices and withdrawals affect known mineral deposit areas in the CDCA.[2]

The U.S. Bureau of Mines, Division of Policy Analysis, completed an investigation of the East Mojave National Scenic Area, CA. The report was available as a Mineral Land Assessment open file in two volumes from the U.S. Bureau of Mines. Volume one is resource information, and volume two is related economics.

The Bureau of Land Management issued a new policy that mandates reclamation bonding on all mining and exploration plans of operation involving 5 acres or more of land. The policy applies for all new operations.[3]

A $9 million plan to develop maglev systems was introduced into Congress as part of the U.S. Department of Transportation budget. Maglev transportation systems consist of a train-like vehicle riding several inches above a metal guideway on a magnetic field at speeds of up to 400 miles per hour. Currently, there are proposed systems connecting southern California with Las Vegas, NV, and a local system in Las Vegas that uses boron magnets.[4]

Production

The majority of the boron production continued to be from Kern County, with the balance from San Bernardino and Inyo Counties, CA.

American Borate Co., a wholly owned subsidiary of Owens-Corning Fiberglas Corp., continued sales of ulexite from storage at Dunn, CA.

Kerr-McGee Chemical Corp. operated the Trona and Westend plants at Searles Lake, in San Bernardino County, to produce refined sodium borate compounds and boric acid from the mineral-rich lake brines. At the Trona plant, a differential evaporative process produced borax with potash as a byproduct. Boric acid was produced by solvent extraction. The Westend plant continued production of sodium borates by a carbonation process. Brines used in the process were pumped to the Argus plant to produce sodium sulfate.

At yearend, three chemical processing facilities, of which two produce boron compounds, and the Trona Railway were sold for $210 million to an investment group led by D. George Harris & Associates. The organization will be known as North American Chemical Co. with a base of operations in Kansas City, MO. The investment group includes Oriental Chemical Industries of Korea and Chase Manhattan Investment Holdings Inc. Oriental Chemical will represent North American for certain product lines sold in the Far East.

United States Borax & Chemical Corp., a part of Borax Consolidated Ltd. of the RTZ Corp. PLC of London, United Kingdom, continued to be the primary world supplier of sodium borates.

U.S. Borax mined and processed crude and refined sodium borates, their anhydrous derivatives, and anhydrous boric acid at Boron, in Kern County, CA. A second plant at Boron used a proprietary process to produce technical-grade boric acid from extensive kernite ore reserves. The boric acid was produced to compete with imported colemanite used in glass manufacture. In addition, colemanite was mined at Shoshone, in Inyo County, CA.

The majority of material was shipped to Wilmington, CA. Products made at a plant in Wilmington included ammonium borates, potassium borates, sodium metaborates, and zinc borate. Corona Corp. continued ownership of the Fort Cady Minerals Corp., but construction of a boric acid plant was delayed by environmental assessment studies of mining and reclamation plans that were necessary to receive permits. The agreement between Corona and Avalon Corp. to acquire the Fort Cady Minerals Corp. was terminated.[5]

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 dimensionally 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 composites the material of choice for a variety of aerospace applications.

In advance composites, carbon, higher module glasses, and aramid fibers account for about 95% of the market; glass accounts for about 20% of the market. At $200 to $500 per pound, less than 1% of the market is specialty fibers, such as boron, silicon carbide, and quartz. In advanced composites, fibers generally make up 60% of the material by volume.[6]

The Bradley Fighting Vehicle is a new fiberglass composite weapon that faced combat for the first time in the Persian Gulf. Because of an invasion of Kuwait by Iraqi forces, troops and equipment, including the Bradley, were transported to Saudi Arabia. The Bradley is produced by FMC Corp. at San Jose, CA, for the U.S. Army. More than 5,249 Bradleys were delivered by yearend.[7]

Consumption of borates in borosilicate glasses remained the third major end use, and demand decreased. Boron added to glass reduced the viscosity of the melt, assisted with fiber formation during processing, and allowed for thermal expansion of the product.

Boron compounds in cleaning and bleaching were the fourth major end use. Oxygen systems, such as peroxygens, including perborates, may replace chlorine-base bleach systems because they are less harsh on fabric. Demand for monohydrate was reported to have doubled between 1987 and 1989. Sodium perborate is a solid peroxygen bleach used in powder detergents. Consumption of the monohydrate was reported to be in excess of 40,000 tons during 1990.[8] E. I. du Pont de Nemours & Co. Inc. planned to become the first domestic producer of a solid peroxygen bleaching chemical. The plant, in Memphis, TN, planned to be operational during 1991.[9] Interox America announced the construction of a 45-million-pound monohydrate plant at Deer Park, TX. The planned startup date was to be early in 1992.

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 or incorporated in herbicides, fertilizers, and irrigation water. Commercial Fertilizers magazine reported that total fertilizer consumed between June 30, 1989, and June 30, 1990, as boron compounds amounted to about 7,000 tons used in five regions. Only a small amount of boron is required on alfalfa, clover, and vegetables to promote optimum growth and yields.[10]

Boron compounds were also used in metallurgical processes as fluxes, shielding slag in the nonferrous metallurgical industry, and components in electroplating baths. Small amounts of boron and ferroboron were constituents of certain nonferrous alloys and specialty steels, respectively.

Boron carbide and boron nitride are two exclusively manufactured materials synthesized by the reaction of boron oxide with other materials.[11] These products are consumed as abrasives, cutting tips, blasting nozzles, nuclear control rods, and various other uses. A market study by Mitchell Market Reports of Gwent, United Kingdom, contained approximately 300 companies in 20 countries that produce, use, or consume boron carbide and boron nitride.

SB Chemical Ltd., a refiner and manufacturer of elemental boron in Franklin Park, IL, changed names to SB Boron Corp. The company is the sole producer of elemental amorphous boron powder in 90% to 92% (pyrotechnic) and 95% to 97% (aerospace) grades.[12]

Prices

Prices for anhydrous-, pentahydrate-, and decahydrate borax and technical boric acid remained essentially at 1989 levels. Other prices, including high-purity boric acid and colemanite, increased.

Foreign Trade

The majority of material from the U.S. Borax facility in Boron was shipped to storage, loading, and ship-

TABLE 4

U.S. CONSUMPTION OF BORON MINERALS AND COMPOUNDS, BY END USE[1]

(Metric tons of boron oxide content)

End use	1989	1990
Agriculture	14,583	5,787
Borosilicate glasses	30,600	27,905
Enamels, frits, glazes	8,149	7,882
Fire retardants:		
Cellulosic insulation	11,920	11,741
Other	509	1,401
Glass-fiber insulation	91,736	95,059
Metallurgy	3,040	2,554
Miscellaneous uses	14,729	14,586
Nuclear applications	611	546
Soaps and detergents	25,145	24,230
Sold to distributors, end use unknown	73,460	71,670
Textile-grade glass fibers	40,499	55,698
Total	314,981	319,059

[1] Includes imports of borax, boric acid, colemanite, and ulexite.

TABLE 5

U.S. CONSUMPTION OF ORTHOBORIC ACID, BY END USE[1]

(Metric tons of boron oxide content)

End use	1989	1990
Agriculture	231	108
Borosilicate glasses	4,862	4,920
Enamels, frits, glazes	1,383	1,013
Fire retardants:		
Cellulosic insulation	1,683	1,647
Other	509	1,401
Insulation-grade glass fibers	1,081	1,682
Metallurgy	278	393
Miscellaneous uses	9,779	8,948
Nuclear applications	494	544
Soaps and detergents	57	50
Sold to distributors, end use unknown	23,379	24,204
Textile-grade glass fibers	22,493	19,482
Total	66,229	64,392

[1] Includes imports.

ping facilities at Wilmington, CA. A large part of output was exported to Western Europe from Wilmington to Botlek, Netherlands.

World Review

Capacity.—The data in table 9 are rated capacity for mines and refineries as of December 31, 1990. Mine capacity for boron was based on rated capacity as reported by the company, by another government agency, or another published source. Capacity outside of the United States was limited by the availability of loading and transportation equipment and market demand rather than limitations of ore grade.

Argentina.—Boroquimica S.A.M.I.C.A.F., a subsidiary of RTZ, continued production of tincal and boric acid from a deposit at Tincalayu, Salta Province.

Belgium.—Degussa Corp. planned to add sodium perborate monohydrate capacity at its Antwerp, Belgium, facility while hydrogen peroxide capacity is expanded. Degussa now makes perborate tetrahydrate, which is used in solid detergents. The trend in Europe is toward liquid detergents using the monohydrate.[13]

Bolivia.—Beginning in August 1987, the United Nations Development Program (UNDP) provided considerable assistance to Bolivia in the assessment of nonmetallic resources. A U.N. Revolving Fund of $1.3 million drilling program began to investigate the economic potential of known and possible mineral resources in Bolivia. Lithium Corp. of America (Lithco) signed a preliminary contract November 17, 1989, for development of Salar de Uyuni, which is reported to contain the world's richest reserves of lithium salts and 3.2 million tons of boron minerals. On May 4, the $46 million contact with Lithco was canceled, and the project was opened for international bidding.[14] During 1989, the Government reported that 10,000 metric tons of ulexite was exported.[15]

Chile.—At yearend, AMAX Exploration Inc. was seeking partners to purchase its 65.5% stake in the Sociedad Minera Salar de Atacama Ltda. (Minsal) project. The feasibility study included the development of a 22,000-ton-per-year boric acid plant at the Salar de Atacama. The salar is one of about 74 arid salt basins in the Chile-Bolivia-Argentina border region. At capacity, the project will also produce 533,000 tons per year of potassium chloride, 276,000 tons of potassium sulfate, up to 35 million pounds of lithium carbonate, and 5 million pounds of lithium hydroxides. The availability of more than 1 million tons per year of sulfuric acid from the Chiquicamat copper smelter will enhance the economic viability of the project.[16]

In 1988, production of ulexite and boric acid was estimated at 35,000 tons per year from salt deposits in the north. Quimica e Industrial del Borax Ltda. (Quiborax) is the main producer of boric acid and concentrated ulexite. Minera del Boro, Minera Ascotan, and Boroquimica are smaller local producers. Quiborax and Minera del Boro planned capacity increases. By 1994, Minsal planned to have completed a boric acid expansion of 18,000 tons per year.[17]

France.—Atochem Inc., a member of the Elf Aquitaine Group, planned a 13,000-ton-per-year sodium perborate monohydrate plant at Pierre Benite, near Lyon, to be operational in 1991.[18] The company already operates a 48,000-ton-per-year plant at the same location for sodium perborate tetrahydrate, the starting material for the monohydrate form. Both hydrates are used as whitening additives in domestic detergents.[19] Atochem has also announced plans to build a monohydrate plant at Warrington, United Kingdom, and convert production from tetrahydrate to monohydrate at sites in Belgium, the Federal Republic of Germany, and Italy.[20]

Cie. de St. Gobain signed an agreement to acquire Norton Co. of Worcester, MA, a producer of boron carbide. St. Gobain is a leading producer of glass products and owns CetainTeed Corp.[21]

India.—The Ministry of Agriculture brought boron-enriched single superphosphate (SSP) under the Fertilizer Control Order to ensure greater benefits and better quality fertilizer in micronutrient-deficient areas. Dharamsi Morarji Chemicals has been asked to resume the production of boron-enriched SSP, a slow-release fertilizer. Maharastra and Gujarat Pradeshes are under intense cotton cultivation and suffer from boron deficiency.[22]

TABLE 6

YEAREND 1990 PRICES FOR BORON MINERALS AND COMPOUNDS[1]

(Per metric ton)

Product	Price, December 31, 1990 (rounded dollars)
Borax, technical, anhydrous, 99%, bulk, carload, works[2]	719
Borax, technical, anhydrous, 99%, bags, carload, works[2]	761–769
Borax, technical, granular, decahydrate, 99.5%, bags, carload, works[2]	285–418
Borax, technical, granular, decahydrate, 99.5%, bulk, carload, works[2]	236
Borax, technical, granular, pentahydrate, 99.5%, bags, carload, works[2]	321
Borax, technical, granular, pentahydrate, 99.5%, bulk, carload, works[2]	272
Boric acid, technical, granular, 99.9%, bags, carload, works[2]	775–784
Boric acid, technical, granular, 99.9%, bulk, carload, works[2]	725–726
Boric acid, United States Borax & Chemical Corp., high-purity anhydrous, 99% B_2O_3, 100-pound bags, carlot	2,849
Colemanite, Turkish, 40% to 42% B_2O_3, ground to a minus 70-mesh, f.o.b. railcars, Kings Creek, SC[3]	507
Ulexite, Turkish, 37% B_2O_3, ground to a minus 100-Mesh, f.o.b railcars, Norfolk, VA.[3]	230

[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. 238, No. 27, Dec. 1990, p. 25.
[3] American Borates Co.

Peru.—Throughout 1989, all companies in the mining sector, regardless of size, faced the problems brought on by high inflation and an unfavorable exchange rate. High interest rates and payroll increases led the rise in local costs, while the rise in revenues lagged behind costs because the depreciation of the currency failed to keep pace with inflation. The exchange rate applied to exporters, including miners, meant export receipts were exchanged at an average of only 74% of the free market exchange rate. Labor problems were less significant to production than in 1988, although terrorists increased their activities, causing loss of lives and important material damages.[23]

Taiwan.—PPG Industries Inc. jointly owns a 20,000-ton-per-year fiberglass plant operated by PFG Fibre Glass Corp. in a joint venture with Nan Ya Plastics, a business of Formosa Plastics Group.[24]

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.—Pilkington Special Glass Ltd. closed a special glass plant producing nuclear shielding and electronics in St. Asaph, Clwyd, North Wales, with the loss of 140 jobs. The operation will continue to employ 190 people who manufacture high index ophthalmic and photochromic glass blanks using boron.[25]

Venezuela.—PPG Industries Inc. (49%), Pittsburgh, PA, and the Sudamtex Group of Caracas began operation of a plant to produce continuous strand fiberglass at Barcelona operated by the Sudamtex subsidiary VFG-Sudamtex (51%). The company is the only fiberglass producer in the Andean Pact countries (Bolivia, Colombia, Ecuador, Peru, and Venezuela).[26]

TABLE 7

U.S. EXPORTS OF BORIC ACID AND REFINED SODIUM BORATE COMPOUNDS, BY COUNTRY

Country	1989			1990		
	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)	
Argentina	—	—	2			
Australia	1,338	$982	8,271	967	$729	7,401
Bangladish	—	—	168	—	—	32
Belgium-Luxembourg	—	—	1,290	—	—	425
Brazil	141	133	2,831	113	89	2,126
Canada	4,822	2,927	50,966	5,682	3,500	41,929
Chile	1	2	1,310	—	—	
China	—	—	8	—	—	175
Colombia	237	132	1,241	137	109	3,837
Costa Rica	17	15	90	—	—	2,593
Dominican Republic	128	20	37	374	203	11
Ecuador	—	—	847	—	—	1,119
Egypt	—	—	1,380	—	—	
El Salvador	—	—	5	—	—	24
Finland	—	—	—	244	144	199
France	—	—	222	88	44	1,224
Germany, Federal Republic of	313	138	12	119	88	92
Guatemala	28	17	39	1,466	562	82
Haiti	20	2	130	—	—	224
Honduras	—	—	82	46	16	41
Hong Kong	270	199	3,536	253	263	2,984
India	26	10	6,593	—	—	
Indonesia	380	279	5,681	256	205	7,450
Israel	87	65	168	104	93	290
Jamaica	3	6	5	2	6	10
Japan	20,270	15,512	46,593	15,999	12,875	39,064
Korea, Republic of	1,863	1,563	15,651	1,472	1,238	19,200
Malaysia	56	48	5,645	154	113	7,268
Mexico	2,662	1,824	23,187	2,282	1,622	24,531
Netherlands	3,647	4,620	404,474	4,382	5,823	349,968
New Zealand	1,363	857	2,817	485	350	3,040
Pakistan	—	—	152	—	—	409
Panama	24	14	28	2	8	79
Papua New Guinea	32	24	32	—	—	80
Peru	57	22	92	3	3	18
Philippines	135	108	1,933	—	—	2,075
Romania	—	—	—	—	—	
Saudi Arabia	42	30	389	31	44	22
Singapore	62	40	1,507	261	195	1,920
South Africa, Republic of	65	58	1,751	47	52	1,762
Spain	—	—	35,642	202	126	43,345
Sri Lanka	9	7	16	—	—	
Taiwan	3,082	2,332	17,561	2,962	2,390	15,291
Thailand	400	329	2,267	544	457	2,380

See footnotes at end of table.

TABLE 7—Continued

U.S. EXPORTS OF BORIC ACID AND REFINED SODIUM BORATE COMPOUNDS, BY COUNTRY

Country	1989			1990		
	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)	
Trinidad and Tobago	—	—	2	—	—	6
United Kingdom	27	$48	181	211	$120	1,171
Uruguay	5	4	8	7	6	5
Venezuela	336	241	704	152	128	469
Zimbabwe	—	—	16	—	—	49
Other	5	4	35	91	78	535
Total[3]	41,953	32,613	645,597	39,138	31,679	584,960

[1] Bureau of the Census: Harmonized Code 2440.11
[2] Bureau of the Census: Harmonized Codes 2840.19, 2840.30, and 2840.20.
[3] Data may not add to totals shown because of independent rounding.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF BORIC ACID, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Brazil	—	—	20	$15
Canada	7	$5	38	52
Chile	1,084	492	2,487	1,208
France	7	11	55	36
Germany, Federal Republic of	19	37	4	4
Italy	1,627	1,471	2,841	2,397
Japan	35	82	88	159
Netherlands	65	42	—	—
Taiwan	1	1	—	—
United Kingdom	53	56	25	50
Total	2,898	2,197	5,558	3,921

[1] U.S Customs declared values.

Source: Bureau of the Census.

Current Research

Traditional ceramics are solids that are stable in temperatures as high as 1,000° C. Advanced ceramics such as boron carbide-aluminum are being developed that are stable at temperatures to 1,500° C or higher. Superconducting material in complex shapes is made by crystallizing material from a previously formed glass. Carefully controlled heating converts this glass to a crystalline ceramic. A combination of metal oxides useful in superconductors can be melted into a glass without adding glass-forming compounds, such as silica or boric oxide, that would dilute the superconductivity of the crystalline ceramic. The boron carbide-aluminum ceramic-metal (cermet) composite combines the toughness of aluminum and the strength of boron carbide ceramic in a single material. Boron carbide powder is sintered at 2,000° C into solid boron carbide sponge and filled with molten aluminum at 1,100° C. The process produces a fully dense, boron carbide-aluminum cermet free of unfilled spaces where cracks could originated.[27]

A plastic composite wheel for cars manufactured using fiberglass-reinforced compounds won the Society of Plastics Engineers' top automotive award. The wheel was developed by Motor Wheel and manufactured by the Goodyear Tire & Rubber Co. The new wheel is 2 to 3 pounds lighter than aluminum wheels and does not corrode.[28]

PPG developed a new fiberglass product for reinforcement applications that creates a surface as smooth as preform molded parts, but at lower costs. The process was available for licensing.[29]

A soccer ball shaped "buckyball" contains 60 carbon atom molecules of the fullerene motif, which are molecules that contain an even number of atoms arranged in closed, hollow cages. Fullerenes have exhibited superconductive properties that are high when compared to other organic superconducting systems. A laser was used to vaporize graphite impregnated with boron nitride and trap the products in macroscopic shapes known as "dopyballs."[30]

Boron 10, a stable isotope of boron, can be concentrated in tumor cells and bombarded with short-range radiation to destroy cancer cells. Developments in boron compounds show marked effectiveness in treating brain tumors. The

TABLE 9

WORLD BORON ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990, RATED CAPACITY[1]

(Thousand metric tons of boron oxide content)

Country	Capacity
North America: United States	735
South America:	
Argentina	28
Chile	5
Peru[e]	5
Total	38
Europe: U.S.S.R.[e]	41
Asia:	
China[e]	5
Turkey	560
Total	565
World total[2]	1,380

[e] Estimated.
[1] Includes capacity at operating plants as well as plants on standby basis.
[2] Data do not add to total shown because of independent rounding.

TABLE 10

BORON MINERALS: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1986	1987	1988	1989	1990[e]
Argentina	192	185	[r]270	[r]261	260
Chile	6	13	32	[r]131	132
China[e]	27	27	27	27	27
Peru[e]	23	23	[e]15	[e]18	18
Turkey	928	[r]980	[r]1,231	[r]1,175	1,200
U.S.S.R.[e]	200	200	200	200	175
United States[2]	1,135	1,256	1,149	[3]1,114	[3]1,094
Total	2,511	[r]2,684	[r]2,924	[r]2,926	2,906

[e]Estimated. [r]Revised.

[1]Tables includes data available through May 14, 1991.

[2]Minerals and compounds sold or used by producers, including both actual mine production and marketable products.

[3]Reported figure.

treatment of malignant melanoma, a pigmented form of skin cancer, is under study. Boron neutron capture therapy may be extended to cancers that respond poorly to current treatment.[31]

OUTLOOK

Production and consumption of boron minerals and compounds have decreased between 1981 and 1990. There are several factors that may lead to misleading outlooks in consumption. One is that production and imports reported in one year may be utilized during a period of years. In addition, environmental concerns may change the demand for boron significantly in a short period. The regulation of fire retardants in products have resulted in changes in boron usage as a fire retardant.

Agriculture

Boron usage in agriculture reached a low in 1982 and has continued to declined. 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 was expected to increase to 20,000 short tons of boron oxide content.

Ceramics and Glass

Boron usage increased during 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. In 1990, the U.S. fiberglass industry was reported to be feeling the effects of recessionary pressures. The sagging economy produced a decline in demand for fiberglass reinforcements that was expected to be long term. Fiberglass is closely related to construction and transportation, which continue to be depressed. The fiberglass reinforcements industry that represents 17% of the total composites market forecasts a 6% decline in its construction market for 1991.[32]

Coatings and Plating

Primarily used as a protective coating for steel products and as a glazing on ceramic tiles, usage has experienced a decline. This decline was a result of the demand for polymers that replace many of the coatings and plating uses. Demand was expected to remain at 1990 levels.

Fabricated Metal Products

Boron usage decreased in metal products during the past decade. Many traditional metal products that require soldering now are produced from polymers as one piece. Usage in specialized metal was expected to increase at the rate of 2% per year.

Soaps and Detergents

This usage declined primarily because chlorine bleaches and cold water washes replace boron soap powders. Recent concern for environmental effects of chlorine may reverse the decline. Perborate bleaches have returned to name brand soap products. The usage of boron in soaps and bleaches was expected to increase by 4% per year during the next 5 years.

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BROMINE

By Phyllis A. Lyday

Mrs. Lyday, a physical scientist with the U.S. Bureau of Mines, has been the commodity specialist for bromine for 12 years. Domestic survey data were prepared by Gail Mason, mineral data assistant; and international data tables were prepared by William Zajac, Chief, Section of International Data.

Production of bromine worldwide in 1990 was as follows: the United States, 40%; Israel, 31%; the U.S.S.R., 14%; the United Kingdom, 6%; and other countries, 9%. 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. The quantity of bromine sold or used in the United States was about 177 million kilograms valued at $173 million based on the average actual price for 1990. Exports of elemental bromine and bromine contained in compounds amounted to 17 million kilograms. The price of elemental bromine in bulk was 95 to 101 cents per kilogram. Primary uses of bromine compounds were in flame retardants (28%), agriculture (20%), petroleum additives (14%), well drilling fluids (11%), and other (27%).

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, two responded, representing 41% of total elemental bromine sold or used. Production at the other four operations was estimated by using quantity of brine produced and estimated bromine concentration.

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. The specification for this grade is as follows: 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 water are processed to obtain the bromine.

Arkansas brines contain about 5,000 ppm at depths of 7,500 feet in limestone of the Smackover Formation of Jurassic age. In Michigan, brines containing about 2,600 ppm of bromine occur in the Sylvania Sandstone Formation of the Detroit River Group of Devonian age.

In Israel, bromine is produced from Dead Sea brines as a byproduct of salt, magnesium oxide, and potash production. The waste brines contain 14,000 ppm bromine.

Technology

The Arkansas Geological Commission report three east-west bromine-rich brine fields. Wells are drilled down to the brine level, and a submersible pump is lowered to pump the liquid to the surface. Brine is separated by gravity from any residual gas at the surface and pumped to one of six processing facilities.

At the processing facility, bromine is separated from the brine by a steaming-out process. The brine is pumped into the top of a tower constructed of granite and filled with ceramic packing. As the brine falls through the packing material, it reacts with chlorine and steam that are injected at the bottom of the tower. One pound of chlorine yields 1 kilogram 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 bromine condenses to a reddish-brown liquid that separates from the condensed water vapor because of its heavier density. 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 was drawn into the base of the tower and rises as the brine descends. Air

TABLE 1

SALIENT BROMINE AND BROMINE COMPOUND STATISTICS

(Thousand kilograms unless otherwise specified)

		1986	1987	1988	1989	1990
United States:						
Bromine sold or used:[1]						
Quantity		141,000	152,000	163,000	175,000	177,000
Value	thousands	$93,000	$107,000	$144,000	$188,650	$173,000
Exports:						
Elemental bromine:						
Quantity		[2]8,119	[2]3,348	[2]4,328	3,557	2,932
Value	thousands	[2]$8,170	[2]$3,526	[2]$3,379	$3,165	$4,008
Bromine compounds:[3]						
Gross weight		12,701	21,908	13,925	35,914	17,094
Contained bromine		10,433	18,643	11,839	28,998	14,443
Value	thousands	$23,900	$18,000	$13,000	$24,093	$18,166
Imports:[2]						
Elemental bromine:						
Quantity		155	248	257	460	756
Value	thousands	$87	$166	$194	$293	$508
Compounds:						
Ammonium bromide:						
Gross weight		2,595	2,243	1,660	2,402	1,526
Contained bromine		2,117	1,830	1,354	1,960	1,245
Value	thousands	$2,994	$2,257	$2,180	$3,471	$2,399
Calcium bromide:						
Gross weight		2,820	3,663	4,286	7,770	11,634
Contained bromine		2,255	2,929	3,427	6,212	9,301
Value	thousands	$741	$833	$1,360	$3,231	$5,236
Potassium bromate:						
Gross weight		291	1,389	4,161	2,314	2,096
Contained bromine		139	665	1,991	1,107	1,003
Value	thousands	$669	$849	$1,107	$3,401	$3,305
Potassium bromide:						
Gross weight		316	866	848	590	593
Contained bromine		212	581	569	395	461
Value	thousands	$486	$1,122	$1,278	$985	$1,028
Sodium bromide:						
Gross weight		212	657	1,925	1,369	1,630
Contained bromine		165	510	1,495	1,063	1,266
Value	thousands	$217	$507	$1,936	$1,922	$2,130
Other:						
Gross weight		4,587	8,294	32,892	28,005	11,591
Contained bromine		3,631	3,762	14,919	19,787	7,083
Value	thousands	$4,627	$13,669	$35,531	$42,589	$50,414
World: Production		375,059	391,116	[r]410,920	[r]442,479	[e]438,000

[e]Estimated. [r]Revised.
[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.

containing bromine passes to the absorption tower. In the absorption tower, bromine reacts with sulfur dioxide and water to form hydrogen bromide and sulfuric acid. The bromine is separated by adding acid to the solution and is distilled by steam. The acid is recycled to acidify the incoming seawater. The gaseous bromine is condensed, separated, and purified. The air-blowing process can also be used to produce an alkali bromide by changing the absorption medium. For instance, using sodium carbonate produces sodium bromide and sodium bromate. The sodium bromate may be recrystallized from solution or reduced with iron to sodium bromide.

Substitutes

Brominated hydrocarbons are used in refrigerant units. Helium could replace a large segment of the chlorofluorocarbon (CFC) market in refrigeration with commercial development of the Stirling cycle engine. Development and testing on a helium refrigeration system is underway that uses less energy than current refrigeration systems.[1]

Economic Factors

Costs.—Chlorine is the largest cost factor, representing 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 1990, 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 is subject to Superfund taxes of $4.45 per ton. Bromine is manufactured using chlorine, which is also subject to a Superfund tax of $2.70 per ton of chlorine.

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

Environmental Requirements.—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. Hydrogen sulfide gas is chemically removed from the incoming brine and converted into elemental sulfur or other nontoxic sulfur-containing compounds.

TABLE 2

TIME-PRICE RELATIONSHIPS FOR BROMINE

Year	Average annual U.S. producer price, cents per kilogram	
	Actual prices	Based on constant 1990 dollars
1971	38.2	113
1972	36.3	103
1973	35.4	94
1974	60.0	146
1975	61.0	135
1976	49.4	103
1977	47.7	93
1978	46.8	85
1979	48.6	81
1980	54.8	84
1981	48.6	68
1982	59.5	78
1983	59.5	75
1984	74.4	91
1985	74.4	88
1986	74.4	86
1987	77.2	86
1988	98.1	106
1989	98.1	102
1990[e]	98.1	98

[e]Estimated.

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 leak proof containers to avoid personal injury. If bromine spills on paper, rags, wood shaving, etc., it will generate considerable heat, which may lead to spontaneous combustion. Bromine reacts with living tissue and must be removed immediately to avoid serious injury.

Bromine vapors are hazardous to the eyes and lungs. Any concentration above 1 ppm in the air for an 8-hour exposure is considered a health hazard. Bromine can be detected by its odor even at this level. Exposure to concentrations of 500 to 1,000 ppm for as little as one-half hour is lethal. The Occupational Safety and Health Administration regulates the working conditions of bromine plants.

When handling bromine, a person should use safety goggles, face shield, rubber gloves, rubber boots, and under some conditions, a self-contained breathing apparatus. Bromine spills are neutralized with a solution of sodium thiosulfate. Gaseous bromine is neutralized with controlled amounts of gaseous ammonia. Electrical switches and connections that may be exposed to bromine vapors should be made of corrosion resistant materials and/or completely sealed from contact with the room air.

Employment.—The U.S. bromine chemical industry employs directly an average of 20 personnel for each $1 million of sales. These employees work in production, packaging, transportation, marketing, product and process development, quality control, and administration. More than two-thirds of these jobs are concentrated in Union and Columbia Counties of south Arkansas.

Energy Requirements.—Approximately 14% of the bromine manufacturing cost is energy related. The manufacturing cost of bromine is heavily dependent on chlorine and brine cost. Of the total brine cost, 46% is power related, 53% is maintenance cost, and 19% is other costs. Brine cost is dependent on well maintenance cost and energy cost associated with well pumping.

Transportation.—The Research and Special Programs Administration (RSPA), U.S. Department of Transportation, published final rules for hazardous substances (49 CFR Parts 171 and 172). The action complies with a 1986 amendment (Public Law 99-499) to section 306(a) of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 (Public Law 96-510). The law mandates that RSPA regulate all Environmental Protection Agency (EPA) designated hazardous substances. The amendment requires shippers and carriers to identify CERCLA hazardous substances, to comply with the Hazardous Materials Regulations, and to make the required notifications if a discharge of a hazardous substance occurs. The effective date of the amendment was December 31, 1990.

ANNUAL REVIEW

Legislation and Government Programs

The EPA concluded that, on the basis of available information, hazards of using brominated flame retardants do not yet warrant regulatory action. Tests performed for the Brominated Fire Retardant Industry Panel and the EPA require extraordinary conditions to produce trace amounts of dibenzofuran, identified as a carcinogen.[2]

A final amendment to the final rule was published by the EPA in the Federal Register February 13, 1990, that amends 40 CFR part 82. The notice amends the Montreal Protocol on Substances that Deplete the Ozone Layer, a treaty to limit the production and consumption of CFC's and halons that included brominated CFC's.

A section 18 exemption was granted by the EPA to the U.S. Department of Agriculture (USDA) for the use of methyl bromide to control oak wilt on oak logs for export.[3] The Governor of the Territory of Guam also received a section 18 quarantine exemption for methyl bromide to control various plant pests on cut flowers and greenery imported from Hawaii and the continental United States. The USDA received a methyl bromide exemption to control various plant pests on imported oranges.[4] The EPA granted the Arkansas State Plant Board, the Mississippi Department of Agriculture and Commerce, and the Louisiana Agriculture Department a section 18 exemption for the use of bromoxynil to control certain weeds in rice growing within 1/4 mile of cotton or soybean fields.[5]

At yearend, 47 petitions and EPA proposals to exempt residues from tolerance requirements were pending, including three for bromoxynil and one for inorganic bromides.[6]

Ethyl Corp. filed with the U.S. Court of Appeals for the D.C. Circuit to stop a final rule issued by the EPA for methyl bromide. Ethyl contends that it does not generate waste because the material is not discarded but recycled, and that wastes from the production facility do not contain hazardous constituents.[7]

EPA assembled a list to use in completing the "Notification of Hazardous Waste Activity," Form 8700-12. Hydrobromic acid is included under EPA Hazardous Waste Number D002 published in the Federal Register April 18, 1990. A complete description of corrosive wastes can be found in 40 CFR 261.22.

The Consumer Product Safety Commission listed in the Federal Register, December 18, 1990, requirements for child-resistant packaging for home cold wave permanent neutralizers containing sodium bromate or potassium bromate. Eight cases of accidental ingestion of bromate were reported since 1984. The Commission concluded that permanent wave products containing more than 50 milligrams of potassium bromate or 500 milligrams of sodium bromate should be subject to child-resistant packaging standards.

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 1990 and 100% of bromine sold or used. Plant capacity was dependent on brine supplies, concentration of the bromine in the brine, and individual plant extraction processes. In Arkansas, one supply and one disposal well were required for each 4.5 million kilograms 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.

Consumption and Uses

Fire retardants were primarily tetrabromobisphenol-A and decabromodiphenyl oxide. The U.S. International Trade Commission's (ITC) publication "Synthetic Organic Chemicals, 1990" listed Ethyl Corp. as the only producer of hexabromocyclododecane. Sales of flame retardants account for one-half the worldwide plastic additives market and are growing. Brominated hydrocarbons are the major materials used to make flame retardants.

Suppliers of flame-retardant polymers continue to develop alternatives for brominated compounds. FMC Corp. planned a high-efficiency brominated phosphate-ester flame retardant for engineering plastics and alloys. The combination of phosphorus and bromine produce a product characterized by high molecular weight and low volatility.[8]

A bromine salt derived from pyridine has several advantages over the corresponding pyridine reagent because of ease in preparation of high yields, stability and ease of handling, utilization on a commercial scale, and ease of separation from the product stream for recycling. Fibers and cords prepared using organic bromides exhibit a high resistance to thermal degradation.[9]

TABLE 3

BROMINE-PRODUCING PLANTS IN THE UNITED STATES IN 1990

State and company	County	Plant	Production source	Elemental bromine plant capacity[1] (million kilograms)
Arkansas:				
Arkansas Chemicals Inc.	Union	El Dorado	Well brines	23
Ethyl Corp.	Columbia	Magnolia	do.	50
Do.	do.	do.	do.	73
Great Lakes Chemical Corp.	Union	El Dorado	do.	48
Do.	do.	Marysville	do.	36
Do.	do.	El Dorado	do.	23
Michigan:				
The Dow Chemical Co.	Mason	Ludington	do.	[2]9
Total				[3]261

[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.

Agricultural usage is primarily as methyl bromide used in soil fumigation. During 1990, alternative agriculture became topical. Farmers practicing alternative agriculture aim at improving profits, limiting dependence on agricultural chemicals, and increasing use of environmentally friendly procedures. Several factors occurring during the 1980's have induced alternative agriculture. Farmers became interested in alternatives because of the rising costs of purchased pesticides and fertilizers and growing concerns about the contamination of water. In 1988, the EPA detected 46 pesticides, including Bromacil, dibromochloropropane, and ethylene dibromide (EDB), that were attributed to normal agricultural use in the ground water of 26 States.[10]

Demand for EDB is in gasoline additives as a scavenger for lead antiknock. The ITC's publication "Synthetic Organic Chemicals, 1990," listed Great Lakes and Ethyl as the only producers of EDB used in gasoline additives during 1990.

Bromine was used in clear brine drilling fluids used in work-over and completion fluids. Clear fluids ensure protection, stability, and control. Densities between 8.35 and 19.2 pounds per gallon are possible. Clear fluids can produce drilling rates double or triple that of a mud systems if used without solids. Clear fluids keep clay damage to a minimum; small amounts of solids can reduce a well's production potential from 10% to 85%.

The ITC's publication, "Synthetic Organic Chemicals, 1990," 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.

Bromoethane is used in pesticide and pharmaceutical manufacture and was imported by one company.[11] The New York City Parks Department reported using bromadiolone, an anticoagulant containing 15% bromine, to decrease the rat population. The rat community was unusually large because poisoning was replaced last summer by "an ecological pure" plan that did not work.[12]

Bromine was also used in water treatment as a slime and biocidal control product. Bromine rivals chlorine in hot water applications, such as hot tubs and spas, where the higher priced bromine-base sanitizers are more competitive because of their longevity due to heat resistance. Bromine is used in cold water, mostly in the south and west where pools stay filled year-round and receive intense sunshine.[13]

Prices

Bromine was sold under contracts negotiated between buyer and seller. Price quotations do not necessarily represent prices at which transactions actually occurred, nor do they represent bid and asked prices. They were quoted here to serve only as a guide to yearend price levels.

Foreign Trade

The ITC held hearings during 1989 concerning the withdrawal of the generalized system of preference (GSP) for imports of sodium bromide from Israel. Israel received duty-free treatment on its bromine products in all major world markets except the United States, where duties are paid on three significant bromine products. The GSP was withdrawn for sodium bromide, but the duty will drop to zero in 1995.

World Review

Capacity.—The data in table 4 are rated capacity for mines and refineries as of December 31, 1990.

Israel.—Israeli Chemicals Ltd. (ICL), the parent company of Dead Sea Bromine, was for sale during the year. At the beginning of the year, a maximum of a 25% share was available for public ownership. In May, the Finance ministry officials stated that up to 49% of ICL was available for sale. Israel declined an offer for purchase of 51% of the ICL and continued plans to offer public shares on the stock exchange.

U.S.S.R.—The Soviet Institute of Geochemistry and Analytical Chemistry was seeking foreign investment for a process to manufacture bromine from seawater. The process uses a two-chamber device with an electrode in each side of the chamber that produces magnesium hydroxide and elementary bromine. Magnesium bromide is formed by reversing the electrical flow. The process was demonstrated on brines from the Black and Okhotst Seas. Extraction efficiency was 75%.[14]

Current Research

Energy Research Corp., under contract

TABLE 4

YEAREND 1990 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, free on board (f.o.b.) works	131	289
Bromine:		
Drums, truckloads, works[1]	103	227
Bulk, tank cars, works[1]	43- 46	95-101
Bromochloromethane, drums, carloads, f.o.b. Midland, MI	125	276
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.	54- 65	119-143
Hydrogen bromide, anhydrous, cylinders, 2,500 pounds, truckloads	390	860
Methyl bromide, tank cars	72	159
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	65- 68	143-150

[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. 238 No. 27, Dec. 31, 1990, pp. 23-32.

TABLE 5

BROMINE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand kilograms)

Country[2]	1986	1987	1988	1989	1990[e]
France[e]	19,000	18,500	18,000	18,000	18,000
Germany, Federal Republic of:					
Western states[e]	2,500	2,500	2,500	3,000	3,000
India	1,229	1,182	1,242	r1,272	1,300
Israel[e]	105,000	110,000	118,000	r135,000	135,000
Italy[e]	450	450	450	r400	400
Japan[e]	15,000	15,000	15,000	15,000	15,000
Spain[e]	280	300	300	300	300
U.S.S.R.[e]	65,000	65,000	65,000	65,000	60,000
United Kingdom	26,000	26,184	r27,128	r29,907	28,000
United States[3]	140,600	152,000	163,300	174,600	[4]177,000
Total	375,059	391,116	r410,920	r442,479	438,000

[e]Estimated. [r]Revised.
[1]Table includes data available through Apr. 19, 1991.
[2]In addition to the countries listed, several other nations produce bromine, but output data are not reported, and available general information is inadequate for formulation of reliable estimates of output levels.
[3]Sold or used by producers.
[4]Reported figure.

TABLE 6

WORLD BROMINE ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1990 RATED CAPACITY[2]

(Thousand kilograms)

Country	Capacity
North America: United States	261,000
Europe:	
France	22,000
Germany, Federal Republic of:	
Western states	2,500
Eastern states	3,500
Italy	900
Spain	900
U.S.S.R.	73,000
United Kingdom	30,000
Total[3]	133,000
Middle East: Israel	113,000
Asia:	
China	500
India	700
Japan	24,000
Total[3]	25,000
World total	532,000

[1]Actual capacity limited by brine supply.
[2]Includes capacity at operating plants as well as at plants on standby basis.
[3]Data may not add to totals shown because of independent rounding.

number 8838 to Sandia Laboratories from funds supplied by the U.S. Department of Energy (DOE), concluded studies on zinc-bromine batteries. The 5-year study (NTIS report number DE90014751/ABS) evaluates the potential of the batteries for bulk energy storage applications, such as utility load leveling. The low cost of the battery reactants and the potential for long life make the system attractive for energy storage.

An evaluation of the harmful results of exposure to dioxin, including brominated flame retardants, indicates that a certain minimum exposure level of any biological or toxic substance must be achieved before any adverse effect occurs. There is a dose level below which no biologically significant effects can occur. No human toxicity, with the exception of chloracne (a skin condition), can be reliably attributed to dioxin exposure.[15]

Chemicals called halons pose a greater threat to the ozone layer than CFC's. Halons, by definition, are hydrocarbon fire extinguishers, and those in general use fluorocarbons that contain bromine. Halon 1301, a gas, and halon 1211, a liquid, are highly volatile, leave no residue on evaporation, and do not conduct electricity. Halons are used to protect aircraft, computer rooms, museums, art galleries, libraries, telephone exchanges, and other areas requiring a clean, nondamaging agent.

Halons suppress fires by several mechanisms. Like carbon dioxide and water, they cool and smother the fire and dilute the burning fuel and oxygen. They also act by combining chemically to remove fuel from the fire. Because of this additional chemical action, halon levels in air of less than 5% are sufficient to suppress almost all flames. Carbon dioxide, the other commercially used fire extinguisher, requires a concentration of greater than 30%, which is above toxic levels, or can leave a residue.[16]

Great Lakes Chemical Corp., the only domestic producer of both halon 1211 and 1301, reported developing FM-100, an effective halon alternative. FM-100, bromodifluoromethane (halon 1201), has an ozone depletion potential (ODP) of one-twentieth of existing halons. E. I. du Pont de Nemours & Co. Inc. reported to have developed HCFC-125, a not fully halogenated CFC, as a replacement for halon 1301 and HCFC-123 as a replacement for halon 1211.[17]

TABLE 7

WORLD BROMINE ANNUAL PLANT CAPACITIES AND SOURCES, DECEMBER 31, 1990

Country and company	Location	Capacity (thousand kilograms)	Source
China:			
Laizhou Bromine Works	Shandong	500	Underground brines.
France:			
Atochem	Port-de-Bouc	13,600	Seawater.
Mines de Potasse d'Alsace S.A.	Mulhouse	8,600	Bitterns of mined potash production.
German Democratic Republic:			
Government	Bleicherode	NA	Do.
	Sondershausen	3,500	Do.
Germany, Federal Republic of:			
Kali und Salz AG: Salzdetfurth Mine	Bad Salzdetfurth	2,500	Do.
India:			
Hindustan Salts Ltd.	Jaipur		
Mettur Chemicals	Mettur Dam	700	Seawater bitterns from salt production.
Tata Chemicals	Mithapur		
Israel:			
Dead Sea Bromine Co. Ltd.	Sdom	113,000	Bitterns of potash production from surface brines.
Italy:			
Societa Azionaria Industrial Bromo Italiana	Margherita di Savo	900	Seawater bitterns from salt production.
Japan:			
Asahi Glass Co. Ltd.	Kitakyushu	4,000	Seawater bitterns.
Toyo Soda Manufacturing Co. Ltd.	Tokuyama	20,000	Do.
Spain:			
Derivados del Etilo S.A.	Villaricos	900	Seawater.
U.S.S.R:			
Government	NA	73,000	Well brines.
United Kingdom:			
Associated Octel Co. Ltd.	Amlwch	30,000	Do.

NA Not available.
[1]Excludes U.S. production capacity. See table 2.

OUTLOOK

Sales of bromine, primarily in compounds, has increased about 23% since 1969. This represents an annual rate of increase of about 1.1% per year. These increases have been attributed to 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 petroleum. Bromine usage in well drilling fluids was expected to remain depressed because well drilling remains at 1990 levels and the Clean Air Act amendments encourage alterate forms of energy.

Petroleum

Demand for bromine as a gasoline additive has declined each year since the EPA issued regulations in the 1970's to reduce the lead in gasoline. Bromine in the form of ethylene dibromide is used as a "scavenger" for the lead to keep the lead from depositing in the engine. In 1979, the amount of bromine sold reached a peak of 225 million kilograms. The rapid decline to 141 million kilograms in 1986 was a direct result of the limits on lead in leaded gasoline. The European Community continued discussions to reduce lead levels in gasoline.

Sanitary Preparations

Bromine has found usage in swimming pools, hot tubs, and whirlpools. The sanitary preparation field is an area where bromine has been found to be safer than its substitutes. The use of bromine will continue to grow in this area, closely following the gross national product in real growth.

Fire Retardants

Federal regulations covering flammability of private and public building materials and furnishings have required

greater amounts of fire retardant chemicals to be used in these materials and furnishings. The costs and/or benefits of fire retardants versus environmental hazards in the United States is expected to grow as organic materials replace metals in transportation, infrastructure, and packaging. Several State governments continue to support strong consumer laws that protect State residents from hazardous products produced in other States.

Other Uses

Usage of calcium bromide and zinc bromide in well drilling fluids decreased during the 1980's when the domestic petroleum industry suffered a severe recession. Federal laws enacted to encourage alternative forms of power in automotive engines are likely to have a depressive effect on increases in petroleum demand. The Clean Air Act Amendments of 1990 (Public Law 101-549) have an amendment that will require mobile sources, such as cars and trucks, to use the most effective technology possible to control emissions.

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CADMIUM

By Thomas O. Llewellyn

Mr. Llewellyn is a physical scientist with the Branch of Industrial Minerals. He has covered cadmium for 4 years. Domestic survey data were prepared by Giovanni Jacarepaqua, mineral data assistant; and international data were prepared by William L. Zajac, Chief, Section of International Data.

Domestic production of cadmium metal in 1990 increased about 8%. Four companies operating four plants produced all of the domestic cadmium. Canada continued as a major source of imported zinc concentrates from which cadmium was extracted as a byproduct. The New York dealer price range of cadmium metal, at $5.25 to $5.35 per pound at the beginning of 1990, declined to $3.00 to $3.20 per pound by yearend.

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, all responded, representing 100% of the cadmium content of production of cadmium compounds shown in table 2.

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Legislation and Government Programs

On February 6, 1990, the Occupational Safety and Health Administration (OSHA) published a proposed rule to reduce the existing limit for occupational exposure to airborne cadmium. The rule, as proposed, would lower the existing permissible 8-hour exposure limit (PEL) of 100 micrograms per cubic meter for cadmium fumes and 200 micrograms

TABLE 1

SALIENT CADMIUM STATISTICS

		1986	1987	1988	1989	1990
United States:						
Production[1]	metric tons	1,486	1,515	1,885	1,550	1,678
Shipments by producers[2]	do.	2,030	1,916	2,074	2,015	1,855
Value	thousands	$1,883	$1,861	$5,389	$2,282	$3,567
Exports	metric tons	38	241	613	369	385
Imports for consumption, metal[3]	do.	3,174	2,701	2,482	2,787	1,741
Apparent consumption	do.	4,385	4,178	3,620	4,096	3,107
Price, average per pound, in 1- to 5-short-ton lots:						
New York dealer		$1.07	$1.60	$6.91	$6.28	$3.38
Producer		$1.25	$1.99	[3]$7.90	—	—
World: Refinery production	metric tons	r18,828	r19,099	r21,794	r21,075	e20,097

eEstimated. pPreliminary. 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.
[3]Includes waste and scrap (gross weight).
[4]Major cadmium producers stopped quoting a published price for cadmium metal effective Sept. 1988. Producer price average of Jan.–Aug. 1988.

TABLE 2

U.S. PRODUCTION OF CADMIUM COMPOUNDS

(Metric tons, cadmium content)

Year	Cadmium sulfide[1]	Other cadmium compounds[2]
1986	645	1,459
1987	540	1,511
1988	345	1,497
1989	267	1,451
1990	228	1,144

[1]Includes cadmium lithopone and cadmium sulfoselenide.
[2]Includes plating salts and oxide.

TABLE 3

SUPPLY AND APPARENT CONSUMPTION OF CADMIUM

(Metric tons)

	1988	1989	1990
Stocks, Jan. 1	720	854	726
Production	1,885	1,550	1,678
Imports for consumption, metal[1]	2,482	2,787	1,741
Total supply	5,087	5,191	4,145
Exports	613	369	385
Stocks, Dec. 31	854	726	653
Consumption, apparent[2]	3,620	4,096	3,107

[1]Includes waste and scrap (gross weight).
[2]Total supply minus exports and yearend stocks.

TABLE 4

INDUSTRY STOCKS, DECEMBER 31

(Metric tons)

	1989		1990	
	Cadmium metal	Cadmium in compounds	Cadmium metal	Cadmium in compounds
Metal producers	241	W	221	W
Compound manufacturers	77	399	107	316
Distributors	8	1	8	1
Total	326	400	336	317

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

per cubic meter for cadmium dust to an 8-hour time-weighted exposure limit of either 5 or 1 micrograms per cubic meter as alternatives for all forms of cadmium.

The proposed rule also covers supplementary provisions for employee protection, including exposure monitoring, medical surveillance, record keeping, and proper selection and maintenance of personal protective equipment. OSHA held two public hearings, one in Washington, DC, in June, and the other in Denver, CO, in July. These hearings were held to obtain further information on the feasibility of meeting a 1 or 5 micrograms per cubic meter PEL for cadmium using engineering controls and/or administrative controls. The agency was expected to reach a final decision by the fourth quarter of 1991.[1]

Strategic Considerations

Cadmium is included in the National Defense Stockpile (NDS) because of its importance in specialized military applications such as plating where substitutes may be in short supply or unsatisfactory. In addition, the United States depends on imports to meet part of its requirements.

Purchase of cadmium under the Strategic and Critical Minerals Stockpiling Act began in 1948, and the initial stockpile requirements were completed in 1955. Cadmium was also acquired for the supplemental stockpile from 1956 through 1963 under provisions of the Agricultural Trade Development and Assistance Act of 1954, which enabled the U.S Department of Agriculture Commodity Credit Corp. to barter surplus perishable goods for foreign-produced cadmium metal. Government shipments from stockpile excesses for 1964–76 totaled 3,918 tons. In April 1980, the stockpile goal for cadmium was set at 5,307 tons. At the end of 1990, the NDS cadmium inventory was 2,871 tons.

Production

Primary cadmium was produced by ASARCO Incorporated, Denver, CO; Big River Zinc Corp., Sauget, IL; Jersey Miniere Zinc Co., Clarksville, TN; and Zinc Corp. of America, Bartlesville, OK. The companies in Illinois, Oklahoma, and Tennessee recovered cadmium as a byproduct of smelting domestic and imported zinc concentrates. The company in Colorado recovered cadmium from other sources such as lead smelter baghouse dust.

Consumption and Uses

Based on production, trade, and stock data, the apparent domestic consumption of cadmium in 1990 was lower than that of 1989.

An estimated apparent consumption pattern for 1990 was as follows: batteries, 40%; coating and plating, 25%; pigments, 13%; plastic and synthetic products, 12%; and alloys and other, 10%.

Stocks

Inventories of cadmium metal held by metal producers at the end of 1990 were 221 tons, 8% under those held at the close of 1989. Compound manufacturers' stocks of cadmium metal rose 39% above those held at yearend 1989. Inventories of metal held by distributors were essentially unchanged from those reported the previous year.

Market and Prices

The New York dealer price range for cadmium metal, published by Metals Week, at the beginning of 1990 was $5.25 to $5.35 per pound, a sharp decline from the price range of $8.45 to $8.65 quoted at the beginning of 1989. The prices for cadmium metal followed a steady downward trend throughout the first 11 months of 1990 and, by the end of November, ranged from $1.20 to $1.50 per pound. The steady price decline was due to lower growth in demand for nickel-cadmium batteries and a decline in the market for other end uses of cadmium such as coating and plating, pigments, and plastics and synthetic products. However, the domestic cadmium market recuperated during December and closed the year at a range of $3.00 to $3.20 per pound.

Foreign Trade

The Bureau of the Census reported that the United States imported about 137 million nickel-cadmium batteries in 1990. Hong Kong, Japan, Mexico, and

TABLE 5

U.S. EXPORTS OF CADMIUM METAL AND CADMIUM IN ALLOYS, DROSS, FLUE DUST, RESIDUES, AND SCRAP

Year	Quantity (metric tons)	Value (thousands)
1988	613	$3,697
1989	369	857
1990	385	1,174

Source: Bureau of the Census.

Singapore supplied approximately 96% of the total battery imports.

Under the Harmonized Tariff Schedule of the United States, which has been in effect since January 1, 1989, cadmium sulfide and pigments and preparations based on cadmium compounds from most favored nations (MFN) are subject to a 3.1% ad valorem duty; for non-MFN, a 25% ad valorem duty was retained. Imports of unwrought cadmium, waste and scrap, and powders, are duty free for MFN, whereas a statutory duty of 33 cents per kilogram was imposed on these materials for non-MFN.

Cadmium producers are granted a depletion allowance of 22% on domestic production and 14% on foreign production.

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 short ton of cadmium metal. The tax ends on December 31, 1991.

World Review

Industry Structure.—World refinery production of cadmium was estimated at 20,097 metric tons in 1990. This represented a decrease of 4.6% below production levels achieved during 1989. The U.S.S.R. was the largest producer of refined cadmium in 1990, followed by Japan, Belgium, the United States, Canada, the Federal Republic of Germany, and Mexico. These seven countries accounted for approximately 60% of the world's refined cadmium production in

TABLE 6

U.S. IMPORTS FOR CONSUMPTION[1 2 3] OF CADMIUM METAL, BY COUNTRY

Country	1988		1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	31	$331	—	—	—	—
Australia	309	4,462	173	$2,391	199	$1,272
Belgium	19	44	120	1,045	37	288
Brazil	80	1,099	22	328	—	—
Canada	858	9,816	947	11,042	743	5,402
China	25	360	40	840	17	171
Finland	30	371	3	46	2	21
France	—	—	333	1,522	29	249
Germany, Federal Republic of	372	4,979	139	1,837	71	615
Italy	—	—	[4]	2	—	—
Japan	—	—	2	48	[4]	31
Korea, Republic of	—	—	21	334	—	—
Mexico	590	7,670	616	7,525	345	1,926
Namibia	5	40	24	337	—	—
Netherlands	26	113	132	559	59	448
Norway	—	—	35	415	85	589
Peru	5	39	59	755	27	95
Poland	12	75	—	—	—	—
South Africa, Republic of	[4]	2	—	—	—	—
Spain	55	465	17	192	22	195
Switzerland	—	—	12	190	—	—
Taiwan	42	68	41	229	22	185
United Kingdom	23	1,147	46	470	83	417
Venezuela	—	—	[4]	4	—	—
Yugoslavia	—	—	5	49	—	—
Total	2,482	31,081	2,787	[5]30,161	1,741	11,904

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 are not necessarily comparable with those in 1988.
[2]General imports and imports for consumption were the same in 1988, 1989, and 1990.
[3]Includes waste and scrap (gross weight).
[4]Less than 1/2 unit.
[5]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

1990. Because cadmium is recovered mainly as a byproduct of zinc ore processing, many producers of zinc and zinc compounds produce primary cadmium as an integral part of their operation. In some cases, residues and flue dusts from zinc producers are used directly by cadmium producers. Some cadmium may also be recovered from flue dust generated at various lead and copper smelters; however, the amount of this production is not known.

Capacity.—The data in table 7 represent rated annual production capacity for mines and refineries on December 31, 1990. 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 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.

TABLE 7

WORLD ANNUAL CADMIUM PRODUCTION CAPACITY, DECEMBER 31, 1990

(Metric tons, cadmium content)

	Mine	Refinery
North America:		
Canada	4,800	2,700
Mexico	2,000	1,500
United States	2,000	3,100
Total	8,800	7,300
Central America	300	—
South America:		
Peru	2,000	600
Other	700	200
Total	2,700	800
Europe	7,500	10,500
Africa	1,000	600
Asia:		
Japan	600	5,100
Other	2,600	1,400
Total	3,200	6,500
Oceania: Australia	2,300	1,100
World total	25,800	26,800

TABLE 8

CADMIUM: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Metric tons)

Country	1986	1987	1988	1989	1990[e]
Algeria	124	102	55	[e]80	80
Argentina	47	46	46	[e]40	40
Australia	915	944	855	[r]696	700
Austria	52	26	26	[r]49	50
Belgium	1,374	1,308	1,836	[r]1,761	1,800
Brazil	233	214	161	[r]197	200
Bulgaria[e]	200	180	180	180	180
Canada	1,484	1,481	1,742	[r]1,620	[2]1,437
China[e]	650	680	750	800	800
Finland	522	690	703	[r]612	625
France	431	457	558	[r]790	600
Germany, Federal Republic of:					
Eastern states[e]	18	18	20	15	15
Western states	1,218	1,125	1,159	1,208	1,200
India	160	214	237	[r]275	290
Italy	411	320	705	[r e]710	720
Japan	2,489	2,450	2,614	[r]2,694	2,380
Korea, North[e]	100	100	100	100	100
Korea, Republic of	—	—	490	[e]500	500
Mexico	[r]719	935	[r]1,117	[r]976	950
Namibia	61	51	106	[r]88	[2]75
Netherlands	557	517	655	[e]350	350
Norway	154	147	169	[e]200	200
Peru	[r]463	461	368	[r]472	390
Poland[e]	600	600	600	600	600
Romania[e]	75	75	75	70	62
South Africa, Republic of	30	33	37	[e]40	40
Spain	247	297	438	[r]361	300
Turkey	6	11	22	[e]22	25
U.S.S.R.[e]	3,000	3,000	3,000	3,000	2,800
United Kingdom	379	498	399	395	400
United States[3]	1,486	1,515	1,885	1,550	[2]1,568
Yugoslavia	259	305	405	[e]400	400
Zaire	364	299	281	[r]224	220
Total	[r]18,828	[r]19,099	[r]21,794	[r]21,075	20,097

[e]Estimated. [p]Preliminary. [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, Federal Republic of 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, 1991.

[2]Reported figure.

[3]Includes secondary.

Reserves.—Cadmium reserves were obtained by applying an average recovery factor of 0.36% to zinc reserve data. On this basis, the domestic reserves of cadmium were estimated at 72,000 tons. Total world reserves were estimated to be about 535,000 tons. The world's largest reserves of cadmium were in the United States and Canada.

Cadmium minerals are not found in commercially viable deposits, and its abundance in the Earth's crust is about

0.2 parts per million. Greenockite (CdS) is the only cadmium mineral of importance. It is not found in any isolated deposit, but is nearly always associated with zinc sulfide. Cadmium is usually produced as a byproduct in the recovery of primary zinc from zinc ores and also from some lead ores or complex copper-lead-zinc ores. However, it is generally agreed that the cadmium in lead and copper ores is associated with the zinc sulfide present rather than with the other minerals.

Current Research

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.

The Cadmium Association, England; the Cadmium Council Inc., Greenwich, CT; and the International Lead Zinc Research Organization Inc., Research Triangle Park, NC, published the Proceedings of the Sixth International Cadmium Conference held in Paris, France, April 19–21, 1989. The edited proceedings contain the text of the 33 papers presented in Paris, which included topics of great interest such as Regulating Cadmium and New Technology and Markets for Cadmium.[2]

The Roskill organization issued its 1990 cadmium report. This comprehensive report discusses and analyzes world production of cadmium by country and individual company. It also contains information on end-use markets, international trade patterns, and trends in prices.[3]

OUTLOOK

The short-term demand for cadmium in the United States was expected to fall below the level of 1990. This decline was expected to be the result of continuing lower demand for cadmium in coating and plating, pigments, and plastics and synthetic products during the next 4 years. There was a strong indication that the world demand for primary cadmium will follow the same trend, for the reasons mentioned above, which are a consequence of stricter environmental and health controls now under consideration in North America and Europe.

[1]Federal Register. Occupational Exposure to Cadmium; Proposed Rule. V. 55, No. 25, Feb. 6, 1990, pp. 4052–4147.

[2]Hiscock, S. A., and R. A. Volpe (eds.). Cadmium 89. (Sixth International Cadmium Conference, Paris, France, Apr. 19–21, 1989), Nov. 1990, 187 pp.

[3]Roskill Information Services Ltd. The Economics of Cadmium 1990. London, England, 7th ed., Aug. 1990, 325 pp. and Appendices A & B.

[4]American Society for Testing and Materials. Standard Specification for Cadmium. B 440-83 in 1984 Annual Book of ASTM Standards: Nonferrous Metal Products, section 2, 02.05, 1984, pp. 246–48.

[5]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.

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Engineering and Mining Journal.
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CALCIUM AND CALCIUM COMPOUNDS

By M. Michael Miller

Mr. Miller, a physical scientist with 13 years of minerals experience with the Department of the Interior, has been the commodity specialist for calcium and calcium compounds since 1989. Domestic survey data were prepared by Joseph C. Daniels, mineral data assistant.

Calcium, the fifth most abundant element in the Earth's crust, is chemically very active and is found in a host of minerals that occur in nearly every geologic environment. The U.S. Bureau of Mines publishes reports for a variety of calcium-containing minerals and compounds because of their commercial significance and contribution to the quality of human life. Calcium fluoride is sold as fluorspar; calcium sulfate as gypsum or anhydrite; calcium oxide and hydroxide as lime; calcium phosphate as phosphate rock; and natural calcium carbonate as either limestone, marble, calcareous marl, or shell. Information on these commodities can be obtained in the U.S. Bureau of Mines annual reports entitled "Fluorspar," "Gypsum," "Lime," "Phosphate Rock," "Crushed Stone," and "Dimension Stone." Other calcium compounds are discussed in the report concerning the element with which calcium is combined; for example, calcium bromide is covered in the "Bromine Annual Report." This "Calcium and Calcium Compounds Annual Report" includes calcium metal, calcium chloride, precipitated calcium carbonate, and various other calcium compounds not covered elsewhere.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines develops domestic production data for calcium chloride from a voluntary survey of U.S. operations entitled "Calcium Chloride and Calcium-Magnesium Chloride." Of the nine operations polled, seven responded, representing less than 25% of the total production shown in table 2. Production for the two nonrespondents was estimated using data from previous years, published plant capacity, and contacts within the industry.

BACKGROUND

Grades and Specifications

Calcium metal is usually sold in the form of crowns, broken crown pieces or nodules, or billets, which are produced by melting crowns in an argon atmosphere. The metal purity in these forms is at least 98%. Higher purity metal is obtained by redistillation. Calcium metal is usually shipped in polyethylene bags under argon in airtight steel drums. Table 1 shows typical specifications for commercial grade, melted grade, and redistilled grade.

The American Society for Testing and Materials (ASTM) issues a standard specification for calcium chloride designated D 98. It covers technical-grade calcium chloride to be used for road conditioning purposes, ice removal, concrete curing, acceleration of the set of concrete, and as a desiccant. D 98 covers two types of calcium chloride, solid (Type S) and liquid (Type L). Solid occurs in flake, pellet, granular, and powder form in concentrations of 77%, 90%, and 94% minimum. Liquid occurs as water solutions of calcium chloride in concentrations varying from 30% to 45%. Calcium chloride is divided into three grades: Grade 1—77% minimum, Grade 2—90% minimum, and Grade 3—94% minimum. Within each grade there are sieve-size requirements for flake, pellet, granular, and powder forms.[1]

Technology

Calcium Metal.[2]—In 1808, Davy produced elemental calcium as a mercury amalgam by the electrolysis of calcium chloride in the presence of a mercury cathode. He and others were only marginally successful in attempts to isolate the pure metal by distilling the mercury. In 1855, Bunsen and Matthiessen attempted to produce calcium metal by the electrolysis of a mixture of calcium, strontium, and ammonium chlorides to lower the electrolyte melting point, but produced only finely divided calcium alloys. This process was slowly improved, and by 1904, Rathenau obtained calcium by the electrolysis of molten calcium chloride held at a temperature above the

TABLE 1

CALCIUM METAL—TYPICAL SPECIFICATIONS

(Parts per million)

Impurity	Commercial	Melted	Redistilled
Magnesium	5,000	5,000	4,000
Nitrogen	500	9,000	70
Aluminum	5,000	5,000	30
Iron	200	300	20
Manganese	400	300	150
Copper	<10	—	<10
Carbon	—	—	150
Minimum calcium content	98.8%	98.0%	99.5%

Source: Quigley Company Inc., a subsidiary of Pfizer Inc.

melting point of the salt but below the melting point of calcium metal. An iron cathode just touched the surface of the bath and was raised slowly as the relatively chloride-free calcium deposited on its end. This process accounted for virtually all calcium metal production from 1904 to 1940.

Prior to 1939, calcium was manufactured exclusively in France and Germany. With the outbreak of World War II, an electrolytic calcium plant was constructed at Sault Ste. Marie, MI, by the Electro Metallurgical Corp. Large quantities of calcium were required as the reducing agent for uranium production. In addition, the U.S. Army Signal Corps used calcium to produce calcium hydride, which could easily be transported to remote areas and used as a source of hydrogen for meteorological balloons. To satisfy these needs, an aluminothermic reduction process was developed. Developed earlier on a laboratory scale in 1922, the process was improved and commercialized by the New England Lime Co. in Canaan, CT, which later became a division of Pfizer Inc.

The aluminothermic process, or Pidgeon process as it is sometimes called, begins with quarried high-calcium limestone calcined to form calcium oxide. The calcium oxide is ground to a small particle size and dry-blended with finely divided aluminum. The mixture is compacted into briquets to ensure good contact of reactants. The briquets are placed in horizontal metal tubes, called retorts, made of heat-resistant steel and heated in a furnace to 1,100° to 1,200° C under high vacuum, and the calcium oxide is reduced to calcium metal. The calcium metal vapor is collected in the water-cooled condenser section of the retort at about 700° C. After the reaction has proceeded for about 24 hours, the vacuum is broken with argon, and the condensed blocks of 98%-pure calcium metal, called "crowns," and the calcium aluminate reaction product are removed.

For certain applications greater than 98% purity is required, which is achieved by redistillation. Crude calcium is placed in the bottom of a large vertical retort equipped with a water-cooled condenser at the top. The retort is sealed and evacuated to a pressure of less than 6.6 pascal (0.05 millimeters of mercury), while the bottom is heated to 900° to 925° C. The calcium quickly distills into the condensing section, leaving behind the bulk of the less volatile impurities. Subsequent processing must take place under exclusion of moisture to avoid oxidation. Redistillation does not greatly reduce the impurity level of volatile materials such as magnesium.

Calcium Chloride.[3]—Domestic calcium chloride is produced from natural brines and by reacting hydrochloric acid with limestone. Most U.S. production is natural from brine wells in Michigan, with a small amount from dry lake beds in California.

Initial efforts to stimulate the development of Michigan salt and brine deposits took place in 1859. The State legislature passed a bill authorizing payment for Michigan salt. By 1870, saw mill operators were augmenting their income by using waste lumber as fuel to evaporate brines. In 1882, solution mining of rock salt began, and Michigan soon became the leading salt-producing State.

By 1914, an integrated process was developed using three vacuum evaporators to extract various brine components. Bromine was extracted first in an electrolytic cell, and the debrominated brine was then processed through a heated vacuum evaporator. This process precipitated sodium chloride, which was used to produce chlorine, hydrogen, and sodium hydroxide. The brine was then sent to a second evaporator where magnesium chloride was precipitated out. The brine from the second evaporator went to a third evaporator, which produced precipitated hydrates of calcium chloride and a 38% calcium chloride product.

Today the process has been expanded and improved to extract, in sequence, iodine, bromine, magnesium chloride, and calcium chloride. The calcium chloride is derived from the brine left over after processing the magnesium chloride into magnesium hydroxide. This brine is about 25% calcium chloride, and it is processed through double or triple effect vacuum evaporators to make a 32% to 45% solution. Unwanted alkali chlorides are precipitated here and can be removed by settlers and centrifuges. The brine undergoes further evaporation to attain an anhydrous product of 78% to 94% calcium chloride concentration.

Precipitated Calcium Carbonate.[4]—Calcium carbonate occurs in two crystalline forms—aragonite and calcite. These forms possess different physical properties. There are three basic processes for the manufacture of calcium carbonate as a precipitate. The processes include the lime-soda process, the lime-ammonium chloride process, and the carbonation process. All three start with a dilute lime hydrate in aqueous suspension, descriptively called milk-of-lime.

In the lime-soda process, milk-of-lime is reacted with sodium carbonate to produce calcium carbonate and sodium hydroxide. The commercial alkali manufacturers used this process, which produced as a byproduct a coarse calcium carbonate precipitate. Production of a uniform, fine-particle-size precipitate could only be achieved at the expense of the primary goal, caustic soda recovery.

In the lime-ammonium chloride process, milk-of-lime is reacted with ammonium chloride to produce calcium chloride. The calcium chloride is purified and then reacted with soda ash to form calcium carbonate. The process can be fine tuned by modifying the addition times, method and rate of agitation, pH, concentrations, and reaction temperatures. This process requires a low-cost source of sodium carbonate and calcium chloride, and production, historically, has been as a satellite to Solvay process synthetic soda ash plants. The last domestic synthetic soda ash plant closed in 1986.

The most common production process used in the United States is the carbonation process. Carbon dioxide is bubbled through milk-of-lime to form a precipitate of calcium carbonate and water. The reaction conditions determine the particle size and shape of the resulting aragonite or calcite. To modify the dimensions and performance characteristics of the precipitate, it is necessary to adjust a range of variables that include concentration, starting temperature, pH, degree and type of mixing, solution rates, and the addition of additives. Calcite, aragonite, or a mixture of both can be produced, although commercial forms are usually exclusively one form or the other. The carbonation process is the most complex of the three processes. Because of the low cost availability of raw materi-

als, it has become the process of choice and forms the foundation of the expanding network of satellite precipitated calcium carbonate plants adjacent to pulp and paper mills.

ANNUAL REVIEW

Strategic Considerations

Redistilled-grade calcium metal was used to reduce uranium dioxide, a fuel in some types of fission reactors. The nuclear applications of calcium metal gave it strategic significance; the U.S. Department of State would not permit sales to countries not signatory to the United Nations Nuclear Nonproliferation Treaty.

Production

Pfizer Inc. produced calcium metal at Canaan, CT, by the Pidgeon process, in which high-purity calcium oxide (produced by calcining limestone) and aluminum powder are compacted into briquets and heated in vacuum retorts. The vaporized calcium metal product collects as a "crown" in a water-cooled condenser. Production was down about 10% compared with that of 1989.

Pfizer produced commercial-grade 98.5% calcium in eight shapes and high-purity redistilled 99.2% metal in three shapes, with other shapes available on request. They produced an 80%-20% calcium-magnesium alloy, a pure calcium wire used in the steel industry to modify inclusions, and a 73%-27% calcium-aluminum alloy or unalloyed calcium-aluminum briquet. Elkem Metals Co., a Norwegian-owned company with headquarters in Pittsburgh, PA, produced a calcium-silicon-barium-aluminum alloy at its plant in Niagara Falls, NY, and imported several other calcium alloys.

Michigan was the leading State in natural calcium chloride production; California was a distant second. The Dow Chemical Co. and Wilkinson Chemical Corp. recovered calcium chloride from brines in Mason and Lapeer Counties, MI. Dow's Ludington plant produced calcium chloride pellets, flake, and liquid; Wilkinson marketed calcium chloride solutions only. In addition, Martin Marietta Magnesia Specialties marketed some byproduct calcium chloride from its brine operations in Michigan. National Chloride Co. of America, Cargill's Leslie Salt Co., and Hill Brothers Chemical Co. produced calcium chloride from dry-lake brine wells in San Bernadino County, CA. Hill Brothers Chemical also produced from a second operation near Cadiz Lake, CA. Magnesium Corp. of America marketed some byproduct calcium chloride from its magnesium production operations in Rowley, UT.

Allied Signal Inc. recovered synthetic calcium chloride as a byproduct at its Baton Rouge, LA, plant using hydrochloric acid and limestone. Tetra Chemicals produced calcium chloride from a plant near Lake Charles, LA, and from its liquids plant at Norco, LA. Occidental Chemical Corp. manufactured calcium chloride at Tacoma, WA, using limestone and hydrochloric acid. Additional synthetic calcium chloride production came from Standard Chlorine at Delaware City, DE.

At the end of 1990, there were 24 precipitated calcium carbonate (PCC) plants operating in the United States. Pfizer Inc. had 15 satellite PCC plants in operation in the United States plus an additional 2 in Canada and 1 in Japan. GK Carbonate operated two satellite plants in the United States and one in Canada. There are reportedly four additional companies operating satellite PCC plants. There are three companies that produce PCC for the open market: Pfizer Inc. at Adams, MA; Mississippi Lime Co. at Ste. Genevieve, MO; and Continental Lime Inc. at Takoma, WA. The 24 U.S. plants have an estimated capacity of 950,000 metric tons.

Calcium hypochlorite was produced by Olin Corp. at Charleston, TN, and PPG Industries Inc. at Natrium, WV. Sales were relatively unchanged from those of 1990. Total domestic calcium hypochlorite capacity was 96,600 metric tons.

Consumption and Uses

Calcium metal was used in the manufacture of maintenance-free and sealed lead-acid batteries, as an aid in removing bismuth in lead refining, and as a desulfurizer and deoxidizer in steel refining. It was used to reduce oxides of the rare earth neodymium and boron for alloying with metallic iron for use in neodymium-iron-boron permanent magnets. It was used as a reducing agent to recover many of the less-common metals such as hafnium, plutonium, thorium, tungsten, uranium, and vanadium and the rare earths from their oxides or fluorides. Some minor uses were in the preparation of vitamin B and chelated calcium supplements and as a cathode coating in some types of photoelectric tubes. Domestic consumption of calcium metal decreased in 1990. This was evidenced by lower production rates by Pfizer Inc. and decreased imports reported by the Bureau of the Census, U.S. Department of Commerce.

Calcium chloride was used to deice pavements, to control dust, to stabilize road bases, to thaw coal and other bulk materials, in oil and gas drilling, for concrete-set acceleration, as tire ballasting, and in miscellaneous other uses. The principal use of calcium chloride was to melt snow and ice from roads. Calcium chloride is more effective at lower temperatures than rock salt and was used mainly in the Northern and Eastern States. Because of its considerably higher price, it was used in conjunction with rock salt for maximum effectiveness and economy.

Precipitated calcium carbonate was

TABLE 2

U.S. PRODUCTION OF CALCIUM CHLORIDE (75% $CaCl_2$)

(Thousand metric tons and thousand dollars)

Year	Natural		Synthetic		Total	
	Quantity	Value	Quantity	Value	Quantity	Value
1986	W	W	W	W	708	109,000
1987[e]	W	W	W	W	597	87,400
1988[e]	W	W	W	W	663	86,700
1989[e]	W	W	W	W	[r]727	[r]113,000
1990[e]	W	W	W	W	626	102,000

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.

used as a pigment for brightness and opaqueness in premium-quality coated papers and as a filler in uncoated papers. In coated paper, PCC was used in the coating to improve paper brightness and print clarity. In uncoated papers, it was used as a filler and extender in the paper to improve the optical, physical, and price-performance characteristics of the paper. The plastics industry used a fine and ultrafine grade of PCC to lower raw material costs, increase impact resistance, improve surface smoothness, and enhance color stability. Its major use was in polyvinyl chloride (PVC), but it was also used in such polymers as polystyrene, polypropylene, and polyethylene. The paint industry used it as a replacement for expensive TiO_2 pigment and to control flow properties, provide body, and maintain dispersion.[5]

Calcium hypochlorite was used to disinfect swimming pools, which accounted for more than 85% of domestic demand, and in other municipal and industrial bleaching and sanitation processes. It was used as an algicide, bactericide, deodorant, water purifier, disinfectant, fungicide, and bleaching agent.

Calcium nitrate was used as a concrete additive to inhibit corrosion of steel reinforcement bars, accelerate setting time, and enhance strength.

Calcium carbide and calcium-silicon alloy were used to remove sulfur from molten pig iron as it was carried in transfer ladles from the blast furnace to the steelmaking furnace.

TABLE 3

CALCIUM CHLORIDE PRICES

Product and specifications	Value per short ton	Value per metric ton
Calcium chloride concentrate, regular grade, 77% to 80%, flake, bulk, carload, works	$165	$182
100-pound bags, carload, same basis	215	237
Anhydrous, 94% to 97%, flake or pellet, 80-pound bags, carload		
Process grade, 80-pound bags	250	276
Calcium chloride, liquid, 30% to 42% basis, tank car, tank truck, barge	113	125
45%, same basis	134	148
Calcium chloride, United States Pharmacopeia, granular, 275-pound drums, truck load, freight equalized	1,580	1,742

Source: Chemical Marketing Reporter. V. 239, No. 1, Jan. 7, 1991, p. 33.

TABLE 4

U.S. EXPORTS OF CALCIUM CHLORIDE, BY COUNTRY

Country	1989		1990	
	Metric tons	Value[1]	Metric tons	Value[1]
Canada	14,461	$2,621,658	16,463	$3,214,953
Mexico	465	162,180	250	81,370
Netherlands	106	615,823	132	67,300
Sweden	326	337,793	51	26,934
Switzerland	482	82,778	195	53,210
United Arab Emirates	511	100,997	2,428	659,282
Venezuela	19	9,656	19	14,008
Other	3,946	1,764,265	3,762	2,497,607
Total	20,316	5,695,150	23,300	6,614,664

[1] U.S. Customs declared value.

Source: Bureau of the Census.

Prices

The published price of calcium metal last changed April 19, 1990, according to the Metal Bulletin. The yearend published price range for calcium metal, minimum 98%, was $2.25 to $2.75 per pound, U.S. free market.[6] This was equivalent to $4.96 to $6.06 per kilogram. This represented a dramatic drop in the published price of more than 20% compared with that of 1989. Calcium metal is sold on a contract basis, and the contract price may vary greatly from the published price. The published price range only serves as a guide to the prices obtained by dealers and producers.

Solid calcium chloride prices were quoted by Chemical Marketing Reporter for Grade 1 (minimum 77%) and Grade 3 (minimum 94%), generally in flake or pellet form. Liquid prices were quoted for a range of 30% to 42% concentration and for 45% concentration. Although actual prices are negotiated and usually discounted, yearend 1990 published prices and specifications are shown in table 3.

Foreign Trade

U.S. exports of calcium chloride increased by about 15% in 1990, with a substantial portion of the increase going to Canada and the United Arab Emirates. The United States exported 28,959 metric tons of calcium hypochlorite to many countries for an export value of about $30,200,000. More than 5,326 metric tons of calcium carbide was exported to 20 countries for an export value of more than $2,861,000. Exports of 534 metric tons of calcium cyanamide went to Canada and Mexico.

Imports of calcium metal decreased by more than 4% compared with those of 1989; this broke a 5-year string of annual increases. The majority of shipments came directly from China, France, Canada, and the U.S.S.R., in descending order. According to Bureau of the Census import data, the average c.i.f. unit value of imported calcium metal was $5.81 per kilogram ($2.63 per pound). Although the average is within the published price range, there was a tremendous disparity between the value of material from the U.S.S.R. and China and the value of material from Canada and France.

During 1990, the U.S. International Trade Administration/Import Administration, Department of Commerce, completed several antidumping duty administrative reviews on calcium hypochlorite from Japan. The reviews covered April 1, 1986, through March

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF CALCIUM AND CALCIUM CHLORIDE

Year	Calcium		Crude calcium chloride		Other calcium chloride	
	Kilograms	Value[1]	Metric tons	Value[1]	Metric tons	Value[1]
1986	256,810	$1,310,084	130,025	$14,403,393	1,903	$1,263,552
1987	352,089	1,918,099	208,620	20,916,867	1,163	706,370
1988	664,419	3,243,663	201,328	21,215,695	3,202	1,796,714
1989	679,603	3,210,216	119,296	20,855,518	r8,048	r3,817,862
1990	651,000	3,779,410	145,534	21,341,378	16,837	6,102,069

r Revised.
[1] U.S. Customs, insurance, freight.

Source: Bureau of the Census.

31, 1990, and involved Tohoku Tosoh Chemical Co. Ltd., Nankai Chemical Industry Co. Ltd., (previously Nissin Denka Co. Ltd.), and Nippon Soda Co. Ltd. The final results were the determination to assess dumping duties equal to the calculated differences between the U.S. price and the foreign market value and to revoke the antidumping duty order with respect to Nippon Soda Co. Ltd. The current antidumping duty was assessed at 10.56%.[7]

Current Research

The U.S. Bureau of Mines, through its basic research program, has investigated an alternative electrochemical process for the production of calcium metal. The process involved electrowinning of a calcium-tin alloy followed by electrorefining to produce calcium metal. The calcium metal analyzed 99.2%, which is purer than most commercial grades (see table 1). This two-step electrochemical process is a simple and efficient method for the production of calcium metal. Although the electrowinning cell should be easily scaled up, the electrorefining cell needs further development to determine what current efficiency can be expected and what recovery problems will be encountered in handling molten calcium metal, in scale up, and in longer term cell operation.[8]

In Israel, Tel Aviv University's Authority for Applied Research and Industrial Development Ltd. (RAMOT) reported the development of a patented, C-size, calcium-thionyl chloride prototype cell and announced that it is now ready for demonstration and evaluation. At low amperage rates of 0.2 milliamps to 25 milliamps, the cell delivers 5.5 ampere-hours, and at 0.8 amperes, it delivers 4.4 ampere-hours. It has an open-circuit voltage of 3.15 volts with a volumetric energy density 50% to 80% higher than a standard lithium-sulfur dioxide cell. Having undergone limited safety testing, it is considered safer than existing lithium-sulfur dioxide batteries.[9]

OUTLOOK

The major end uses of calcium metal are in the lead industry, primarily in maintenance-free and sealed lead-acid batteries; in the steel industry; and as a reducing agent of rare-earth oxides for permanent magnet manufacture. These three areas each account for roughly one-third of domestic calcium metal consumption.

The majority of the maintenance-free and sealed lead-acid batteries go into the U.S. starter battery market. Owing to the economic slowdown in 1990, it is estimated that calcium metal consumption in this market segment shrank by nearly 3%. Based on projections made for the battery industry, and assuming no growth in overall lead consumption and the continuation of sluggish economic conditions, it is estimated that consumption will be flat in

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF CALCIUM CHLORIDE, BY COUNTRY

Country	1989		1990	
	Metric tons	Value[1]	Metric tons	Value[1]
Crude:				
Canada	89,682	$14,288,798	109,880	$13,276,894
Germany, Federal Republic of	6,854	1,672,643	9,471	2,264,418
Mexico	17,784	3,878,249	18,251	4,143,726
Sweden	4,822	723,128	2,517	291,482
Other	154	292,700	5,415	1,364,858
Total	119,296	20,855,518	145,534	21,341,378
Other:				
Canada	4	39,863	2	1,993
Germany, Federal Republic of	13	117,085	—	—
Sweden	261	422,709	5,201	864,247
Other	r7,770	r3,238,205	11,634	5,235,829
Total	r8,048	r3,817,862	16,837	6,102,069

r Revised.
[1] U.S. Customs, insurance, freight.

Source: Bureau of the Census.

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF OTHER CALCIUM COMPOUNDS

	1989		1990	
	Metric tons	Value[1]	Metric tons	Value[1]
Calcium bromide	7,769	$3,230,923	16,837	$6,110,817
Calcium carbide	12,884	5,648,553	NA	NA
Calcium carbonate, precipitated	19,745	12,029,684	20,120	12,819,918
Calcium cyanamide	1,085	430,952	414	267,042
Calcium hypochlorite	4,065	6,703,152	3,973	6,516,100
Calcium nitrate	89	11,637,357	79	10,253,525
Dicalcium phosphate	1,786	2,088,291	2,380	2,744,325

NA Not available.
[1]U.S. Customs declared value.

Source: Bureau of the Census.

1991. Beyond 1991, calcium metal consumption in this market segment is expected to grow by 2% to 3% annually through 1994.[10]

Raw steel production was essentially unchanged in 1990 compared with that of 1989. However, owing to the condition of the economy, raw steel production is expected to decrease by 5% to 10% in 1991. The number of steel companies using calcium metal is expected to increase in 1991, but because of the anticipated decrease in raw steel production, consumption of calcium metal in this market is expected to be flat in 1991. Industry estimates call for 5% to 10% annual growth when the economy and the steel industry rebound. This growth is fueled by the increased efficiences achieved by using calcium.

The most disappointing market for calcium metal in 1990 appears to have been its use as a reducing agent of rare-earth oxides for permanent magnet manufacture. Estimates of annual growth failed to materialize in 1990, partially owing to the economy and possibly owing to a shift in rare-earth production to Pacific Rim countries. Consumption in this area is expected to be flat in 1991 and then grow at a rate of 5% to 10% per year.

Calcium chloride consumption during the next 3 to 5 years is projected to be static or decreasing for its major use in deicing and dust control. The mild winter hurt consumption in 1990 for deicing uses. Annual consumption for deicing is projected to be static or decrease. Dust control is expected to remain steady. Growth is expected in the area of drilling fluids for the oil and gas industry. Calcium chloride is added to specially designed oil muds to deal with plastic flowing shale encountered offshore Louisiana, in Wyoming, and in other locations.

The outlook for precipitated calcium carbonate consumption continues to be driven by the pace of conversions to alkaline sizing by the paper industry. One industry estimate sees alkaline papermaking capturing 60% of the total domestic paper market in the next 2 years. The North American market has the potential for 35 to 40 satellite plants. Pfizer plans to build an additional 10 plants in 1991.

The many benefits of PCC use by the paper industry have recently been balanced by criticism that, as paper filler levels increase, PCC performance will deteriorate because of poor drainage and increased water retention. Pfizer, which has reinvested much of its PCC profits into research and development, reports that new products with increased filler-loading levels will be available in the near future.

Although most paper markets are expected to slow down during 1991, long-term growth is expected when the economy turns around. Because paper accounts for the largest portion of PCC consumption, this growth will be reflected by increased PCC sales. The outlook for PCC consumption in paints and plastics is tied to the health of the economy, the construction industry, and the automobile industry. Both markets are expected to be flat through 1991 and then grow at a rate of 4% per year for paints and 4% to 7% for plastics.

[1]American Society for Testing and Materials. 1988 Annual Book of ASTM Standards. V. 4.03, 1988, pp. 88-90.

[2]Kunesh, C. Calcium and Calcium Alloys. Sec. in Kirk-Othmer: Encyclopedia of Chemical Technology, v. 4. John Wiley & Sons, 3d ed., 1978, pp. 412-421.

[3]Pavlick, J. Chemicals From Michigan Brines. Soc. Min. Eng. AIME preprint 84-385, 1984, 10 pp.

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[5]Hagemeyer, R. W. Precipitated Calcium Carbonate—Fillers for Paint, Paper and Elastomers. Soc. Min. Eng. AIME preprint 89-22, 1989, 14 pp.

[6]Metal Bulletin (London). No. 7545, Dec. 31, 1990, p. 22.

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[8]Lukasko, J. J., and J. E. Murphy. Electrolytic Production of Calcium Metal. BuMines RI 9315, 1990, 8 pp.

[9]Advanced Battery Technology. New Products and Literature. V. 26, No. 12, 1990, pp. 7-8.

[10]McClain, G. Battery Market Update & Five Year Forecast. The Battery Man, v. 32, No. 12, Dec. 1990, pp. 28-36.

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CEMENT

By Wilton Johnson

Mr. Johnson, a minerals industry specialist with 29 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for cement since 1983. Domestic survey data were prepared by Howard L. Sullivan, mineral data assistant; and international survey data were prepared by Audrey D. Wilkes, international data coordinator.

Cement is the primary ingredient for making concrete. Concrete is used extensively in a variety of construction structures, including buildings, highways and streets, bridges, and water supply and sewerage disposal systems. Substitute materials such as aluminum, steel, fiberglass, wood, stone, and clay products are not expected to impact concrete as the principal building material.

In 1990, U.S. demand for cement declined slightly for the third year following 5 consecutive years of growth. Corresponding declines were experienced in residential and commercial construction. Gains in the public construction sector continued to offset declines in other segments of the construction industry.

Domestic production of portland cement increased slightly, while masonry cement experienced marginal decline. Cement imported for consumption declined for the third year, making up 14% of apparent consumption compared with 19% experienced in the record year of 1987.

After approximately a decade of filing petitions alleging that foreign cement was being dumped in U.S. markets, the industry received a favorable ruling from the International Trade Commission (ITC) on Mexican cement imports.

Cement prices improved for the second straight year following 6 years of depression.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for cement are developed by means of the portland and masonry cement voluntary survey. Of the 125 cement manufacturing plants to which an annual survey collection request was made, 123 responded, representing 98.4% of the cement production and consumption data shown in table 1. Estimates were made for nonrespondents using monthly survey data and data received from previous annual surveys.

BACKGROUND

Definitions, Grades, and Specifications

Section 4 of the Annual Book of the American Society for Testing and Materials (ASTM) publishes standards, test methods, definitions, recommended practices, classifications, and specifications for cement, lime, and gypsum.[1] Following is a brief discussion of various types of hydraulic cements and the materials from which they are made.

TABLE 1

SALIENT CEMENT STATISTICS

(Thousand short tons unless otherwise specified)

		1986	1987	1988	1989	1990
United States:[1]						
Production[2]		78,786	78,198	76,867	77,189	77,111
Shipments from mills[2 3]		87,592	89,246	89,460	86,238	86,200
Value[2 3 4]	thousands	$4,407,722	$4,393,684	$4,370,463	$4,242,931	$4,280,105
Average value per ton[2 3 4]		$50.32	$49	$49	$49	$50
Stocks at mills,[2] Dec. 31		6,725	6,159	5,997	6,300	6,214
Exports		59	52	101	512	554
Imports for consumption		16,091	17,536	17,298	15,548	12,980
Consumption, apparent[5 6]		91,501	93,886	93,256	90,676	89,623
World: Production		r1,110,608	r1,160,473	1,171,836	p1,248,916	e1,251,112

eEstimated. pPreliminary. 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.

Clinker.—Clinker is produced by heating a properly proportioned mixture of finely ground raw materials containing calcium carbonate, silica, alumina, and iron oxide in a kiln to a temperature of about 2,700° F at which partial fusion occurs. The fused material, which ranges from fine sand grains to walnut size, is ground with small amounts, 3% to 5%, of calcium sulfate, usually gypsum or anhydrite, to make portland cement.

Portland Cement.—ASTM specification C-150 covers five types of portland cement: Type I, for use when special properties specified for other types are not required; Type II, for general use, especially when moderate sulfate resistance or moderate heat of hydration is desired; Type III, for use when high early strength is required; Type IV, for use when a low heat of hydration is desired; and Type V, for use when high sulfate resistance is required. ASTM specifications also include Type IA, Type IIA, and Type IIIA for the same uses but with the addition of air entraining compounds to protect concrete against freeze-thaw damage.

White Cement.—White cement is made from iron-free materials of exceptional purity, usually limestone, china clay or kaolin, and silica. The clinker is burned with a reducing flame in the kiln and rapidly quenched in a water spray to keep any iron in the ferrous state to avoid coloration by ferric ions. The clinker is then ground with high-purity white gypsum using ceramic balls and liners in grinding mills. White cement is used in decorative concrete, including terrazzo, highway lane markers, and architectural concrete.

Masonry Cement.—Masonry cement is a hydraulic cement used in mortars for masonry construction. It contains one or more of the following materials: portland cement, portland-pozzolan cement, slag cement, or hydraulic lime, usually with hydrated lime, limestone, chalk, calcareous shale, talc, slag, or clay interground for plasticity. ASTM designation C-91 contains specifications for masonry cement.

Blended Hydraulic Cement.—ASTM designation C-595 covers four kinds of blended hydraulic cements, each with an optional provision for air entraining.

Portland-Blast Furnace Slag.—This is essentially an intimately interground mixture of portland cement clinker and granulated blast furnace slag, or an intimate and uniform blend of portland cement and fine granulated blast furnace slag in which the slag constituent ranges between 25% to 70% of the total weight of the cement.

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 constituents at least 70% of the total weight of the blended 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.

Oil-Well Cement.—Oil-well cement was developed to seal oil and gas wells under pressures up to 1,800 pounds per square inch and temperatures up to 350° F. This cement must remain fluid up to about 4 hours to be effective.

Expansive Cement.—Expansive cement is a hydraulic cement that tends to increase in volume after setting during the early hardening period. There are three types of expansive cements, Types K, M, and S. Expansive cements are used primarily in shrinkage-compensating concrete. ASTM specification C-845 covers all expansive cements.

Aluminous Cement.—Sometimes known as calcium aluminate cement, high alumina cement, or "Ciment Fondu," aluminous cement is a hydraulic nonportland cement. Special applications of aluminous cement are based on its rapid-hardening qualities, resistance to sulfate action, and refractory properties when used as "castable refractories" and mortars for furnaces and kilns.

Concrete.—Concrete is a proportioned mixture of coarse mineral aggregates of sand and gravel or crushed stone, bound together by a paste of hydraulic cement and water. Volume 04.02 of ASTM standards covers concrete and aggregates.

Products For Trade and Industry

Portland cement makes up 96% of total domestic output; the remainder is mostly masonry cement. About 92% of total portland cement production in 1990 comprised Types I and II cement, and 4% was Type III. Type V and oil well cements accounted for 1% each. White, expansive, portland slag and pozzolan, waterproof, and a variety of miscellaneous cements accounted for the balance. Each product requires either a change in proportion of raw materials mixed for kiln feed or additives to make clinker.

Industry Structure

The industry is composed of 125 cement-producing plants in 39 States. Multiplant operations were being run by 23 companies. Because of overall poor financial performance by the industry during the 1980's, many companies have left the cement business or closed plants and began importing finished cement or clinker for grinding into finished cement. Fifteen independent importers have constructed terminals to receive foreign cement for markets near coastal areas. The industry has also undergone dramatic changes in ownership. At yearend, foreign investors controlled approximately 65% of U.S. production capacity.

Resources

Primary raw materials required for ce-

ment clinker production are, in order of importance, limestone, clay and shale, and iron ore. In instances where essential chemical components are not present in primary raw materials in the required amount, other mined materials or industrial products may be used as additives to correct these deficiencies. Gypsum is added during the clinker grinding process to make finished portland cement.

Although raw materials for cement manufacturing have not been quantified, they are abundant in most countries. Some countries deficient in raw materials meet their requirements by importing. Many domestic companies have reported reserves of raw materials exceeding 100 years of supply.

Technology

Principal steps in manufacturing portland cement consist of crushing, grinding, mixing, and burning raw materials and grinding the resultant clinker. About 1.8 tons of raw materials is required to make 1 ton of cement.

Raw Material Grinding.—Both dry and wet grinding are used to obtain a fineness that may range from 75% to 90% passing through a 200-mesh sieve. In wet milling, water is added with the mill feed to produce a slurry containing about 65% solids. The raw material is then dried and ground for burning.

Burning.—Burning is the most important operation in manufacturing cement because fuel consumption is a major expense, plant capacity is measured by kiln output, and strength and other properties of cement depend on the quality of the clinker. Burning takes place in a rotary kiln that is a refractory-lined steel cylindrical shell. It rotates on an axis inclined at ⅜ to ½ 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. Extreme 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.—Cement production costs are determined by such factors as plant location, plant age and level of modernization, type of production process used, the availability of raw materials, and labor. Energy represents by far the largest portion of production costs, accounting for up to 40% of the total. The industry has had considerable success in stabilizing production costs by undertaking modernization projects that not only conserve energy but increase production capacity.

Tariffs.—For countries with most-favored-nation status, duties are imposed only on white cement in the amount of 22 cents per metric ton, including the weight of containers. Other hydraulic cement and clinker are duty free. The statutory import duty for countries without most-favored-nation status is $1.76 per metric ton and $1.32 per metric ton for all other types of cement and clinker, respectively.

Operating Factors

Environmental Requirements.—Since the 1970's, the U.S. cement industry has been required to make substantial capital investments in order to comply with environmental restrictions. The biggest source of pollution associated with cement production is controlling dust from kilns and clinker coolers. That requires the installation of dust collectors such as bag houses and electrostatic precipitators, both of which add considerably to operating costs without improving production. In addition to meeting air quality standards, the industry must also comply with water quality, land use, health and safety, and noise requirements. It has been estimated that capital costs for meeting these requirements can account for 20% to 25% of the capital expenditures for new plants and major additions.

Employment.—In 1990, the U.S. cement industry employed approximately 19,900 workers, including individuals employed in mining and milling operations. Employment in the industry has continued to decline primarily because automated process control technology permits greater productivity with fewer employees.

Energy Requirements.—The U.S. cement industry is one of the largest users of energy, consuming about 283 trillion British thermal units (Btu's) in 1990. Substantial energy savings have been achieved since the Federal Government implemented the voluntary energy conservation program in 1972. The installation of improved raw material grinding and processing technology, the use of preheater-precalciner systems for burning raw materials, the conversion from wet to dry process, and the conversion from oil and gas to coal for kiln firing all contributed to improved energy efficiency. Further improvements in energy consumption will result as technological and institutional barriers to the use of municipal, industrial, and hazardous wastes for kiln firing are removed.

ANNUAL REVIEW

Issues

The primary issue facing the cement industry is a lack of investment capital for new plant construction or capacity modernization and expansion. Foreign import penetration into coastal markets and regional competition among domestic producers have combined to reduce the profitability of the U.S. industry. The lack of domestic investment capital has opened the door for foreign investors who now own more than two-thirds of U.S. cement production capacity.

Production

One State agency and 49 companies operated 125 plants in 39 States. In addition, two companies operated two plants in Puerto Rico, manufacturing hydraulic cement. The production data obtained are arranged by State or groups of States that form cement districts. A cement district may represent a group of States or a portion of a State. The States of California, Illinois, New York, Pennsylvania, and Texas are divided to provide more definitive marketing information within those States as follows:

California, Northern.—Points north and west of the northern borders of San Luis Obispo and Kern Counties and the western borders of Inyo and Mono Counties.

California, Southern.—All other counties in California.

Chicago, Metropolitan.—The seven Illinois counties of Cook, DuPage, Kane, Kendall, Lake, McHenry, and Will.

Illinois.—All other counties in Illinois.

New York, Western.—All counties west of a dividing line following the eastern boundaries of Broome, Chenango, Lewis, Madison, Oneida, and St. Lawrence Counties.

New York, Eastern.—All counties east of the aforementioned dividing line, except Metropolitan New York.

New York, Metropolitan.—The five counties of New York City (Bronx, Kings, New York, Queens, and Richmond) plus Nassau Counties, Rockland, Suffolk, and Westchester.

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 Production.—Clinker production in the United States, excluding Puerto Rico, increased slightly to 69.8 million tons. California continued to lead all States in clinker production, followed by Texas, Pennsylvania, Michigan, and Missouri. Together these five States accounted for 46% of total U.S. clinker production.

By yearend, multiplant operations were being run by 23 companies. The size of individual companies, as a percentage of total U.S. clinker production capacity, ranged from 0.3% to 6%. The 5 largest producers provided 30% of total clinker production; the 10 largest producers provided a combined 52%. The 10 largest companies, in decreasing order of size of clinker production, were Holnam Inc., Lafarge Corp., Southdown Inc., Lone Star Industries Inc., CalMat Co., Lehigh Portland Cement Co., Ash Grove Cement Co., Blue Circle Inc., Medusa Cement Co., and Gifford-Hill and Co.

Portland Cement.—Portland cement production increased slightly to 73.9 million tons. This was the second year that production increased after 2 consecutive years of decline. The increase was attributed to less reliance on imports of finished cement to satisfy demand primarily in the north-central and south-central areas of the United States.

The industry operated 120 plants, including 8 grinding facilities, to produce various types of finished hydraulic cement compared with 122 plants in 1989. California continued to lead all States in the production of cement, followed by Texas, Pennsylvania, Michigan, and Missouri. Together these five States accounted for 46% of total U.S. cement production.

The size of individual companies, as a percentage of total U.S. finished cement production capacity, ranged from 0.4% to 7.0%. The top 10 producing companies, in declining order of production, were Holnam Inc., Lafarge Corp., Southdown Inc., Lone Star Industries Inc., Lehigh Portland Cement Co., Ash Grove Cement Co., Blue Circle Inc., Gifford-Hill and Co., CalMat Co., and Medusa Cement Co.

Masonry Cement.—Production of masonry cement declined 3% to 3.2 million tons. At yearend, 80 plants were manufacturing masonry cement in the United States. Two plants producing masonry exclusively were Chaney Lime & Cement Co., Algood, AL; and Riverton Corp., Riverton, VA.

Aluminous Cement.—Aluminous cement continued to be produced by Lehigh, Buffington, IN; Lone Star Lafarge, Chesapeake, VA; and Aluminum Co. of America, Bauxite, AR.

Fuel Consumption.—The average energy consumption per ton of clinker produced was 3.9 million Btu, about the same as that required in 1989. Coal accounted for 92% of the fuel used. Oil and gas accounted for 4% each. The consumption of electrical energy remained at the equivalent of 1.1 million Btu per ton. Average fuel consumption for kiln firing plus electricity for grinding was 5.0 million Btu per ton. Fuel used in wet-process plants was 4.5 million Btu per ton, 27% higher than the dry process of 3.3 million Btu per ton. Approximately 65% of clinker was produced by the dry process method.

The industry reported 61 suspension and 10 grate preheaters in use during the year. Kilns without preheaters averaged 4.6 million Btu per ton, those with suspension preheaters averaged 3.3 million Btu per ton, and those with grate-type preheaters averaged 4.9 million Btu per ton.

Corporate Changes.—Lone Star Falcon, an import terminal owned by a joint venture between Lone Star Industries and Falcon Cement Co., was leased by Gulf Coast Portland Cement Co. Gulf Coast also acquired Sun Star Cement Co., an affiliate of Cementos Mexicanos, Mexico's largest cement company. Cementos Mexicanos also purchased the remaining 50% interest in Pacific Coast Cement Co., an import terminal in Long Beach, CA. Ciment Francais, a French-based company, acquired two plants from Carlow Group Companies—Bessemer, PA, and Middlebranch, OH. Carlow retained its Zanesville, OH, plant. Onoda Cement Co. of Japan acquired Lone Star Industries interest in their joint venture, Lone Star Northwest, which included cement distribution terminals in Alaska, Oregon, and Washington. Onoda also purchased the Los Angeles-based CalMat Co., including plants and terminals in Arizona and California. Pioneer Concrete Co. of America Inc. acquired 50% interest in the Midlothian, TX, plant of Beazer PLC of Great Britain. The plant was formerly owned by Gifford-Hill and Co. The plant name was changed to North Texas Cement Co.

Consumption and Uses

Consumer demand for cement in the United States, excluding Puerto Rico, declined slightly to 89.6 million tons. This was the third year of decline following 5 consecutive years of growth after the 20-year low experienced at the depth of the

recession in 1982. Cement consumption mirrored construction activity in most segments of the building construction industry throughout the country. According to U.S. Department of Commerce data, housing starts declined 13% to 1.2 million units. The value of new construction put in place was virtually unchanged at $434 billion. The value of residential construction put in place declined 5% to $186 billion, primarily in single-unit structures. The value of nonresidential construction put in place declined slightly to $102 billion, owing primarily to decreases in office and other commercial building construction. Public construction experienced the biggest increase, 15%, caused primarily by increases in spending for public buildings, highways and streets, military facilities, sewer systems, and water supply facilities.[2]

Among the consuming States, California continued to lead all areas in the amount of portland cement consumed, followed by, in order of shipments received, Texas, Florida, Illinois, Ohio, and Pennsylvania. Together, these States consumed 42% of total U.S. tonnage.

TABLE 2

PORTLAND CEMENT PRODUCTION, CAPACITY, AND STOCKS IN THE UNITED STATES, BY DISTRICT[1]

District	1989					1990				
	Plants active during year	Production[3] (thousand short tons)	Capacity[2] Finish grinding (thousand short tons)	Capacity[2] Percent utilized	Stocks[4] at mills, Dec. 31 (thousand short tons)	Plants active during year	Production[3] (thousand short tons)	Capacity[2] Finish grinding (thousand short tons)	Capacity[2] Percent utilized	Stocks[4] at mills, Dec. 31 (thousand short tons)
New York and Maine	5	2,980	4,265	69.8	308	5	3,174	4,315	73.5	298
Pennsylvania, eastern	8	4,492	5,771	77.8	435	8	4,325	5,771	74.9	357
Pennsylvania, western	4	1,513	2,417	62.5	176	4	1,364	2,195	62.1	160
Maryland	3	1,884	2,030	92.8	185	3	1,807	2,030	89.1	228
Ohio	4	1,449	2,200	65.8	153	4	1,409	2,200	64.0	106
Michigan	5	5,266	6,090	86.4	335	5	5,679	6,090	93.2	306
Indiana	4	2,469	3,140	78.6	224	4	2,462	3,090	79.6	196
Illinois	4	2,700	2,750	98.2	283	4	2,662	2,750	96.8	301
Georgia and Tennessee	4	1,987	2,595	76.5	192	4	2,141	2,595	82.5	247
South Carolina	3	2,270	3,306	68.6	140	3	2,266	3,330	68.0	135
Kentucky, Virginia, West Virginia	3	2,277	3,132	72.7	227	3	2,436	3,122	78.0	224
Florida	6	3,804	4,660	81.6	290	5	2,912	4,675	62.3	299
Alabama	5	3,411	5,276	65.9	302	5	3,629	5,276	68.7	192
Arkansas and Mississippi	3	1,191	2,200	54.1	75	3	1,300	2,225	58.4	83
South Dakota	1	W	W	W	W	1	W	W	W	W
Iowa	4	2,230	2,725	81.8	323	4	2,585	2,725	94.9	264
Missouri	5	4,418	4,780	92.4	287	5	4,663	4,863	95.8	377
Kansas	5	1,544	2,425	63.6	208	5	1,709	2,224	76.8	203
Oklahoma	3	1,526	2,048	74.5	217	3	1,406	1,873	75.0	218
Texas, northern	7	3,217	5,825	55.2	286	7	3,296	5,167	63.7	260
Texas, southern	6	4,204	5,712	73.6	186	6	4,343	6,063	71.6	192
Idaho, Montana, Utah	5	W	W	W	W	5	1,760	2,095	84.0	155
Colorado, Nebraska, Wyoming	5	W	W	W	W	5	2,152	3,920	54.9	187
Alaska, Oregon, Washington	4	W	W	W	W	3	W	W	W	W
Arizona, Nevada, New Mexico	4	1,949	3,060	63.7	97	4	2,048	3,060	66.9	126
California, northern	3	3,150	3,175	99.2	99	3	2,931	3,175	92.3	101
California, southern	8	7,796	8,357	93.2	332	8	7,129	8,001	89.1	288
Hawaii	1	474	600	79.0	46	1	527	600	87.8	39
Total or average	122	73,895	98,104	75.3	5,847	120	73,902	96,810	76.3	5,768
Puerto Rico	2	1,370	2,116	64.7	34	2	1,495	2,116	70.6	31

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

[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 1989-90) 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 cement produced from imported clinker (1989—1,932,281 tons, 1990—1,759,197 tons).

[4]Includes imported cement. Source of imports withheld to avoid disclosing company proprietary data.

TABLE 3

CLINKER CAPACITY AND PRODUCTION IN THE UNITED STATES,[1] BY DISTRICT, AS OF DECEMBER 31, 1990

District	Active plants			Total	Number of kilns	Daily capacity (thousand short tons)	Average number of days for maintenance	Apparent annual capacity[2] (thousand short tons)	Production[3] (thousand short tons)	Percent utilized
	Process used									
	Wet	Dry	Both							
New York and Maine	4	1	—	5	6	12	80	3,309	2,850	86.1
Pennsylvania, eastern	2	5	—	7	16	16	61	4,870	4,362	89.5
Pennsylvania, western	3	1	—	4	8	6	11	2,125	1,306	61.4
Maryland	1	2	—	3	7	6	39	1,956	1,833	93.7
Ohio	2	—	1	3	6	6	72	1,763	1,340	76.0
Michigan	2	2	—	4	9	16	59	4,902	4,834	98.6
Indiana	2	2	—	4	8	11	40	2,601	2,535	97.4
Illinois	—	4	—	4	8	8	53	2,497	2,458	98.4
Georgia and Tennessee	1	2	1	4	7	7	25	2,380	2,087	87.6
South Carolina	2	1	—	3	7	8	57	2,469	2,358	95.5
Kentucky, Virginia, West Virginia	1	2	—	3	9	8	48	2,661	2,338	87.9
Florida	2	2	—	4	8	10	10	3,553	2,538	71.4
Alabama	—	5	—	5	6	13	43	4,191	3,142	74.9
Arkansas and Mississippi	3	—	—	3	6	6	52	1,883	1,303	69.1
South Dakota	—	—	1	1	4	W	33	W	W	W
Iowa	—	3	—	3	5	8	62	2,124	2,120	99.8
Missouri	2	3	—	5	7	15	68	4,456	4,451	99.8
Kansas	3	2	—	5	15	7	66	2,097	1,686	80.4
Oklahoma	1	2	—	3	7	6	66	1,798	1,332	74.0
Texas, northern	3	3	—	6	14	14	49	4,424	3,389	76.6
Texas, southern	—	4	1	5	6	14	45	4,484	4,079	90.9
Idaho, Montana, Utah	4	1	—	5	7	5	30	1,679	1,675	99.7
Colorado, Nebraska, Wyoming	1	4	—	5	8	10	62	3,036	2,030	66.8
Alaska, Oregon, Washington	1	1	—	2	2	W	125	W	W	W
Arizona, Nevada, New Mexico	—	4	—	4	11	8	44	2,573	1,843	71.6
California, northern	—	3	—	3	3	10	64	3,012	3,010	99.9
California, southern	1	7	—	8	22	26	41	8,442	6,772	80.2
Hawaii	—	1	—	1	1	1	119	246	215	87.3
Total or average[4]	41	67	4	112	223	262	52	81,463	69,805	85.7
Puerto Rico	2	—	—	2	8	6	126	1,438	1,134	78.8

W Withheld to avoid disclosing company proprietary data; included in "Total."
[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

DAILY CLINKER CAPACITY IN THE UNITED STATES,[1] DECEMBER 31, 1990

Short tons per 24-hour period	Number		Total capacity (short tons)	Percent of total capacity
	Plants	Kilns[2]		
1989:				
Less than 1,150	13	21	10,782	4.0
1,151 to 1,700	30	53	44,156	16.3
1,701 to 2,300	24	41	50,647	18.6
2,301 to 2,800	16	33	39,960	14.7
2,801 and more	33	86	126,139	46.4
Total	116	234	271,684	100.0

See footnotes at end of table.

TABLE 4—Continued

DAILY CLINKER CAPACITY IN THE UNITED STATES,[1] DECEMBER 31, 1990

Short tons per 24-hour period	Number		Total capacity (short tons)	Percent of total capacity
	Plants	Kilns[2]		
1990:				
Less than 1,150	12	21	8,457	3.2
1,151 to 1,700	30	53	43,543	16.3
1,701 to 2,300	25	45	46,415	17.3
2,301 to 2,800	15	27	37,468	14.0
2,801 and more	32	85	131,651	49.2
Total	114	231	267,534	100.0

[1]Includes Puerto Rico and white-cement-producing facilities.
[2]Total number in operation at plants.

TABLE 5

RAW MATERIALS USED IN PRODUCING PORTLAND CEMENT IN THE UNITED STATES[1]

(Thousand short tons)

Raw materials	1988	1989	1990
Calcareous:			
Limestone (includes aragonite, marble, chalk)	79,517	81,792	86,098
Cement rock (includes marl)	23,398	21,920	20,239
Coral	783	911	1,128
Other	9	13	17
Argillaceous:			
Clay	4,784	4,801	4,661
Shale	4,126	4,289	4,447
Other (includes staurolite, bauxite, aluminum dross, alumina, volcanic material, other)	310	436	565
Siliceous:			
Sand and calcium silicate	2,011	1,991	1,839
Sandstone, quartzite, other	993	605	770
Ferrous: Iron ore, pyrites, millscale, other iron-bearing material	1,036	1,026	1,031
Other:			
Gypsum and anhydrite	4,174	4,254	3,858
Blast furnace slag	86	181	168
Fly ash	940	905	696
Other, n.e.c.	348	356	317
Total	122,515	123,480	[2]125,835

[1]Includes Puerto Rico.
[2]Data do not add to total shown because of independent rounding.

On a regional basis, only three of the nine Census regions, East South Central, West South Central, and West North Central, experienced increases in consumption. The East North Central and Mountain regions remained unchanged, while the remaining regions experienced marginal declines.

Shipments of domestically produced portland cement from U.S. mills improved slightly, while masonry cement shipments were virtually unchanged. Cement imported for consumption declined by 17%. This was the third consecutive year that imports declined and accounted for only 14% of apparent consumption compared with 17% in 1989.

Ready-mix concrete producers were the primary consumers of cement, accounting for about 72% of the total, followed by concrete product manufacturers with 12%, highway contractors with 5%, building material dealers with 4%, and other contractors with 3%. Smaller amounts were consumed by Federal, State, and other government agencies and by a variety of other miscellaneous users.

Transportation

The pattern of cement transport did not differ significantly from that of recent years. U.S. shipments of portland cement to consumers were primarily in bulk, 96%;

TABLE 6

MASONRY CEMENT PRODUCTION AND STOCKS IN THE UNITED STATES, BY DISTRICT

District	1989			1990		
	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	139	15	4	115	17
Pennsylvania, eastern	6	252	40	6	230	41
Pennsylvania, western	4	90	13	4	75	14
Maryland	2	W	W	2	W	W
Ohio	3	129	19	3	131	19
Michigan	4	242	41	4	270	38
Indiana	4	369	67	4	360	54
Illinois	1	W	W	—	—	6
Georgia and Tennessee	4	193	29	4	176	32
South Carolina	2	W	W	2	W	W
Kentucky, Virginia, West Virginia	4	305	19	4	294	25
Florida	4	487	29	4	437	29
Alabama	5	205	41	5	211	32
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	127	8	3	127	11
Kansas	5	45	24	5	30	15
Oklahoma	2	W	W	2	W	W
Texas, northern	5	87	12	4	77	10
Texas, southern	3	55	9	4	62	9
Idaho, Montana, Utah	3	W	W	3	12	4
Colorado, Nebraska, Wyoming	3	W	W	3	26	6
Arizona, Nevada, New Mexico	3	56	6	3	55	6
California, southern	1	W	W	1	W	W
Hawaii	1	10	1	1	12	1
Total or average[2]	81	3,294	453	80	3,209	446

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Includes imported cement.
[2]Data may not add to totals shown because of independent rounding.

TABLE 7

CLINKER PRODUCED IN THE UNITED STATES,[1] BY FUEL

Fuel	Clinker produced			Fuel consumed		
	Plants active during year	Quantity (thousand short tons)	Percent of total	Coal[2] (thousand short tons)	Oil (thousand 42-gallon barrels)	Natural gas (thousand cubic feet)
1989:						
Coal	10	7,747	11.0	1,390	—	—
Natural gas	2	563	.8	—	—	102,486
Coal and oil	25	18,103	25.7	3,067	331	—
Coal and natural gas	50	30,248	42.9	4,371	—	7,077,874
Oil and natural gas	4	737	1.0	—	208	295,301
Coal, oil, natural gas	25	13,077	18.6	1,763	681	2,854,863
Total	116	70,475	100.0	10,591	1,220	10,330,524

See footnotes at end of table.

TABLE 7—Continued

CLINKER PRODUCED IN THE UNITED STATES,[1] BY FUEL

Fuel	Clinker produced			Fuel consumed		
	Plants active during year	Quantity (thousand short tons)	Percent of total	Coal[2] (thousand short tons)	Oil (thousand 42-gallon barrels)	Natural gas (thousand cubic feet)
1990:						
Coal	5	3,345	4.7	701	—	—
Natural gas	3	1,651	2.3	—	—	151,015
Coal and oil	29	19,246	27.2	3,006	572	—
Coal and natural gas	51	30,664	43.2	4,663	—	7,014,026
Oil and natural gas	3	801	1.1	—	179	178,610
Coal, oil, natural gas	23	15,233	21.5	2,077	1,130	3,054,608
Total	114	70,940	100.0	10,447	1,881	10,398,259

[1]Includes Puerto Rico.
[2]Includes 1% anthracite, 98% bituminous coal, and 1% petroleum coke in 1989, and 4% anthracite, 92% bituminous coal, and 4% petroleum coke in 1990.

TABLE 8

CLINKER PRODUCED AND FUEL CONSUMED BY THE PORTLAND CEMENT INDUSTRY IN THE UNITED STATES,[1] BY PROCESS

Process	Clinker produced			Fuel consumed		
	Plants active during year	Quantity (thousand short tons)	Percent of total	Coal[2] (thousand short tons)	Oil (thousand 42-gallon barrels)	Natural gas (thousand cubic feet)
1989:						
Wet	43	22,132	31.4	3,892	708	2,642,033
Dry	71	47,165	66.9	6,509	512	7,627,432
Both	2	1,178	1.7	190	—	61,059
Total	116	70,475	100.0	10,591	1,220	10,330,524
1990:						
Wet	43	22,633	31.9	3,730	1,278	2,797,345
Dry	67	45,986	64.8	6,411	599	7,487,272
Both	4	2,321	3.3	306	4	113,642
Total	114	70,940	100.0	10,447	1,881	10,398,259

[1]Includes Puerto Rico.
[2]Includes 1% anthracite, 98% bituminous coal, and 1% petroleum coke in 1989, and 4% anthracite, 92% bituminous coal, and 4% petroleum coke in 1990.

TABLE 9

ELECTRIC ENERGY USED AT PORTLAND CEMENT PLANTS IN THE UNITED STATES,[1] BY PROCESS

Process	Electric energy used						Finished cement produced (thousand short tons)	Average electric energy used per ton of cement produced (kilowatt-hours)
	Generated at portland cement plants		Purchased		Total			
	Active plants	Quantity (million kilowatt-hours)	Active plants	Quantity (million kilowatt-hours)	Quantity (million kilowatt-hours)	Percent		
1989:								
Wet	—	—	44	2,823	2,823	28.2	23,018	122.6
Dry[2]	5	807	75	6,190	6,997	70.0	50,983	137.2

See footnotes at end of table.

TABLE 9—Continued

ELECTRIC ENERGY USED AT PORTLAND CEMENT PLANTS IN THE UNITED STATES,[1] BY PROCESS

Process	Electric energy used						Finished cement produced (thousand short tons)	Average electric energy used per ton of cement produced (kilowatt-hours)
	Generated at portland cement plants		Purchased		Total			
	Active plants	Quantity (million kilowatt-hours)	Active plants	Quantity (million kilowatt-hours)	Quantity (million kilowatt-hours)	Percent		
1989—Continued								
Both	—	—	2	176	176	1.8	1,264	139.2
Total or average	5	807	121	9,189	9,996	100.0	75,265	132.8
Percent of total electric energy used	—	8.1	—	91.9	—	—	—	—
1990:								
Wet	3	171	41	2,753	2,924	29.0	23,895	122.4
Dry[2]	6	561	71	6,264	6,825	67.7	49,118	139.0
Both	—	—	4	327	327	3.3	2,382	137.2
Total or average	9	732	116	9,344	10,076	100.0	75,395	133.6
Percent of total electric energy used	—	7.3	—	92.7	—	—	—	—

[1]Includes Puerto Rico. Includes grinding plants and white cement facilities.
[2]Includes data for grinding plants.

TABLE 10

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				Total shipments[2]
			From terminal to consumer		From plant to consumer		
	In bulk	In containers	In bulk	In containers	In bulk	In containers	
1989:							
Railroad	8,915	47	1,525	—	3,041	12	4,579
Truck	3,408	212	27,210	495	44,488	3,260	75,453
Barge and boat	9,392	13	2,879	—	214	—	3,092
Unspecified[3]	517	—	495	9	581	18	1,103
Total[2]	22,232	273	32,109	504	48,324	3,291	[4]84,229
1990:							
Railroad	9,925	72	1,733	15	3,834	24	5,607
Truck	3,621	207	27,134	522	44,551	3,035	75,242
Barge and boat	9,149	22	2,191	—	127	—	2,318
Unspecified[3]	480	—	449	2	727	26	1,204
Total[2]	23,176	301	31,507	539	49,239	3,086	[5]84,370

[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 95.5% and container (bag) shipments were 4.5%.
[5]Bulk shipments were 95.7% and container (bag) shipments were 4.3%.

by truck, 89%; and made directly from cement manufacturing plants (rather than from distribution terminals), 58%.

With respect to shipments of cement from plants to terminals, the preferred modes of transportation were railroads, 43%; waterways, 39%; and by truck, 16%. The remaining 2% was used by producers at the plant.

TABLE 11

PORTLAND CEMENT SHIPPED BY PRODUCERS IN THE UNITED STATES, BY DISTRICT[1]

District	1989			1990		
	Quantity (thousand short tons)	Value (thousands)	Average per ton	Quantity (thousand short tons)	Value (thousands)	Average per ton
New York and Maine	2,999	153,319	51	3,321	168,247	51
Pennsylvania, eastern	4,259	230,506	54.12	4,270	222,026	51.99
Pennsylvania, western	1,498	71,474	47.70	1,351	64,159	47.50
Maryland	1,871	94,002	50.25	1,798	91,172	50.70
Ohio	1,446	73,230	50.64	1,426	72,883	51.11
Michigan	5,449	253,324	46.49	5,906	263,607	44.64
Indiana	2,364	108,297	45.81	2,417	114,414	47.34
Illinois	2,776	117,224	42.23	2,842	116,781	41.10
Georgia and Tennessee	2,072	100,818	48.66	2,211	104,884	47.44
South Carolina	2,188	99,083	45.28	2,464	109,644	44.50
Kentucky, Virginia, West Virginia	2,288	114,077	49.86	2,478	125,068	50.46
Florida	4,357	207,857	47.71	3,954	186,401	47.14
Alabama	3,169	130,590	41.21	3,585	165,344	46.13
Arkansas and Mississippi	1,234	48,414	39.24	1,319	53,806	40.80
South Dakota	W	W	W	W	W	W
Iowa	2,072	102,387	49.42	2,525	122,466	48.50
Missouri	4,922	182,005	36.98	4,481	180,090	40.19
Kansas	1,505	69,390	46.12	1,707	76,564	44.85
Oklahoma	1,236	39,360	31.85	1,544	60,457	39.17
Texas, northern	3,293	155,937	47.36	3,317	147,987	44.62
Texas, southern	3,907	130,300	33.35	4,361	148,692	34.09
Idaho, Montana, Utah	W	W	W	1,644	95,589	58.13
Colorado, Nebraska, Wyoming	W	W	W	2,109	98,316	46.63
Alaska, Oregon, Washington	W	W	W	W	W	W
Arizona, Nevada, New Mexico	2,234	130,749	58.53	2,264	134,556	59.44
California, northern	3,127	184,543	59.02	2,883	176,337	61.16
California, southern	7,784	457,476	58.77	7,149	427,743	59.84
Hawaii	493	40,495	82.17	532	46,311	87.01
Total[2 3] or average	74,202	3,592,252	48.41	75,596	3,683,400	48.72
Foreign imports[4]	8,653	416,988	48.19	7,288	368,335	50.54
Puerto Rico	1,374	112,318	81.77	1,486	122,027	82.09
Grand total[3 5] or average	84,229	4,121,558	48.93	84,370	4,173,762	49.47

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

[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 1989-90) as follows: Alaska (1), Florida (2), Iowa (1), Michigan (1), Pennsylvania (1), and Texas (2).

[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 12

MASONRY CEMENT SHIPPED BY PRODUCERS IN THE UNITED STATES, BY DISTRICT[1]

District	1989			1990		
	Quantity (thousand short tons)	Value (thousands)	Average per ton	Quantity (thousand short tons)	Value (thousands)	Average per ton
New York and Maine	155	$8,925	$57.74	122	$7,057	$58.05
Pennsylvania, eastern	254	18,577	73.22	226	16,412	72.46
Pennsylvania, western	95	7,895	82.78	76	6,182	81.21

See footnotes at end of table.

TABLE 12—Continued

MASONRY CEMENT SHIPPED BY PRODUCERS IN THE UNITED STATES, BY DISTRICT[1]

District	1989			1990		
	Quantity (thousand short tons)	Value (thousands)	Average per ton	Quantity (thousand short tons)	Value (thousands)	Average per ton
Maryland	W	W	W	W	W	W
Ohio	128	$11,233	$88.07	124	$10,880	$87.50
Michigan	255	22,286	87.50	272	23,880	87.82
Indiana	357	24,054	67.36	368	27,813	75.58
Illinois	W	W	W	W	W	W
Georgia and Tennessee	193	13,307	68.98	175	11,286	64.36
South Carolina	W	W	W	W	W	W
Kentucky, Virginia, West Virginia	289	19,463	67.25	296	19,963	67.53
Florida	477	31,231	65.54	442	27,777	62.89
Alabama	252	13,852	54.99	262	15,462	59.08
Arkansas and Mississippi	W	W	W	W	W	W
South Dakota	W	W	W	W	W	W
Iowa	W	W	W	W	W	W
Missouri	123	6,193	50.39	118	5,683	48.17
Kansas	42	2,514	59.44	39	2,011	50.92
Oklahoma	W	W	W	W	W	W
Texas, northern	79	7,010	88.95	77	5,768	74.54
Texas, southern	54	3,725	69.16	64	4,339	67.58
Idaho, Montana, Utah	W	W	W	5	267	54.38
Colorado, Nebraska, Wyoming	W	W	W	24	1,330	54.94
Alaska, Oregon, Washington	W	W	W	5	518	103.60
Arizona, Nevada, New Mexico	57	4,545	79.61	54	4,201	77.22
California, northern	—	—	—	—	—	—
California, southern	W	W	W	W	W	W
Hawaii	10	1,566	160.00	12	1,870	160.00
Total[2] or average	3,329	229,441	68.93	3,274	225,404	68.84
Foreign imports[3]	54	4,250	78.19	41	2,966	71.76
Grand total[2] or average	3,383	233,691	69.08	3,316	228,370	68.88

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Does not include quantities produced on the job by masons.
[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 13

CEMENT SHIPMENTS, BY DESTINATION AND ORIGIN[1]

(Thousand short tons)

Destination and origin	Portland cement[2]			Masonry cement		
	1988	1989	1990	1988	1989	1990
Destination:						
Alabama	1,423	1,266	1,500	122	107	125
Alaska[3]	r95	111	144	W	—	W
Arizona	2,131	2,090	1,971	W	W	W
Arkansas	690	765	803	37	36	43
California, northern	3,958	4,190	3,961	W	W	W
California, southern	8,584	8,851	7,702	W	W	W
Colorado	992	1,082	1,114	13	12	13

See footnotes at end of table.

TABLE 13—Continued

CEMENT SHIPMENTS, BY DESTINATION AND ORIGIN[1]

(Thousand short tons)

Destination and origin	Portland cement[2]			Masonry cement		
	1988	1989	1990	1988	1989	1990
Destination—Continued:						
Connecticut[3]	990	775	707	24	19	17
Delaware[3]	277	268	258	15	12	14
District of Columbia[3]	198	195	247	1	(4)	(4)
Florida	7,002	7,181	6,210	561	556	491
Georiga	3,170	2,666	2,730	238	197	189
Hawaii	355	493	533	10	10	12
Idaho	324	305	354	(4)	(4)	1
Illinois	1,278	1,259	1,354	30	28	27
Chicago, metropolitan[3]	2,294	2,421	2,287	69	69	65
Indiana	1,773	1,865	1,867	108	98	100
Iowa	1,225	1,262	1,362	12	12	15
Kansas	1,147	1,094	1,156	21	18	16
Kentucky	1,138	1,100	1,139	91	83	88
Louisiana	1,527	1,621	1,867	36	34	38
Maine	366	319	272	15	9	7
Maryland	1,722	1,518	1,540	171	136	137
Massachusetts[3]	1,439	1,090	1,008	49	38	29
Michigan	2,720	2,717	2,702	152	141	135
Minnesota[3]	1,464	1,588	1,630	48	42	45
Mississippi	760	705	766	48	43	43
Missouri	2,165	1,971	1,949	48	48	43
Montana	199	172	188	1	1	1
Nebraska	749	829	868	10	10	11
Nevada	1,081	1,256	1,225	(4)	(4)	1
New Hampshire[3]	337	272	254	15	11	8
New Jersey[3]	r1,973	1,813	1,635	83	72	62
New Mexico	507	522	540	6	6	5
New York, eastern	638	637	593	42	36	32
New York, western	1,070	1,036	1,024	55	55	50
New York, metropolitan[3]	r1,622	1,539	1,496	52	49	48
North Carolina[3]	2,179	1,959	2,065	281	241	245
North Dakota[3]	223	208	201	4	3	2
Ohio	3,439	3,451	3,455	205	184	190
Oklahoma	1,061	1,017	999	28	29	30
Oregon	799	844	868	(4)	1	(4)
Pennsylvania, eastern	2,446	2,251	2,061	99	89	82
Pennsylvania, western	1,215	1,100	1,276	79	75	79
Rhode Island[3]	215	189	164	7	6	6
South Carolina	1,213	1,109	1,163	151	126	128
South Dakota	275	289	299	4	5	7
Tennessee	1,698	1,621	1,649	185	161	158
Texas, northern	3,270	3,273	3,316	87	77	80
Texas, southern	3,940	4,017	4,152	66	75	2
Utah	620	741	763	1	2	4
Vermont[3]	209	172	119	6	7	205
Virginia	2,604	2,349	2,132	241	221	9
Washington	r1,660	1,698	1,814	r7	8	34

See footnotes at end of table.

TABLE 13—Continued

CEMENT SHIPMENTS, BY DESTINATION AND ORIGIN[1]

(Thousand short tons)

Destination and origin	Portland cement[2]			Masonry cement		
	1988	1989	1990	1988	1989	1990
Destination—Continued:						
West Virginia	375	361	444	30	29	46
Wisconsin	1,635	1,752	1,793	47	46	1
Wyoming	257	227	258	1	1	
U.S. total[5]	r88,719	87,472	85,948	3,711	3,374	3,300
Foreign countries[6]	184	230	240	33	101	83
Puerto Rico	1,397	1,379	1,487	—	—	—
Total shipment[5]	90,300	89,081	87,675	3,744	3,475	3,383
Origin:						
United States[7]	74,074	74,202	75,596	3,468	3,190	3,142
Puerto Rico	1,397	1,374	1,486	—	—	—
Foreign:[8]						
Domestic producers	11,267	8,653	7,288	r211	264	225
Others	3,562	4,852	3,306	66	22	16
Total shipment[5]	90,300	89,081	87,676	3,744	3,475	3,383

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]Excludes cement (1987—318,000 tons, and 1989—183,935, and 1990—96,432) used in the manufacture of prepared masonary cement.
[3]Has no cement-producing plants.
[4]Less than 1/2 unit.
[5]Data may not add to totals shown because of independent rounding.
[6]Direct shipments by producers to foreign countries and U.S. possessions and territories; includes States indicated by the symbol W.
[7]Includes cement produced from imported clinker by domestic producers.
[8]Imported cement distributed by domestic producers, Canadian cement manufacturers, and other importers. Origin of imports withheld to avoid disclosing company proprietary data.

TABLE 14

CEMENT SHIPMENTS,[1] BY REGION AND SUBREGION

Region and subregion[2]	Portland cement				Masonry cement			
	Thousand short tons		Percent of grand total		Thousand short tons		Percent of grand total	
	1989	1990	1989	1990	1989	1990	1989	1990
Northeast:								
New England	2,818	2,523	3	3	89	71	3	2
Middle Atlantic	8,377	8,085	10	9	376	352	11	11
Total[3]	11,194	10,608	13	12	465	423	14	13
South:								
Atlantic	17,606	16,790	20	20	1,518	1,442	45	44
East Central	4,692	5,054	6	6	394	414	12	13
West Central	10,692	11,138	12	13	251	273	7	8
Total[3]	32,990	32,982	38	39	2,164	2,129	64	64
Midwest:								
East	13,465	13,458	15	16	565	563	17	17
West	7,241	7,465	8	9	139	140	4	4
Total	20,706	20,923	23	25	704	703	21	21
West:								
Mountain	6,396	6,414	7	7	22	24	1	1
Pacific	16,187	15,021	19	17	18	21	—	1
Total[4]	22,583	21,435	26	24	40	45	1	2
Grand total[3]	87,472	85,948	100	100	3,374	3,300	100	100

[1]Includes imported cement shipped to 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 13.

TABLE 15

PORTLAND CEMENT SHIPMENTS IN 1990, 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	
New York and Maine	179	5.4	442	13.3	2,438	73.4	131	3.9	106	3.2	1	0.1	25	.7	3,321
Pennsylvania, eastern	358	8.4	949	22.2	2,721	63.7	99	2.3	38	.9	29	.7	77	1.8	4,270
Pennsylvania, western	128	9.5	160	11.9	902	66.8	109	8.0	19	1.4	—	—	33	2.4	1,351
Maryland	88	4.9	339	18.9	1,265	70.3	41	2.3	51	2.8	—	—	15	.8	1,798
Ohio	53	3.7	195	13.6	1,150	80.7	25	1.8	3	.2	—	—	—	—	1,426
Michigan	211	3.6	635	10.7	4,436	75.1	505	8.6	88	1.5	8	.1	22	.4	5,906
Indiana	87	3.6	267	11.1	1,890	78.2	121	5.0	33	1.4	—	—	18	.7	2,417
Illinois	39	1.4	165	5.8	2,478	87.2	155	5.4	—	—	—	—	5	.2	2,842
Georgia and Tennessee	86	3.9	345	15.6	1,665	75.3	77	3.5	33	1.5	1	—	4	.2	2,211
South Carolina	50	2.0	442	18.0	1,763	71.5	84	3.4	60	2.4	2	.1	64	2.6	2,464
Kentucky, Virginia, West Virginia	105	4.2	358	14.5	1,763	71.1	129	5.2	91	3.7	—	—	32	1.3	2,478
Florida	437	11.1	508	12.8	2,668	67.5	140	3.5	73	1.8	3	.1	126	3.2	3,954
Alabama	250	7.0	493	13.7	2,424	67.6	171	4.8	66	1.9	120	3.3	62	1.7	3,585
Arkansas and Mississippi	56	4.3	132	10.0	856	64.9	143	10.9	94	7.1	11	.8	27	2.0	1,319
South Dakota	W	W	W	W	W	W	W	W	W	W	—	—	W	W	W
Iowa	55	2.2	514	20.3	1,671	66.2	237	9.4	10	.4	7	.3	31	1.2	2,525
Missouri	97	2.2	543	12.1	3,245	72.4	414	9.2	117	2.6	65	1.5	1	—	4,481
Kansas	90	5.3	103	6.0	1,228	71.9	98	5.7	71	4.2	—	.1	117	6.8	1,707
Oklahoma	91	5.8	95	5.1	623	40.3	130	8.4	528	34.2	70	4.5	11	.7	1,544
Texas, northern	137	4.1	305	9.2	1,674	50.4	206	6.2	233	7.0	78	2.4	687	20.7	3,317
Texas, southern	177	4.1	402	9.2	2,963	67.9	300	6.9	128	2.9	11	.3	381	8.7	4,361
Idaho, Montana, Utah	34	2.0	147	9.0	1,170	71.2	57	3.4	122	7.4	16	1.0	99	6.0	1,644
Colorado, Nebraska, Wyoming	57	2.7	194	9.2	1,380	65.6	345	16.3	96	4.5	—	—	38	1.7	2,109
Alaska, Oregon, Washington	W	W	W	W	W	W	W	W	W	W	—	—	W	W	W
Arizona, Nevada, New Mexico	76	3.3	393	17.4	1,401	61.9	23	1.0	268	11.8	9	.4	94	4.2	2,264
California, northern	186	6.5	323	11.2	2,187	75.8	18	.6	39	1.4	—	—	130	4.5	2,883
California, southern	369	5.2	1,058	14.8	5,225	73.1	15	.2	308	4.3	10	.1	166	2.3	7,149
Hawaii	22	4.2	52	9.7	433	81.4	16	3.0	5	.9	2	.4	2	.4	532
Foreign Imports[3]	—	—	207	2.8	7,081	97.2	—	—	—	—	—	—	—	—	7,288
Total[2] or average	3,567	4.4	9,898	11.9	60,050	72.4	3,852	4.6	2,695	3.3	442	.5	2,380	2.9	82,884
Puerto Rico	666	44.8	99	6.6	696	46.8	—	—	25	1.7	1	—	—	—	1,486

W Withheld to avoid disclosing company proprietary date; included in "Total."
[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.

Markets and Prices

The average mill value of portland cement increased slightly for the second straight year following 5 consecutive years of decline. The increase can be attributed to higher production levels and a reduction of imports. Import prices also improved because of increases in transportation costs and the result of antidumping petitions filed by domestic producers. Masonry cement prices declined slightly while the industry experienced a corresponding decline in demand.

The average value of cement as reported by Engineering News—Record (ENR) declined slightly to $62.10 per ton. The ENR prices are based on an average per ton value of cement delivered to 20 cities. The prices ranged from a low of $46.00 in Dallas, TX, to a high of $76 in Detroit.[3]

TABLE 16

PORTLAND CEMENT SHIPPED FROM PLANTS IN THE UNITED STATES,[1] BY TYPE

Type	1989			1990		
	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)	77,597	$3,718,291	$47.92	77,342	$3,758,475	$48.60
High-early-strength (Type III)	3,133	164,291	52.45	3,152	159,311	50.55
Sulfate-resisting (Type V)	758	43,970	58.03	957	55,927	58.45
Oil well	869	42,316	48.70	963	44,286	45.97
White	456	70,715	155.24	415	64,980	156.40
Portland slag and portland pozzolan	545	29,618	54.33	436	23,651	54.30
Expansive	40	3,999	100.62	45	4,405	98.48
Miscellaneous[3]	832	48,358	58.10	1,060	62,727	59.19
Total[4 5] or average	84,229	4,121,558	48.93	84,370	4,173,762	49.47

[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.

FIGURE 1

SHIPMENTS OF CEMENT BY GEOGRAPHIC REGION OF DESTINATION IN 1990

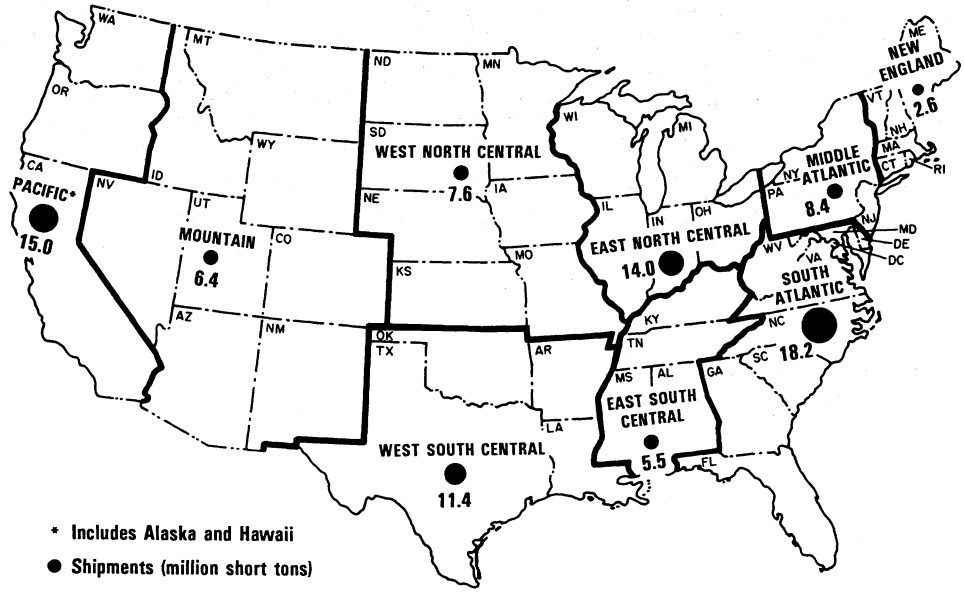

TABLE 17

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
1986	$50.10	$65.68	$50.73
1987	48.79	70.55	49.70
1988	48.55	68.48	49.36
1989	48.93	69.08	49.71
1990	49.47	68.88	50.20

[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.

Foreign Trade

According to trade data reported by the U.S. Department of Commerce, Bureau of the Census, cement imported for consumption into the United States and its possessions and territories was 13.3 million tons or 16% below the level of 1989. This was the third year of decline following 3 consecutive years of record-high imports. The decline corresponded to the marginal decrease in total demand resulting from reduced construction activity. Canada, Mexico, Japan, and Venezuela were the principal import sources, accounting for 69% of the total. The industry continued to find it more economical to import finished cement instead of clinker for grinding. Clinker accounted for 14% of total imports compared with 32% reached in the peak year 1985. This was the fifth consecutive year that clinker imports declined, reaching its lowest level since 1983. The average value of foreign cement and clinker, including cost, insurance, and freight, delivered to American ports averaged $41.67 per ton, up 8% from that of 1989.

Florida led all States in the amount of imports received, accounting for 22% of the total. Sixty-five percent or 1.9 million tons of the Florida imports was shipped through the Tampa Customs District. Imports made up about 46% of Florida's portland cement consumption compared with 14% of apparent consumption nationally. Thirty-nine percent of imports into Florida came from Venezuela. Los Angeles was the second largest recipient of imported cement, receiving 1.9 million

TABLE 18

U.S. EXPORTS OF HYDRAULIC CEMENT AND CEMENT CLINKER, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1988		1989		1990	
	Quantity	Value	Quantity	Value	Quantity	Value
Bahamas	2	161	8	747	12	963
Canada	91	6,381	447	18,609	449	30,569
Ghana	2	133	14	1,018	10	712
Mexico	4	1,164	27	2,120	31	2,509
Netherlands	(1)	31	1	139	3	274
Other[2]	2	1,037	15	2,928	49	3,279
Total	101	8,907	512	25,561	554	38,306

[1]Less than 1/2 unit.
[2]Includes 27 countries in 1988, 37 in 1989, and 58 in 1990.
Source: Bureau of the Census.

TABLE 19

U.S. IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1988			1989			1990		
	Quantity	Value		Quantity	Value		Quantity	Value	
		Customs	C.i.f.		Customs	C.i.f.		Customs	C.i.f.
Canada	3,628	139,968	143,889	3,420	132,558	142,733	3,216	132,138	144,317
Colombia	647	16,798	23,924	849	23,594	34,122	1,088	30,219	41,021
France	758	27,085	34,473	355	18,909	28,646	443	24,860	35,922
Greece	2,271	62,450	78,470	1,403	41,945	55,948	808	25,242	32,711
Japan	1,758	46,719	57,619	2,415	62,239	78,622	2,101	59,368	75,859
Korea, Republic of	520	11,326	14,521	211	5,808	7,440	87	2,150	2,949
Mexico	4,992	124,527	149,885	4,411	118,468	146,452	2,307	56,144	85,906
Spain	1,857	54,463	68,860	1,562	47,218	62,010	1,309	44,071	53,826
Venezuela	641	16,530	22,484	755	22,205	30,149	1,503	44,718	58,462
Other	416	15,857	21,982	360	16,579	19,203	411	20,707	22,074
Total	17,488	515,723	616,107	15,741	489,523	605,325	13,273	439,617	553,047

Source: Bureau of the Census.

tons or 14% of the total, most of which was received from Japan.

Exports of hydraulic cement and clinker as reported by the Bureau of the Census increased 8% to 554,000 tons. Cement was shipped to 63 countries, with Canada receiving 81% of the total.

In other trade developments, in August, the ITC issued a final determination on a petition filed by cement producers from Arizona, California, Florida, New Mexico, and Texas alleging that cement from Mexico was being sold in these areas at less than fair value. The ITC concluded that the industry was being materially injured by Mexican imports. Consequently, antidumping duties ranging from 3.7% to 58.4% were placed on cement imported from Mexico.

Concurrent with ITC's final investigation of imports from Mexico, an ad hoc committee of southern California producers of gray portland cement filed a petition against imported cement from Japan. The petition alleged Japanese cement was being sold in their market areas at less than fair value. The ITC immediately instituted a preliminary investigation. A final determination was expected in spring 1991.

TABLE 20

U.S. IMPORTS FOR CONSUMPTION OF CLINKER, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1988			1989			1990		
	Quantity	Value		Quantity	Value		Quantity	Value	
		Customs	C.i.f.		Customs	C.i.f.		Customs	C.i.f.
Canada	417	12,943	14,163	407	13,063	14,459	524	14,698	15,091
Colombia	39	946	1,235	82	2,012	3,037	419	11,084	16,189
France	402	11,801	15,006	185	8,991	10,949	163	10,580	12,126
Greece	53	1,098	1,101	43	1,155	1,569	—	—	—
Japan	137	3,030	4,281	235	5,462	7,598	163	4,289	5,969
Mexico	437	8,363	10,415	423	10,511	13,647	87	2,455	3,175
Spain	344	8,282	10,889	254	5,469	7,251	57	5,112	7,008
Other	90	2,163	3,007	116	3,351	4,018	441	8,692	12,764
Total	1,919	48,626	60,097	1,745	50,014	62,528	1,854	56,910	72,322

Source: Bureau of the Census.

TABLE 21

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	1989			1990		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.		Customs	C.i.f.
Anchorage:						
Canada	12	717	976	10	1,337	1,665
Japan	65	2,378	3,194	66	2,255	3,086
Total[1]	77	3,095	4,170	77	3,592	4,751
Baltimore:						
Canada	64	1,710	1,864	—	—	—
Colombia	94	2,763	2,988	105	3,004	3,244
Greece	81	2,251	2,447	13	385	571
Japan	(2)	62	80	(2)	26	32
Mexico	160	4,066	4,454	16	365	396
Netherlands	(2)	59	63	(2)	59	64
Spain	23	675	860	28	834	1,238
Total[1]	422	11,586	12,757	162	4,673	5,546

See footnotes at end of table.

TABLE 21—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	1989			1990		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.		Customs	C.i.f.
Boston:						
Canada	42	1,178	1,235	52	1,411	1,469
Colombia	10	285	303	—	—	—
Greece	220	7,147	7,329	151	4,388	5,228
Mexico	24	669	682	—	—	—
Spain	30	790	800	—	—	—
Venezuela	7	286	296	—	—	—
Total[1]	333	10,355	10,647	203	5,799	6,697
Buffalo:						
Canada	925	41,564	43,692	848	41,556	47,042
United Kingdom	—	—	—	(2)	4	4
Total[1]	925	41,564	43,692	848	41,560	47,047
Charleston:						
France	(2)	19	24	—	—	—
Mexico	75	2,176	3,205	27	795	1,174
Netherlands	—	—	—	(2)	26	30
Spain	43	1,090	1,392	—	—	—
Venezuela				63	1,876	2,830
Total[1]	118	3,285	4,623	90	2,697	4,035
Chicago:						
Belgium	(2)	2	6	—	—	—
Canada	—	—	—	27	683	683
Germany, Federal Republic of	—	—	—	(2)	6	8
Japan	(2)	26	34	(2)	47	61
Total	(2)	28	40	27	736	752
Cleveland: Canada	138	4,673	6,284	192	6,289	8,456
Columbia-Snake: Japan	116	2,872	3,861	280	7,549	10,229
Detroit:						
Canada	550	21,572	23,266	610	22,384	23,173
Turkey	20	783	783	—	—	—
Venezuela	19	770	866	—	—	—
Total	589	23,125	24,915	610	22,384	23,173
Duluth:						
Canada	80	2,083	2,458	98	2,740	3,314
Japan	—	—	—	(2)	2	2
Total	80	2,083	2,458	98	2,742	3,316
El Paso:						
Canada	—	—	—	305	8,956	16
Mexico	496	18,011	20,022	(2)	14	12,246
Total	496	18,011	20,022	305	8,970	12,262
Great Falls: Canada	(2)	12	12	73	2,882	3,475
Honolulu:						
Colombia	30	529	1,148	152	3,636	6,642
Japan	195	4,524	6,319	135	3,589	5,037
Mexico	33	788	1,436	—	—	—
New Zealand	—	—	—	100	2,946	4,547
Total[1]	258	5,841	8,902	387	10,171	16,226

See footnotes at end of table.

TABLE 21—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	1989			1990		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.		Customs	C.i.f.
Houston-Galveston:						
Denmark	(2)	6	6	(2)	15	17
Germany, Federal Republic of	(2)	32	41	—	—	—
Japan	—	—	—	(2)	43	57
Mexico	54	1,079	1,403	23	451	586
Spain	11	711	711	—	—	—
Total[1]	66	1,828	2,161	23	509	660
Laredo:						
China	1	136	161	1	81	98
Mexico	144	5,894	6,531	94	5,436	6,203
Total[1]	145	6,030	6,692	95	5,516	6,300
Los Angeles:						
Colombia	—	—	—	74	2,598	3,093
Denmark	4	181	469	—	—	—
France	(2)	40	44	—	—	—
Greece	—	—	—	35	1,036	1,584
Japan	1,607	41,629	50,115	1,186	32,476	40,751
Korea, Republic of	134	3,833	5,052	—	—	—
Mexico	—	—	—	373	10,288	13,544
Romania	—	—	—	39	1,068	1,558
Spain	214	6,738	8,650	101	3,298	4,033
Sri Lanka (Ceylon)	20	585	716	—	—	—
Taiwan	76	1,848	2,470	—	—	—
Turkey	33	753	1,300	45	1,349	1,988
United Kingdom	29	750	1,001	—	—	—
Venezuela	46	1,811	2,148	—	—	—
Yugoslavia	(2)	56	62	(2)	14	18
Total[1]	2,162	58,224	72,028	1,853	52,127	66,569
Miami:						
Belgium-Luxembourg	2	184	340	3	243	403
Colombia	60	1,917	2,344	3	94	115
Denmark	11	656	839	15	913	1,167
France	(2)	13	14	(2)	33	40
Greece	180	5,255	9,131	138	4,002	5,037
Mexico	591	13,073	19,652	251	5,728	9,224
Spain	328	13,587	14,724	172	6,515	8,499
United Kingdom	—	—	—	(2)	6	6
Venezuela	187	5,047	6,779	421	12,608	16,407
Total[1]	1,360	39,732	53,823	1,002	30,142	40,899
Minneapolis, MN: Germany, Federal Republic of	—	—	—	(2)	18	20
New Orleans:						
Belgium-Luxembourg	(2)	42	46	(2)	67	76
France	206	6,146	8,332	273	10,671	13,952
Mexico	124	2,696	4,490	—	—	—
Portugal	—	—	—	(2)	38	40
Spain	75	2,439	3,071	113	3,787	4,886
Total[1]	405	11,323	15,940	386	14,563	18,954

See footnotes at end of table.

TABLE 21—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	1989			1990		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.		Customs	C.i.f.
New York City:						
Australia	—	—	—	(2)	7	11
Belgium	(2)	54	65	—	—	—
Colombia	14	287	443	11	278	498
Germany, Federal Republic of	—	—	—	(2)	3	4
Greece	611	18,677	25,138	327	11,227	14,273
Guatemala	—	—	—	50	633	813
Mexico	14	313	391	—	—	—
Spain	344	10,224	13,937	440	16,257	17,836
United Kingdom	(2)	1	1	(2)	25	25
Venezeula	—	—	—	25	535	830
Total[1]	985	29,556	39,976	853	28,965	34,291
Nogales: Mexico	416	10,434	11,806	272	8,075	9,968
Norfolk:						
Bahamas	3	96	149	—	—	—
Colombia	129	3,866	5,501	—	—	—
France	75	9,925	18,194	61	10,286	18,357
Greece	25	731	975	—	—	—
Mexico	91	1,978	3,289	71	1,776	2,787
Netherlands	—	—	—	(2)	53	60
Spain	—	—	—	60	1,815	2,284
United Kingdom	1	442	506	3	1,040	1,186
Venezuela	180	5,330	8,233	214	6,503	8,895
Total[1]	506	22,368	36,846	409	21,473	33,569
Ogdensburg:						
Canada	316	10,531	11,181	242	8,208	8,899
Netherlands	(2)	12	14	—	—	—
Total	316	10,543	11,195	242	8,208	8,899
Pembina: Canada	253	10,962	12,037	236	10,443	12,220
Philadelphia:						
Colombia	—	—	—	7	222	342
Germany, Federal Republic of	(2)	8	11	(2)	4	4
Greece	156	4,062	6,180	86	2,499	3,534
Spain	224	7,292	9,613	19	567	896
Total[1]	380	11,362	15,804	112	3,292	4,777
Portland, ME:						
Canada	16	723	772	(2)	12	15
Greece	—	—	—	59	1,705	2,484
Total	16	723	772	59	1,717	2,499
Providence:						
Canada	5	135	146	—	—	—
Colombia	118	2,900	7,219	39	1,099	1,361
Greece	113	3,319	4,093	—	—	—
Spain	8	237	351	8	349	544
Total[1]	243	6,591	11,810	47	1,448	1,905
St. Albans:						
Canada	467	15,484	17,415	327	10,463	12,159

See footnotes at end of table.

TABLE 21—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	1989			1990		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.		Customs	C.i.f.
St. Albans—Continued						
France	(2)	130	135	—	—	—
Netherlands	(2)	12	14	—	—	—
Total[1]	468	15,626	17,564	327	10,463	12,159
San Diego:						
Colombia	—	—	—	21	755	924
Mexico	627	21,049	22,685	490	13,944	16,840
Total	627	21,049	22,685	511	14,699	17,764
San Francisco:						
Canada	—	—	—	(2)	176	1,879
Colombia	—	—	—	35	2	3
Japan	160	4,229	5,732	150	4,623	6,003
Korea, Republic of	77	1,975	2,388	87	2,150	2,949
Mexico	290	7,724	8,173	152	3,959	5,439
Yugoslavia	(2)	7	12	(2)	4	6
Total[1]	527	13,935	16,305	425	10,914	16,279
San Juan, PR:						
Belgium-Luxembourg	7	499	854	6	458	783
Canada	(2)	11	15	1	2	4
Colombia	49	1,224	1,602	159	5,028	6,391
Denmark	10	626	1,064	13	1,025	1,309
Germany, Federal Republic of	(2)	10	19	—	—	—
Honduras	56	1,581	2,051	50	1,182	1,552
Ireland	(2)	10	18	—	—	—
Japan	(2)	9	9	—	—	—
Mexico	1	34	62	(2)	2	4
Venezuela	(2)	2	4	2	89	93
Total[1]	122	4,006	5,698	229	7,786	10,137
Savannah:						
Colombia	30	903	910	12	312	316
Denmark	—	—	—	6	479	590
Mexico	18	506	506	—	—	—
United Kingdom	(2)	1	2	(2)	2	3
Venezuela	8	249	249	—	—	—
Total[1]	56	1,659	1,668	18	793	908
Seattle:						
Canada	552	21,042	21,405	501	21,057	21,723
China	(2)	19	22	(2)	10	12
Japan	271	6,503	9,267	284	7,754	10,596
Spain	—	—	—	57	1,559	2,521
Venezuela	—	—	—	51	1,701	2,331
Total[1]	823	27,564	30,695	892	32,081	37,183
Tampa:						
Bahamas	3	104	124	—	—	—
Belgium	(2)	73	96	(2)	13	17
Colombia	283	7,683	10,163	449	W	W
Denmark	66	W	W	65	W	W

See footnotes at end of table.

TABLE 21—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	1989			1990		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.		Customs	C.i.f.
Tampa—Continued						
France	73	W	W	108	W	W
Mexico	1,227	27,628	36,838	234	5,312	7,493
Spain	263	6,096	7,899	312	9,090	11,089
Venezuela	282	7,913	10,675	700	20,340	25,730
Total[1]	2,197	56,043	72,979	1,867	53,841	68,166
Virgin Islands of the United States:						
Antigua	—	—	—	2	63	79
Barbados	[2]	11	11	2	44	49
Colombia	28	978	1,216	21	947	1,029
Dominican Republic	15	427	433	—	—	—
Italy	—	—	—	2	69	81
Japan	1	8	10	[2]	4	4
Leeward and Windward Islands	[2]	34	35	3	62	87
Trinidad and Tobago	1	38	40	8	237	273
Venezuela	25	796	899	27	1,066	1,344
Total[1]	71	2,292	2,644	64	2,492	2,945
Wilmington, NC:						
Germany, Federal Republic of	[2]	24	24	[2]	8	8
Greece	17	503	656	—	—	—
Mexico	28	616	1,132	—	—	—
Total[1]	45	1,143	1,812	[2]	8	8
Grand total[1]	15,741	489,523	605,325	13,273	439,617	553,047

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Data may not add to totals shown because of independent rounding.
[2]Less than 1/2 unit.
Source: Bureau of the Census.

TABLE 22

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)
1986	12,086	361,149	3,972	79,699	261	28,145	16,319	468,993
1987	13,782	384,989	3,668	79,373	276	24,170	17,726	488,532
1988	15,225	438,978	1,919	48,626	344	28,119	17,488	515,723
1989	13,601	410,326	1,745	50,014	395	29,183	15,741	489,523
1990	11,033	354,662	1,854	56,910	386	28,045	13,273	439,617

[1]Data may not add to totals shown because of independent rounding.
Source: Bureau of the Census.

World Review

World cement production was essentially unchanged at 1.3 billion tons. China continued to lead all nations with 18% of production, followed by the U.S.S.R. with 12%, Japan with 7%, and the United States with 6%. Countries with excess capacity continued to export cement to the United States. Twenty-eight countries exported cement to the United States in 1990, essentially the same as in 1989. The

amount of cement imports declined by 16% because of increased demand within exporting countries and because of a continued decline in demand in certain U.S. markets.

There was considerable activity in plant modernization or expansion by industry throughout the world. The international issue of Rock Products magazine describes individual plant activities of the cement-producing nations.[4]

Capacity.—Data in table 23 are estimated and were obtained from a number of different sources, including Government representatives, cement associations, producers, and consultants. Capacity is defined as the maximum quantity of cement that can be produced in a period of time on a normally sustainable basis taking into consideration downtime required for maintenance and repair. Capacity includes operating plants and plants temporarily closed that can be brought into production within a short period of time with minimum capital expenditure.

During 1990, clinker-producing plants in an estimated 132 countries had a combined annual capacity of about 1.4 billion tons. The seven leading countries, China, the U.S.S.R., Japan, the United States, India, Brazil, and the Federal Republic of Germany, Western states, controlled 51% of world capacity.

In the United States, 46% of the clinker production capacity was concentrated in five States: California, Texas, Pennsylvania, Michigan, and Missouri. At yearend, 223 kilns at 112 plants were being operated, excluding Puerto Rico. The average downtime experienced by the industry for maintenance was 52 days, slightly less than that in 1989. The average annual kiln capacity decreased slightly to 365,000 tons. The average annual plant capacity decreased slightly to 727,000.

Canada.—Canadian cement production declined for the second consecutive year. Canada regained its position as the largest supplier of foreign cement to the United States with 3.2 million tons. Mexico had replaced Canada in that capacity in 1987. Canadian cement comes into U.S. markets through 15 ports, primarily along the northern borders of the United States from Anchorage, AK, to St. Albans, VT. Buffalo, NY, Detroit, MI, and Seattle, WA, received 61% of all Canadian imports.

TABLE 23

WORLD CEMENT ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990[1]

(Million short tons)

Country	Rated clinker capacity[e 1]
North America:	
Canada	16
Mexico	27
United States (including Puerto Rico)	86
Total	129
South America:	
Argentina	13
Brazil	49
Venezuela	9
Other	20
Total	91
Europe:	
Belgium	10
Czechoslovakia	13
France	26
Germany, Fed Republic of Eastern States	14
Germany, Fed Republic of Western States	46
Greece	19
Italy	45
Poland	20
Portugal	9
Romania	18
Spain	40
Turkey	25
U.S.S.R.	154
United Kingdom	20
Yugoslavia	10
Other	95
Total	564
Africa:	
Algeria	13
Egypt	25
South Africa, Republic of	12
Other	30
Total	80
Asia:	
China	223
India	58
Indonesia	22
Japan	97
Korea, North	11
Korea, Republic of	36
Thailand	12
Taiwan	22
Other	34
Total	515
Oceania:	
Australia	9
Other	2
Total	11
World total	1,390

[e]Estimated.

[1]Includes capacities of operating plants as well as plants on standby basis.

TABLE 24

HYDRAULIC CEMENT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Afghanistan[e]	95	110	110	110	110
Albania[e]	r935	945	880	880	880
Algeria[e]	7,120	7,170	7,170	7,170	7,170
Angola[e]	390	390	1,100	1,100	1,100
Argentina	6,122	6,947	6,667	4,927	[3]4,000
Australia	6,534	6,469	7,055	e7,165	7,165
Austria	5,036	4,985	5,250	r e5,235	5,235
Bahamas	([4])	—	—	—	—
Bangladesh[5]	322	342	343	345	347
Barbados	219	226	203	e237	220
Belgium	6,349	6,271	7,111	e7,600	7,500
Benin[e]	331	331	550	550	550
Bolivia	325	437	499	557	550
Brazil	27,885	28,076	27,919	28,531	27,550
Bulgaria	6,285	6,056	6,101	e6,100	6,100
Burma	478	429	385	434	414
Canada	11,687	13,892	13,614	13,879	[3]12,403
Chile	1,580	1,757	2,021	e1,900	1,990
China[e]	178,000	198,000	224,000	228,000	224,000
Colombia	6,626	6,575	7,031	7,323	7,300
Congo[e]	64	[5]42	64	64	64
Costa Rica	r610	r641	613	882	880
Cote D'Ivoire (Ivory Coast)	855	719	e770	e770	550
Cuba	3,643	3,897	3,931	e4,100	4,100
Cyprus	952	941	956	1,149	1,250
Czechoslovakia	11,352	11,430	12,097	12,002	11,900
Denmark	2,237	2,080	1,853	e2,200	2,200
Dominican Republic	1,175	e1,200	1,647	1,764	[3]1,168
Ecuador	2,221	r2,364	2,425	2,480	2,500
Egypt	8,391	9,641	10,789	e10,700	10,700
El Salvador	488	669	687	697	700
Ethiopia	298	386	447	r e440	440
Fiji	102	r65	49	64	88
Finland	1,567	1,572	1,658	r e1,760	1,700
France	e25,900	25,970	27,888	e26,500	26,500
Gabon	232	r155	146	127	127
Germany, Federal Republic of:					
Eastern states	13,214	13,702	13,790	e13,800	11,000
Western states	29,299	27,853	28,897	31,415	33,100
Ghana	r242	302	526	623	660
Greece	14,706	14,515	14,388	13,817	13,800
Guadeloupe	199	e210	220	e220	220
Guatemala	710	1,459	1,660	1,779	1,900
Haiti	278	278	276	e240	[3]316
Honduras	397	497	617	715	720
Hong Kong	2,465	2,454	2,413	2,360	[3]1,993
Hungary	4,239	4,578	4,269	4,252	4,400
Iceland	125	144	e148	e130	132
India	40,124	40,763	44,900	46,407	48,500

See footnotes at end of table.

TABLE 24—Continued

HYDRAULIC CEMENT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Indonesia	12,060	13,055	13,495	15,541	[3]15,170
Iran	13,529	14,031	13,450	[e]13,800	13,800
Iraq[e]	8,800	11,000	11,600	13,800	14,300
Ireland	1,541	1,596	1,857	[e]1,800	1,800
Israel	2,270	2,454	2,564	2,523	3,160
Italy	39,615	41,069	[e]40,800	[e]40,200	40,200
Jamaica	266	337	409	454	[3]480
Japan	78,555	78,871	85,489	87,873	90,400
Jordan	1,978	[e]2,500	2,015	1,962	1,960
Kenya	1,446	1,456	1,366	1,341	[3]1,666
Korea, North[e]	8,800	9,900	[r]13,000	[r]18,000	18,000
Korea, Republic of	25,797	28,287	31,961	33,592	[3]37,038
Kuwait	1,118	[e]1,120	979	1,224	880
Lebanon[e]	1,000	1,000	1,000	1,000	1,000
Liberia	[r]106	116	117	94	55
Libya	2,289	2,976	[e]3,000	[e]3,000	3,000
Luxembourg	429	561	621	[e]610	650
Madagascar[e]	39	39	39	39	39
Malawi	77	80	72	[e]77	77
Malaysia	3,934	3,655	4,161	5,284	6,400
Mali[e]	22	24	28	[r]22	22
Martinique[e]	220	220	220	220	220
Mauritania	—	88	99	99	99
Mexico	21,772	24,633	24,816	25,095	[3]25,091
Mongolia[e]	470	600	[r]550	[r]570	560
Morocco[e]	[3]4,125	4,200	4,200	4,200	4,200
Mozambique	80	[r e]80	76	[r e]88	110
Nepal	102	167	237	240	[3]118
Netherlands	3,417	3,229	3,768	3,903	[3]4,111
New Caledonia[e]	44	55	66	[3]74	70
New Zealand	999	970	895	804	830
Nicaragua[e]	110	110	110	[3]144	140
Niger	[e]42	[e]44	29	30	30
Nigeria	4,255	4,189	3,748	[e]3,860	3,860
Norway	1,929	1,807	1,574	1,516	1,520
Oman	[e]770	926	953	1,044	1,050
Pakistan[e]	5,760	7,530	[3]7,761	7,700	7,900
Panama	370	[e]385	[r e]220	186	220
Paraguay	197	288	354	360	360
Peru	2,432	2,849	[e]2,800	[e]2,200	2,200
Philippines	3,910	3,660	4,700	[e]4,400	4,400
Poland	17,416	17,747	18,740	18,850	18,700
Portugal	6,001	6,451	[r e]2,100	[e]6,600	6,600
Qatar	340	[e]330	[e]330	606	600
Romania[e]	[3]15,670	15,760	15,400	15,400	14,300
Saudi Arabia	10,287	9,474	[e]10,500	[e]10,500	11,000
Senegal	[r]396	410	431	419	415
Singapore	1,989	1,684	1,759	1,881	[3]2,041
South Africa, Republic of	7,399	7,424	9,354	8,852	8,800

See footnotes at end of table.

TABLE 24—Continued

HYDRAULIC CEMENT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Spain (including Canary Islands)[e]	26,500	25,800	26,500	27,000	27,600
Sri Lanka[e]	660	660	440	440	440
Sudan[e]	165	134	165	165	165
Suriname[e]	55	55	55	55	55
Sweden	[r]2,262	[r]2,484	[e]2,425	[e]2,425	2,600
Switzerland	4,842	5,089	5,473	6,020	6,000
Syria	4,630	4,266	3,671	3,859	3,860
Taiwan	16,321	17,226	19,049	19,889	20,350
Tanzania[e]	330	330	330	330	330
Thailand	8,723	[r]10,858	12,692	16,561	19,900
Togo	384	407	416	429	440
Trinidad and Tobago	360	357	397	419	[3]483
Tunisia[e]	[3]3,289	3,750	5,500	5,500	5,500
Turkey	22,050	24,228	24,995	26,235	26,600
Uganda	[e]17	12	10	[e]11	11
U.S.S.R.	148,943	151,462	153,771	154,804	151,000
United Arab Emirates	[r e]3,020	[r]3,424	3,285	3,430	3,430
United Kingdom	14,785	15,775	18,195	[r e]17,600	17,600
United States (including Puerto Rico)	79,916	79,501	78,252	78,559	[3]78,606
Uruguay	375	442	479	513	510
Venezuela	6,335	6,735	6,833	4,971	[3]5,765
Vietnam	7,046	7,539	2,154	[r e]2,200	2,800
Yemen (Sanaa)	1,279	838	712	[e]770	770
Yugoslavia	10,061	9,880	9,744	9,436	[3]8,768
Zaire	490	542	546	[e]500	480
Zambia	368	413	446	425	415
Zimbabwe	[e]825	894	855	793	800
Total	[r]1,110,608	[r]1,160,473	1,171,836	1,248,916	1,251,112

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through June 29, 1991.

[2]In addition to the countries listed, Cameroon produces cement, but available information is inadequate to make reliable estimates of output levels.

[3]Reported figure.

[4]Less than 1/2 unit.

[5]Data are for the year ending June 30 of that stated.

China.—China continued to be the world's largest producer of cement. Its production stabilized in 1990 after reaching a record level 228 million tons in 1989. The industry continued to flourish amid new plant construction, modernization, and expansion projects, as well as the formation of joint ventures with Japanese cement producers.

India.—The Indian cement industry continued to aggressively expand its production capacity through new plant construction, modernization, and expansion activities. It is anticipated that demand will continue to increase. Cement production in India reached an alltime high of 48.5 million tons. This was the eighth consecutive year of reported production growth.

Japan.—Japan continued to maintain its position as the third highest cement producer in the world, producing just over 90 million tons, slightly more than in 1989. Japanese exports to the United States declined 13% to 2.1 million tons in 1990. Fifty-six percent of Japanese exports to the United States was shipped to the Los Angeles area. Japan was again the subject of an antidumping petition filed by southern California producers. A final determination on the petition was expected to be made by the International Trade Commission in spring 1991.

Korea, Republic of.—Korea's cement production increased 44% over the past 5 years, to 37 million tons in 1990, in response to unprecedented growth in demand. Korea continued to expand its production capacity through new plant construction, modernization, and expansion projects, including building one of the largest plants in the world. Korea was once a major exporter of cement to the United States, primarily to the Los Angeles and San Francisco areas. Because of increased demand at home, however, cement exports to the United States have declined significantly.

Mexico.—Cement production in Mexico remained essentially unchanged from that of 1989. Production capacity, however, continued to grow as a result of modernization and expansion projects currently underway. Since 1987, Mexico had been the principal supplier of imported cement to the United States, replacing Canada. As a result of antidumping allegations and an affirmative determination by the International Trade Commission that domestic cement producers were being injured by cement from Mexico, imports from Mexico declined by 48% in 1990. However, given the rapid growth of the Mexican cement industry, the proximity of plants to U.S. markets, and the acquisition of import terminals in the United States, it is only logical to assume that Mexican cement will play a major role in supplying U.S. requirements for many years to come.

Current Research

Passamaquoddy Technology LP, USA, developed a new scrubbing system that recycles waste cement kiln dust (CKD) and reduces sulfur dioxide (SO_2) emissions. The process, named the Passamaquoddy Technology Recovery Scrubber, uses 90% of the SO_2 and a portion of the carbon dioxide (CO_2) in the kiln exhaust gas to recycle 100% of the plant's CKD into kiln feed, potassium fertilizer, and distilled water. The system can also be used to reclaim landfilled CKD. The system was installed at the Thomaston, ME, plant of Dragon Products Co. The plant is the only one in the State and was formerly owned by the Passamaquoddy Indian Tribe.[5]

OUTLOOK

The recession that began in 1990 is expected to carry through 1991, causing cement consumption to decline to about 81 million tons. The decline will continue to be precipitated by weakness in the residential and in nonresidential building construction markets. Gradual increases in demand are anticipated for 1992 and 1993 as the economy is relieved of some of the existing recessionary pressures. It is estimated that demand for portland and masonry cement will reach 95 million tons by 1994. The projected increase will be influenced by new construction activity primarily in the public construction sector. The Portland Cement Association makes a more optimistic forecast of 98.5 million and about 100 million tons by 1994 and 1995, respectively.[6]

There has been considerable attention given to repairing or rebuilding the Nation's infrastructure. These cement consumption forecasts could be altered dramatically depending on the level of spending authorized for this undertaking.

Imports will continue to be a significant source of supply. The trend toward increased world consumption of cement, however, could impact the amount of cement available for export to U.S. markets, particularly given the political and economic changes taking place in Eastern Europe.

Cement prices could benefit from a restricted supply of foreign cement. Recent antidumping duties imposed on cement from Mexico and Japan by the ITC could dramatically impact the pricing structure of domestic cement.

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[1]American Society for Testing and Materials. S. 4, V. 04.01, Cement Lime and Gypsum. Apr. 1, 1988, pp. 1-544.

[2]U.S. Department of Commerce, International Trade Administration. Construction Review. V. 37, No. 2, Mar.-Apr. 1991, pp. 1-7.

[3]Engineering News-Record. ENR Materials Prices. V. 225, No. 1, Jan. 1991, pp. 73-74.

[4]Cement International. Rock Products. V. 94, No. 4, Apr. 1990, pp. 55-79.

[5]Tureen, T. N. Clean Emissions, Valuable By-Products. Int. Cement Rev., Mar. 1991, pp. 45-50.

[6]Portland Cement Association. The Monitor. V. 1, No. 2, Apr. 1991, pp. 1-28.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Cement. Ch. in Minerals Yearbook, annual.

Cement. Ch. in Mineral Commodity Summaries, annual.

Other Sources

Pit and Quarry.
World Cement.

CHROMIUM

By John F. Papp

Dr. Papp, a physical scientist with 20 years U.S. Bureau of Mines experience, has been the commodity specialist for chromium since 1983. Domestic survey data were prepared by Lillian Wood and Robin Johnson, mineral data assistants; chromite world production data by country were prepared by Audrey D. Wilkes, international data coordinator. Cost of production data were prepared by the Minerals Availability Field Office, Division of Statistics and Information Services. (All tonnages are in metric tons unless otherwise specified.)

Chromium has a wide range of uses in metals, chemicals, and refractories. It is one of the Nation's most important strategic and critical materials. Chromium use in iron, steel, and nonferrous alloys enhances hardenability and resistance to corrosion and oxidation. The use of chromium to produce stainless steel and nonferrous alloys are two of its more important applications. Other applications are in alloy steel, plating of metals, pigments, leather processing, catalysts, surface treatments, and refractories.

Because the United States has no chromite ore reserves and a limited reserve base, domestic supply has been a concern during every national military emergency since World War I. World chromite resources, mining capacity, and ferrochromium production capacity are concentrated in the Eastern Hemisphere. The National Defense Stockpile (NDS) contains chromium in various forms, including chromite ore, chromium ferroalloys, and chromium metal in recognition of the vulnerability of long supply routes during a military emergency.

Research is conducted by the Federal Government to reduce U.S. vulnerability to potential chromium supply interruption. That research covers both domestic resource utilization and alternative materials identification. Domestic chromium resources include mineral deposits and recyclable materials. The U.S. Geological Survey and the U.S. Bureau of Mines evaluate U.S. territory for chromium mineral deposits. The U.S. Bureau of Mines also studies minerals extraction and processing and materials substitution and recycling. Alternative materials research is also conducted by the National Aeronautics and Space Administration, the National Institute of Standards and Technology, the Department of Defense, and the Department of Energy.

World chromite ore reserves are more than adequate to meet anticipated world demand.

DOMESTIC DATA COVERAGE

Domestic data coverage of the primary consuming industries—metallurgical, refractory, and chemical—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 refractory companies and all of the chemical companies that consumed chromite in 1990 reported to the Bureau, while 75% of the metallurgical companies reported. Consumption was estimated for the remaining 25% of the metallurgical firms.

Domestic production data for chromium ferroalloys and metal are developed by the U.S. Bureau of Mines by means of two separate voluntary surveys. These two surveys are the monthly "Chromium 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. Seventy-five percent of those companies responded to both surveys. Production for the remaining 25% was estimated.

BACKGROUND

Chromium is primarily used in the metallurgical industry as an alloying element. That is, it is mixed with a base metal to form an alloy. Chromium confers properties on the alloy that are not achievable with the base metal alone. The most common use of chromium is with iron to make stainless steel, an iron-chromium alloy that contains chromium by definition. Chromium confers oxidation resistance to stainless steel, making it "stainless." Stainless steel, in addition to being commonly found in home and commercial kitchens, is an important engineering alloy used throughout industry in machinery and pipes. Chromium is also used in chemicals for a variety of purposes. Chromite, the mineral from which chromium is derived for use in the metallurgical and chemical industries, is used directly by the refractory industry to produce heat-, spalling-, corrosion-, and abrasion-resistant bricks for metallurgical and high-temperature industrial mineral processing applications. Chromite is not mined domestically; thus, the United States is 100% import dependent to meet domestic chromite demand. Some domestic chromium demand is met by recycling. Chromium is a critical and strategic material contained in the NDS to ensure adequate supply in the event of a national defense emergency.

Definition, Grades, and Specifications

U.S. industry sets chemical and physical specifications for chromium materials through the American Society for Testing and Materials (ASTM). Other organizations also make specifications for chromium materials. The Defense Logistics Agency (DLA), in cooperation with the Department of Commerce, maintains purchase specifications for chromium materials contained in the NDS. The Treasury Department, in cooperation with the Department of Commerce and

TABLE 1

COMPOSITION OF TYPICAL CHROMIUM FERROALLOYS AND CHROMIUM METAL

(Composition, percentage)

Material[1]	Grade	Chromium[2]	Carbon[3]	Silicon[3]	Sulfur[3]	Phosphorus[3]	Nitrogen[3]
Ferrochromium:							
High-carbon	A	52–58	6.0–8.0	6.0	0.040	0.030	0.050
	B	55–64	4.0–6.0	8.0–14.0	.040	.030	.050
	C	62–72	4.0–9.5	3.0	.060	.030	.050
Low-carbon	A	60–67	.025	1.0– 8.0	.025	.030	.12
	B	67–75	.025	1.0	.025	.030	.12
	C	67–75	.050	1.0	.025	.030	.12
	D	67–75	.75	1.0	.025	.030	.12
Vacuum low-carbon	E	67–72	.020	2.0	.030	.030	.050
	F	67–72	.010	2.0	.030	.030	.050
	G	63–68	.050	2.0	.030	.030	5.0–6.0
Nitrogen-bearing	—	62–70	.10	1.0	.025	.030	1.0–5.0
Ferrochromium-silicon	A	34–38	.060	38–42	.030	.030	.050
	B	38–42	.050	41–45	.030	.030	.050
Chromium metal	A	99.0	.050	.15	.030	.010	.050
	B	99.4	.050	.10	.010	.010	.020

[1]Chemical requirements in addition to those listed here are specified by American Society for Testing Materials (ASTM).
[2]Minimum, except where range of values indicating minimum and maximum appears.
[3]Maximum, except where range of values indicating minimum and maximum appears.

Source: 1988 Annual Book of ASTM Standards.

participants in the General Agreement on Tariffs and Trade, maintains definitions of chromium materials for the purpose of recording trade and applying tariff duties.

For the purpose of importation, chromite ore and concentrates made therefrom are classified by their chromic oxide content. Ore and concentrate is divided into three categories: containing not more than 40% chromic oxide, containing more than 40% and less than 46% chromic oxide, and containing 46% or more chromic oxide. Producers of chromite ore and concentrate typically specify chromic oxide content; chromium-to-iron ratio; and iron, silica, alumina, magnesia, and phosphorous contents. They also specify the size of the ore or concentrate. Typically, chromic oxide content ranges from 36% to 56%, with values in the 40% to 50% range being most common. Chromium-to-iron ratios typically range from about 1.5:1 to about 4.0:1, with typical values of about 1.5:1 to 3.0:1. In trade, the chromite ore is also called chromium ore, chromite, chrome ore, and chrome.

For the purpose of importation, chromium ferroalloys are classified as ferrochromium and ferrochromiumsilicon. Ferrochromiumsilicon, also called ferrosiliconchromium and chromium silicide, is not further classified. Ferrochromium is classified by its carbon content as containing not more than 3% carbon, more than 3% but not more than 4% carbon, or more than 4% carbon. Producers of ferrochromium typically classify their material as low- or high-carbon or charge-grade ferrochromium. Charge-grade ferrochromium is also called charge chrome. Producers of chromium ferroalloys typically specify chromium, carbon, silicon, phosphorous, and sulfur contents and material size. Ferrochromiumsilicon typically contains 24% to 40% chromium, 38% to 50% silicon, and 0.05% to 0.1% carbon. Ferrochromium typically contains 50% to 75% chromium and 0.05% to 8% carbon. Low-carbon ferrochromium typically contains 55% to 75% chromium and 0.02% to 0.1% carbon. High-carbon ferrochromium typically contains 60% to 70% chromium and 6% to 8% carbon. Charge-grade ferrochromium typically contains 50% to 55% chromium and 6% to 8% carbon.

Products for Trade and Industry

Chromium is primarily used in the metallurgical industry as an alloying element. Small quantities of chromium are alloyed with (i.e., added to) a base metal to achieve certain desired properties not attainable with the base metal alone. Before its use as an alloying element, chromium was used predominantly in chemicals to make pigments or to plate metals. Chromite was used as a refractory material. As a pigment, chromium provided color to many end products and corrosion protection to ferrous metals. As a plating material, chromium provided a lustrous or a hard finish and corrosion protection to the substrate metal. As a refractory, chromite found major use in blast furnace iron production. The decline in use of this process has resulted in a corresponding decline in chromite refractory use. Environmental concern over hexavalent chromium contamination has resulted in reduced use or increased expense of chromium use in pigments and plating. Chromium is traded primarily as chromite ore or as ferrochromium. Substantial amounts of chromium chemicals, pigments, and metal are also traded.

Health and Nutrition[1]

Chromium is a trace mineral required by the human body. 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 form of chromium is as trivalent compounds. Because humans cannot convert trivalent chromium to hexavalent chromium, the carcinogenicity of hexavalent chromium compounds bears no relevance to the nutritional role of trivalent chromium. (See Toxicity section of this report.)

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 the United States, Europe, and Japan, the major steel producers. The U.S. trend to obtain chromium in the ferroalloy form is a result of the world trend to produce ferrochromium in chromite-producing countries.

The structure of the chromium industry from a material processing perspective begins with mining of chromite ore. (See figure 1, chromium material flow.) Once mined, the ore is beneficiated. The resulting chromite ore or concentrate made therefrom may be consumed in the refractory, chemical, or metallurgical industry. Chromite ore is consumed in the refractory industry for its chromite mineral content. The chromite is typically crushed, ground, and sized. It is then mixed with magnesite to make chrome-magnesite bricks that are subsequently consumed in the steel, glass, or cement industry. The chromite refractories are used to line steelmaking furnaces, cement kilns, or heat exchangers associated with glass production.

Chromite ore consumed in the chemical or metallurgical industry is processed to extract the chromium from the chromite mineral. Chromite ore consumed in the chemical industry is kiln roasted, and the chromium is leached out in the form of sodium bichromate. The sodium bichromate is further processed to make chromic acid and other chromium chemicals and pigments. Chromic oxide is a chemical industry product. Chromite ore consumed in the metallurgical industry is smelted to produce ferrochromium. In effect, the oxygen is removed from the iron-chromium-oxygen mineral, leaving an iron-chromium alloy, ferrochromium. Ferrochromium is produced to meet a variety of chemical and physical specifications. Several variations of the ferrochromium production process are practiced; the submerged electric arc furnace is central to each process. Ferrochromium is the source of chromium units for alloys, especially ferrous alloys. When nonferrous alloys require chromium and the iron is undesirable, chromium metal is used. Chromium metal is produced from ferrochromium by an electrolytic process or from chromic oxide by an aluminothermic process.

The major vertical structure of the chromium industry is mining-smelting-stainless steelmaking. In some instances, the ownership of mining operations, smelters, and stainless steel production facilities is integrated. In many other cases, integration is limited to mining and smelting or to smelting and stainless steelmaking. Often the ownership of operations is shared. Major mining, smelting, or stainless steel production facilities are typically privately owned by large companies or groups of companies.

Geology-Resources

The geology of many chromium deposits has been characterized.[2]

The data in table 22 are rated reserves and reserve base for major chromite ore-producing countries.[3] 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 and by mining and market economies. 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 will vary owing to differing physical and economic criteria applied to a deposit by different analysts.

Technology

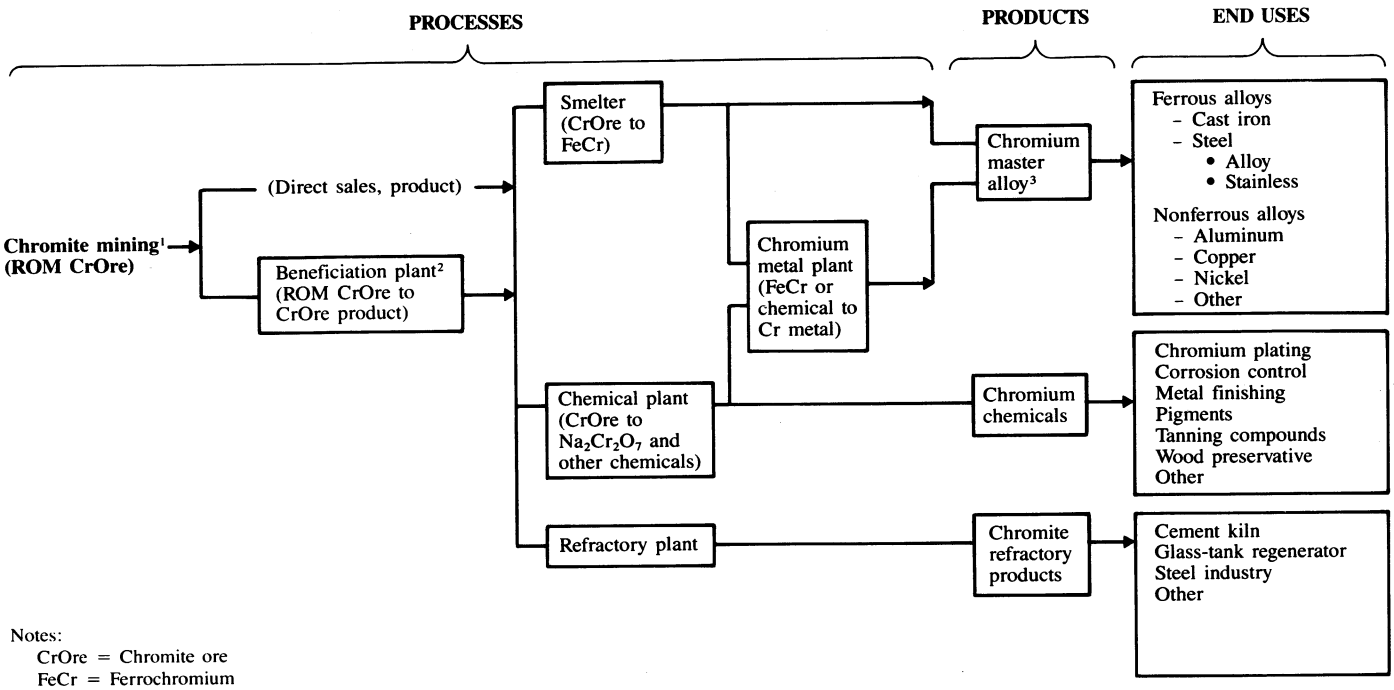
Mining.—A wide variety of mining technology is applied to the surface and subsurface mining of chromite ore. Most ore comes from large mechanized mines. However, small labor-intensive mining operations contribute to world supply.

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. Industry is developing new production

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 techniques, including gravimetric, heavy media, and magnetic.
[3]Master alloy is an alloy used as a feedstock to produce other alloys.

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.

Technological change in stainless steel production permitted the replacement of expensive high-chromium, low-carbon ferrochromium by less expensive low-chromium, high-carbon ferrochromium. This change permitted the use of low chromium-to-iron ratio ore for smelting to ferrochromium, which is subsequently alloyed to produce stainless steel. 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. Advanced smelting technologies have been designed to use fine ore.

TABLE 2

PRINCIPAL WORLD CHROMITE PRODUCERS, 1990

Country[1]	Company
Albania	Government owned.
Brazil	Bayer AG (Federal Republic of Germany)
	Coitezeiro Mineração S.A. (COMISA).
	Cia. de Ferro-Ligas de Bahia S.A. (FERBASA).
	Cia. de Mineração Serra de Jacobina S.A. (SERJANA).
	Mineração Vale do Jacurici S.A.
	Magnesita S.A.
Finland	Outokumpu Oy (Government owned).
India	Ferro Alloys Corp. Ltd.
	Misrilal Mines Pvt. Ltd.
	Mysore Mineral Ltd.
	Orissa Mining Corp. Ltd. (Government owned).
	Tata Iron and Steel Co. (TISCO).
Philippines	Acoje Mining Co. Inc.
	Benguet Corp.
	Philchrome Mining Corp.
South Africa, Republic of	African Mining and Trust Co. Ltd.
	Zeerust Chrome Mine Ltd.
	Rustenburg Minerals Development Co. (Pty.) Ltd.
	Chrome Chemicals SA (Pty.) Ltd.
	Chromecorp Technology (Pty.) Ltd.
	Chroombronne (Pty.) Ltd.
	Lavino South Africa (Pty.) Ltd.
	Grootboom Chrome Mine.
	Lebowa Development Corp. Ltd.
	Dilokong Chrome Mine.
	National Manganese Mines (Pty.) Ltd.
	Buffels Chrome Mine.
	Rand Mines Ltd.
	Millsell Chrome Mines (Pty.) Ltd.
	Henry Gould (Pty.) Ltd.
	Samancor Ltd.
	Batlhako Mining Ltd.
	Ruighoek Chrome Mine.
	Grasvally Chrome Mine.
	Jagdlust Mine.
	Montrose Mine.
	Mooinooi Mine.
	Waterkloof Chrome Mines (Pty.) Ltd.
	Vansa Vanadium S.A. Ltd.
	Winterveld Chrome Mines Ltd.
	Vereeninging Refractories Ltd.
	Marico Chrome Corp. (Pty.) Ltd.
Turkey	Etibank (Government owned).
	Bursa Toros Kromlari AS.
	Egemetal Madencilik AS.
	Sitki Kocman Mines.

See footnotes at end of table.

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 prompt and purchased stainless steel scrap. Advanced stainless steel production technology like continuous casting reduces prompt scrap generation and permits a higher product yield per unit of raw material feed.

Byproducts and Coproducts

Chromium is mined as a primary product. Chromium is not a byproduct or coproduct of the mining of any mineral, nor are there byproducts or coproducts associated with chromium mining. Chromium 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 Bushweld 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, chromium-containing tailings will continue to grow. The feasibility of utilizing these resources has been demonstrated, and new ferrochromium production facilities under development by Middelburg Steel and Alloys 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 chromium a byproduct of some platinum operations.

Economic Factors

Prices.—Inadequate supplies of ferrochromium in the late 1980's resulted from strong demand for stainless steel in all three major producing regions: the United States, Japan, and Europe. This inadequate supply resulted in increasing ferrochromium prices until mid-1989, when supply exceeded demand and prices began to decline. In 1989 and 1990, new ferrochromium plants and plant expansions were under construction or being completed. Reduced stainless steel production permitted ferrochromium producers, traders, and consumers to rebuild stocks after about 3 years of generally increasing production. Reduced demand for ferrochromium, resulting

TABLE 2—Continued

PRINCIPAL WORLD CHROMITE PRODUCERS, 1990

Country[1]	Company
Turkey—Continued	Turk Maadin Sirketi AS.
	Hayri Ogelman Madencilik AS.
U.S.S.R.	Government owned.
Zimbabwe	Zimbabwe Alloys Ltd. (Zimalloys).
	Zimbabwe Mining and Smelting Co. (Pvt.) Ltd. (Zimasco).

[1]Other chromite-producing countries included Bulgaria, China, Cuba, Greece, Indonesia, Iran, Japan, Madagascar, New Caledonia, Pakistan, Sudan, Thailand, Yugoslavia, and Vietnam.

TABLE 3

PRINCIPAL WORLD FERROCHROMIUM PRODUCERS, 1990

Country[1]	Company
Brazil	Cia. de Ferro-Ligas da Bahia S.A. (FERBASA).
China	Government owned.
Finland	Outokumpu Oy (Government owned).
France	Chromeurope S.A.
Germany, Federal Republic of	Gesellschaft für Elektrometallurgie mbH (GfE)
	Elektrowerk Weisweiler GmbH.
Greece	Hellenic Ferroalloys S.A.
India	Ferro Alloys Corp. Ltd. (Facor)
	Indian Metals & Ferroalloys Ltd. (IMFA).
	Indian Charge Chrome Ltd.
	Industrial Development Corp.
	OMC Alloys Ltd. (State owned)
	Visvesvaraya Iron & Steel Ltd. (State owned)
Italy	Darfo Srl.
	Acciaierie e Ferriere Lombarde Falck SpA.
	Ferroleghe SpA.
	Fucinati SpA.
Japan	Japan Metals and Chemicals Co. Ltd.
	Nippon Denko Co. Ltd.
	NKK Corp.
	Pacific Metals Co. Ltd.
	Showa Denko K.K.
Norway	Elkem Rana.
Philippines	Ferro Chemicals Inc.
	Ferrochrome Philippines Inc.
	Integrated Chrome Corp.
South Africa, Republic of	Anglovaal Ltd.
	Feralloys Ltd.
	Chromecorp Technology (Pty.) Ltd.
	Johannesburg Consolidated Investment Co. Ltd.
	Consolidated Metallurgical Industries Inc.
	Middelburg Steel and Alloys Holdings (Pty.) Ltd.
	Alloys Division Middelburg.

See footnotes at end of table.

from decreased stainless steel production, and increased supply of ferrochromium, resulting from producer expansions and new plant construction, have resulted in declining ferrochromium prices through 1990.

The historical value of chromite ore by grade, ferrochromium by grade, and chromium metal imported to the United States is shown in tables 4 and 5. These values show that as chromite ore is processed to ferrochromium and to chromium metal, the added value is quite large. On a per unit of contained chromium basis, the value of ferrochromium is about 7 times that of chromite ore; the value of chromium metal is about 30 times that of chromite ore. Variations of the value of ore are shown to follow those of ferrochromium, indicating values of chromite ore change in response to demand with ferrochromium value first to reflect demand changes.[4] 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.

Costs.[5]—Operating and transportation are the two major components of chromite ore cost in the market place. 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.

Electrical energy, 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%.

Tariffs.—Import tariffs are typically imposed to protect 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

TABLE 3—Continued

PRINCIPAL WORLD FERROCHROMIUM PRODUCERS, 1990

Country[1]	Company
South Africa, Republic of—Continued	Alloys Division Krugersdorp.
	Samancor Ltd.
	Batlhako Ferrochrome Ltd.
	Ferrometals Ltd.
	Tubatse Ferrochrome (Pty.) Ltd.
Sweden	Vargön Alloy AB.
Turkey	Etibank (Government owned).
U.S.S.R.	Government owned.
United States	Elkem Metals Co.
	Macalloy Corp.
	SKW Alloys Inc.
Yugoslavia	Tvornica Karbida i Ferolegura Dalmacija.
	Tovarna Dušika Ruše.
Zimbabwe	Zimbabwe Alloys Ltd. (Zimalloys).
	Zimbabwe Mining and Smelting Co. (Pvt.) Ltd. (Zimasco).

[1]Other ferrochromium-producing countries included Albania, Chile, Czechoslovakia, Poland, Mexico, Romania, Spain, and Taiwan.

duties on chromium materials.) In some cases, such as ferrochromium imports to the European Community, import tariffs are used along with import quotas. That is, a duty-free quota is allocated to member countries. The quotas may be revised as necessary to meet the needs of domestic consumers and producers. Only in a few cases, such as ferrochromium exports from China and certain grades of chromite ore exports from India, are export duties applied.

Operating Factors

Environmental Requirements.—Chromium releases into the environment are regulated by the Environmental Protection Agency (EPA). Workplace exposure is regulated by the Occupational Safety and Health Administration.

Toxicity.[6]—The toxic effect of an element depends on its chemical form and concentration, and on the conditions and

TABLE 4

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	1982	Actual	1982	Actual	1982	Actual	1982
1963	86	28	40	13	63	20	54	17
1964	84	28	44	14	59	19	57	19
1965	88	30	48	16	59	20	59	20
1966	82	29	45	16	62	22	58	20
1967	87	31	48	17	66	24	62	22
1968	81	31	45	17	60	23	59	22
1969	75	30	51	20	66	26	64	25
1970	85	36	53	22	90	38	79	33
1971	98	43	58	26	98	43	87	39
1972	99	46	62	29	94	44	89	41
1973	104	52	55	27	93	46	82	41
1974	109	59	67	36	104	56	96	52
1975	178	106	101	60	209	124	175	104
1976	222	140	146	92	262	165	212	134
1977	235	158	166	112	254	171	206	138
1978	230	166	177	128	185	134	200	144
1979	240	189	187	147	232	182	215	169
1980	288	247	195	167	189	162	222	190
1981	266	250	192	181	184	173	219	206
1982	293	293	201	201	213	213	229	229

See footnotes at end of table.

TABLE 4—Continued

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	1982	Actual	1982	Actual	1982	Actual	1982
1983	359	373	172	179	166	172	194	202
1984	403	434	141	151	156	168	186	200
1985	261	290	160	178	160	177	184	205
1986	218	248	145	164	146	166	163	186
1987	185	217	160	188	155	182	168	197
1988	241	292	269	r326	187	227	229	278
1989	292	r369	290	r366	247	r313	271	r342
1990	313	p411	228	p300	237	p312	242	p318

pPreliminary. rRevised.
[1]Customs value per ton of chromium contained in imported material.

NOTE.—1982 value is actual value multiplied by gross national product (GNP) ratio. GNP ratio is annual GNP divided by 1982 GNP. GNP ratio calculated as the ratio of GNP index reported in Economic Report of the President, U.S. Government, February 1990, available from Superintendent of Documents, U.S. Government Printing Office.

TABLE 5

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	1982	Actual	1982	Actual	1982	Actual	1982
1963	397	129	290	94	376	122	1,677	543
1964	380	125	304	100	360	119	1,670	549
1965	408	138	268	90	395	133	1,661	561
1966	410	143	232	81	367	129	NA	NA
1967	417	150	264	95	394	142	NA	NA
1968	399	151	261	98	382	144	1,656	624
1969	426	169	236	94	370	147	1,800	717
1970	453	190	272	114	401	168	NA	NA
1971	585	260	342	152	464	206	2,003	889
1972	556	258	282	131	422	196	2,206	1,026
1973	617	305	289	143	392	194	2,491	1,233
1974	797	431	512	277	600	324	3,030	1,636
1975	1,534	910	942	558	1,061	629	4,486	2,660
1976	1,406	887	719	454	916	578	4,350	2,745
1977	1,385	932	702	472	826	556	4,938	3,324
1978	1,405	1,014	640	462	686	496	NA	NA
1979	1,737	1,366	853	671	945	743	NA	NA
1980	1,826	1,565	890	762	972	833	7,682	6,584
1981	1,609	1,513	870	817	952	895	7,662	7,203
1982	1,551	1,551	887	887	1,008	1,008	6,018	6,018
1983	1,437	1,493	683	710	737	766	4,491	4,667

See footnotes at end of table.

TABLE 5—Continued

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	1982	Actual	1982	Actual	1982	Actual	1982
1984	1,496	1,612	782	843	833	897	5,674	6,111
1985	1,571	1,742	847	939	914	1,013	5,468	6,064
1986	1,409	1,604	779	886	851	968	5,320	6,055
1987	1,544	1,812	783	919	893	1,049	6,098	7,159
1988	1,988	2,412	1,317	1,598	1,403	1,702	7,231	8,772
1989	r1,908	r2,410	1,524	r1,924	1,609	r2,032	r6,598	r8,333
1990	1,619	p2,129	1,883	p1,161	1,017	p1,337	6,459	p8,494

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.—1982 value is actual value multiplied by gross national product (GNP) ratio. GNP ratio is annual GNP divided by 1982 GNP. GNP ratio calculated as the ratio of GNP index reported in Economic Report of the President, U.S. Government, February 1990, available from Superintendent of Documents, U.S. Government Printing Office.

duration of exposure. At about 200 parts per million, chromium is the sixth most common element in the Earth's crust; at 1 to 2.5 parts per billion, the fifteenth most common element in seawater. 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. (See Health and Nutrition section of this report.)

Energy Requirements.—Ferrochromium production is an energy-intensive process, requiring about 3,800 kilowatt-hours per metric ton of product. Currently available technology can reduce the electrical energy requirement to about 2,000 kilowatt-hours per ton by thermal energy recovery and recycling. Traditional technology uses electricity to supply the energy required to smelt chromite ore. Advanced production technology permits the use of liquid or gas fuel to substitute for part of the energy required. Alternative production technology is being developed that would permit nonelectrical energy sources to supply a significant fraction of the energy required to smelt chromite ore.

Transportation.—Chromite ore is typically transported by trackless truck or conveyor belt from the mine face to storage or processing facilities on the mine site. From there, it is transported by truck from the mine site to the local railhead. It is then transported by rail to ports or to smelters. Smelters that do not have associated loading and unloading facilities for ships transport their product by rail to ports. Following transport by ship to consumer countries, chromium materials are typically barged or hauled by truck to end users who have no loading and unloading facilities for ships.

ANNUAL REVIEW

In 1990, chromium apparent consumption was 447,000 metric tons of contained chromium. The reported consumption of chromite by the chemical and metallurgical industry and by the refractory industry decreased. Metallurgical industry chromite consumption includes material consumed as part of the NDS program to convert chromite to ferrochromium. Imports of chromite decreased, while imports of chromium ferroalloys increased compared with those of 1989.

U.S. supply consisted of recycled and imported chromium materials. The United States recycled about 561,000 tons, gross weight, of stainless steel scrap and imported about 742,000 tons of chromite ore, ferroalloys, chemicals, and pigments valued at about $338 million. The United States exported about 25,000 tons of chromium materials valued at about $36 million.

Legislation and Government Programs

In accordance with the President's November 1982 directive and Public Law 99-591, the DLA continued to upgrade NDS chromite ore to high-carbon ferrochromium. The Agency reported conversion of chromite ore to ferrochromium on a calendar year contract basis. DLA signed a contract with Macalloy Corp., Charleston, SC, in 1990 to upgrade NDS chromite ore. The contract period covers the years 1990 through 1994, the last 2 years of which are optional for DLA.

As part of its plan to modernize the NDS, DLA contracted with Elkem Metals Co., Marietta, OH, to upgrade

TABLE 6

SALIENT CHROMIUM STATISTICS

(Thousand metric tons, gross weight)

	1986	1987	1988	1989	1990
CHROMITE					
United States:					
Exports	84	1	4	40	6
Reexports	1	5	1	2	4
Imports for consumption	443	490	615	525	306
Consumption	388	506	551	561	402
Stocks, Dec. 31: Consumer	285	332	390	392	355
World production	r11,797	r11,637	r12,593	r13,542	e12,846
CHROMIUM FERROALLOYS[1]					
United States:					
Production[2]	96	107	120	147	109
Exports	5	5	8	9	9
Reexports	1	2	2	2	2
Imports for consumption	361	303	431	351	420
Consumption	331	396	413	r354	382
Stocks, Dec. 31: Consumer	29	23	30	r19	17
World production[3]	r2,964	r3,148	r3,273	e3,288	NA

eEstimated. rRevised. NA Not available.
[1]High-, medium-, and low-carbon ferrochromium plus ferrochromium-silicon.
[2]Includes chromium metal, exothermic chromium additives, and other miscellaneous alloys.
[3]As reported in the 1989 Ferroalloys annual report.

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	40,058	28.8
1988	111,105	41,511	26,727	26.7
1989	120,651	46,940	30,392	31.5
1990	113,453	42,881	28,082	30.9
PROJECTED PERFORMANCE[e]				
1991	114,615	46,496	NA	30.6
1992	103,977	46,707	NA	32.7
1993	112,238	51,424	NA	34.2

eEstimated. NA Not available.
Source: Defense Logistics Agency.

NDS nonspecification-grade low-carbon ferrochromium into electrolytic (vacuum melting-grade) chromium metal. In 1989, Elkem was awarded a $7.2 million contract to convert 2,129 metric tons of low-carbon ferrochromium to about 1,043 metric tons of chromium metal during a 1-year period starting in December 1989. That contract was completed in December 1990. In 1990, DLA awarded a contract to Elkem to convert about 1,090 tons of low-carbon ferrochromium to about 779 tons of chromium metal at a cost of about $7.0 million, with completion scheduled for 1991. A second year of this contract is optional for DLA.

DLA continued a program to evaluate plasma smelting technology. The program was being carried out by South Carolina Research Authority (SCRA), along with Macalloy Corp., Massachusetts Institute of Technology, Clemson University, and Arthur D. Little Inc. In 1990, a pilot-scale (2,000 kilowatt) furnace, capable of producing about 500 kilograms of ferrochromium per hour, was built at Macalloy's smelting facility in Charleston, SC. After successful test firings of the furnace, several production campaigns were run by SCRA and Macalloy. The group is expected to now plan, develop, and construct a larger prototype furnace.

DLA revised the goal for refractory-grade chromite ore in the NDS to 630,000 metric tons as authorized by Congress in the National Defense Authorization Act for Fiscal Years 1990 and 1991. This revision represents a goal reduction of 18%. The stockpile inventory remains unchanged at a level equivalent to about 56% of the revised stockpile goal.[7]

EPA completed its rulemaking on chromium containing treated residues from roasting and/or leaching of chrome ore with the publication of its final rule.[8] EPA recommended treated residues from roasting and/or leaching of chrome ores to be regulated under subtitle D of the Resource Conservation and Recovery Act. EPA found no significant danger associated with treated residue from roasting and/or leaching of chrome ore based on waste characteristics, management practices, and damage case investigations.[9]

Chromite refractory use could be significantly impacted by EPA regulation of waste containing chromium. EPA has determined that chromium-containing

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			
1989–90	2,129	1,043	$7.3
PROJECTED PERFORMANCE[e]			
1990–91	1,090	779	7.0

[e]Estimated.
[1]Nonspecification grade.

Source: Defense Logistics Agency.

wastes exhibit toxicity. EPA has, therefore, established a policy that, if the extract from a representative waste sample contains chromium at a concentration greater than or equal to 5.0 milligrams per liter (total chromium), it is hazardous. EPA has promulgated a treatment standard for chromium-containing refractory brick wastes based on chemical stabilization. (Stabilization is a process that keeps a compound, mixture, or solution from changing its form or chemical nature.) EPA has also determined that some chromium-containing refractory brick wastes can be recycled as feedstock in the manufacture of refractory bricks or metal alloys. EPA recognized that there is insufficient capacity to process inorganic solid debris (i.e., treatable material that is greater than 9.5 millimeters in size and requires cutting or crushing and grinding in mechanical sizing equipment) prior to chemical stabilization. As such a material, chromite-containing refractory bricks were granted a 2-year capacity variance (i.e., a variance until May 1992).[10]

Congress enacted the Clean Air Act Amendments Law of 1990 (Public Law 101-549), completely revising the Air Toxics Program. Congress identified 189 hazardous air pollutants to be regulated. Chromium compounds—defined as any unique chemical substances that contain chromium as part of their infrastructure—were included among those hazardous air pollutants. Under the revised Air Toxics Program, Congress instructed EPA to regulate hazardous air pollutants by regulating the source of those pollutants. Congress required EPA to identify pollution sources by November 1991, then to set emission standards for those sources. The Act included a provision for EPA to review petitions to delete specific pollution sources or chemicals identified as hazardous air pollutants from those identified by Congress or EPA.[11]

Motion pictures and videotape programs distributed by the U.S. Bureau of Mines are designed to inform viewers of the importance of minerals in our society and of the need for conservation of these finite resources. The Bureau made "Chromium," a new video recording, available to the public.[12]

Strategic Considerations

U.S. strategic minerals policy and practice has recently been reviewed and analyzed. The United States is import dependent for its chromium needs. This dependence results from our economic system, a system that requires most economically exploitable resources to be used first. The economic system that causes dependence also benefits all consumers by providing low-cost materials. Dependence was found to result in supply vulnerability due to long supply routes between chromium sources and the United States. U.S. policy is to reduce the risk of supply disruption in the event of a national emergency by maintaining a stockpile. Other policy alternatives not currently practiced include resource sharing, diversifying supply sources, and technological changes.[13]

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 or chromium chemicals (i.e., chromic oxide). 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. supply of chromium (contained in chromite ore and chromium ferroalloys and metal) was predominantly from the Republic of South Africa (50%), Turkey (11%), Zimbabwe (11%), and Yugoslavia (9%). Imports from the Republic of South Africa are currently restricted by the Comprehensive Anti-Apartheid Act (Public Law 99-440). In 1987 and again in 1989, the Department of State determined chromium (including ferrochromium) to be a critical and strategic material unavailable from reliable alternative sources, making it possible to import chromite ore and ferrochromium from the Republic of South Africa. Figure 2 summarizes world chromite ore and ferrochromium production capacity and chromium consumption, comparing centrally planned economy countries with market economy countries. The figure also shows NDS inventory.

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, and 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

FIGURE 2

ESTIMATED WORLD CHROMITE ORE AND FERROCHROMIUM SMELTER PRODUCTION CAPACITY, CHROMIUM CONSUMPTION, AND U.S. CHROMIUM STOCKPILE IN 1990

(Million metric tons of chromium content)

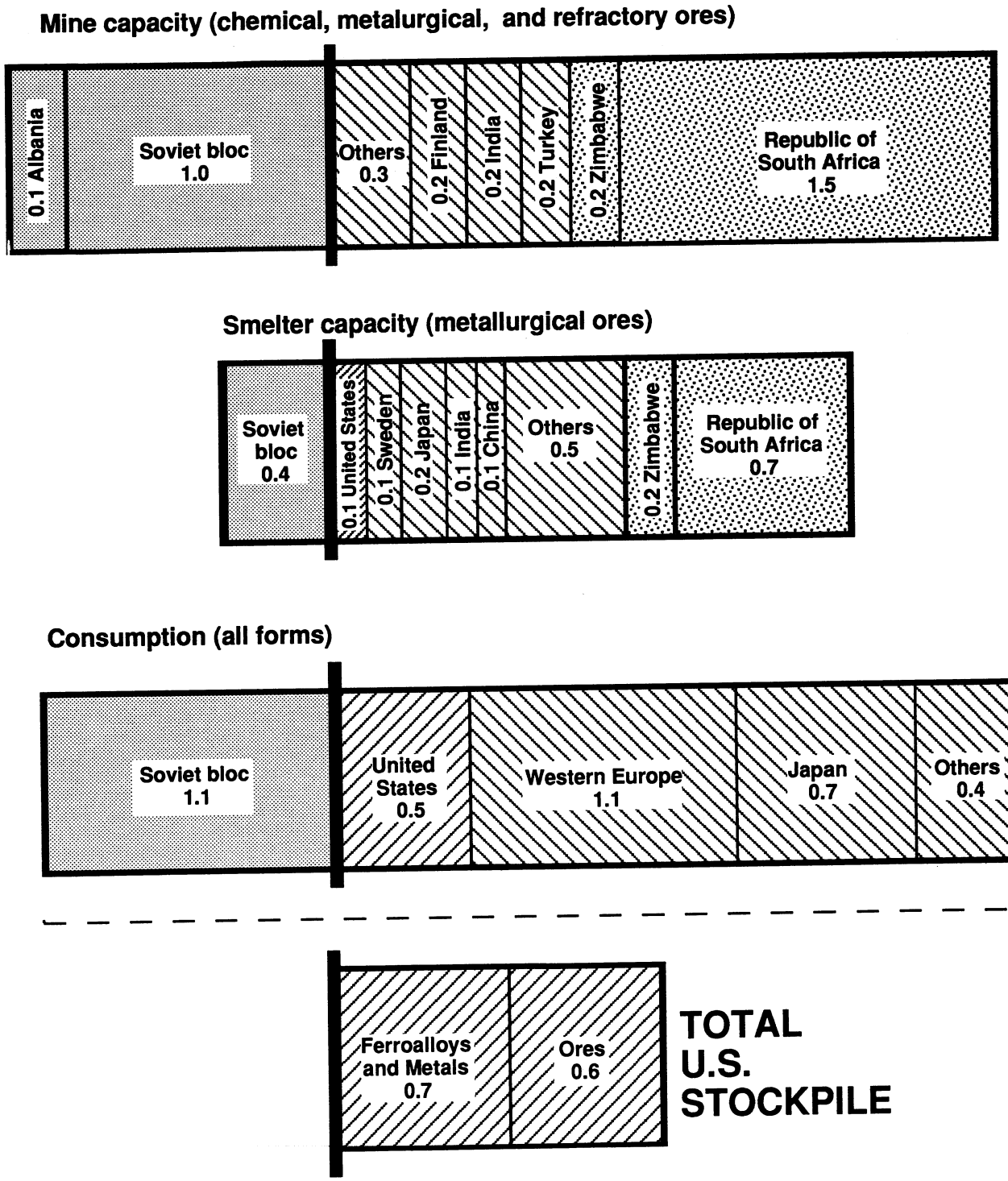


TABLE 9

U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND INVENTORIES FOR CHROMIUM IN 1990

(Thousand metric tons, gross weight)

Material	Stockpile goals	Physical inventory		
		Stockpile-grade	Nonstockpile-grade	Total
Chromite, metallurgical	2,903	1,287	252	1,539
Chromite, chemical	612	220	—	220
Chromite, refractory	630	355	—	355
High-carbon ferrochromium	168	628	1	629
Low-carbon ferrochromium	68	272	17	289
Ferrochromium-silicon	82	52	1	53
Chromium metal	18	3	—	3

Source: Defense Logistics Agency.

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.)

Issues

World ferrochromium production capacity in 1990 increased significantly. 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, Western Europe, and the United States) 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, including net expansion by about 400,000 tons in 1989 and about 240,000 tons in 1990, has continued that trend. (Some new production facilities were completed but not put into production. Thus, there are production facilities that could be started up quickly, resulting in prompt production expansion when it is needed.) About 80% of added capacity was in chromite ore-producing countries in 1989 and 100% in 1990. All of capacity contraction was in nonchromite-producing countries. The largest addition to national annual capacity was in the Republic of South Africa, where about 120,000 tons was added in 1989 and 280,000 tons was added in 1990, 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. In 1990, reduced demand for ferrochromium, resulting from decreased stainless steel production, and increased supply of ferrochromium, resulting from producer expansions and new plant construction, caused excess ferrochromium production capacity. Despite strong demand for ferrochromium resulting from production of stainless steel, excess ferrochromium production capacity caused declining ferrochromium prices since their peak values in 1988. In 1990, world ferrochromium production was limited by delaying the startup of new furnaces, the idling of some furnaces, the conversion of some furnaces from ferrochromium to other ferroalloy production, and the closure of one plant.

Thus, by mid-1990, a combination of marginally reduced demand and added production capacity resulted in a large imbalance between demand and production capacity. With stainless steel production growing at a long-term average annual rate of 3% to 4%, it is estimated that it will take about 5 years for demand to catch up with added capacity. Experience shows that short-term variations in chromium consumption and production can be significantly larger than long-term trends.

Production

The major marketplace chromium materials are chromite ore and chromium metal, ferroalloys, and chemicals. In 1990, the United States produced chromium metal, ferroalloys, and chemicals, but no chromite ore.

Chrome Corp. of America, a subsidiary of Boulder Gold (Australia), entered a joint venture with Phelps Dodge to explore chromite at the Stillwater Complex (Montana) and to study the possibility for mining and producing ferrochromium. The study was planned to be completed in 1991. Chrome Corp. estimated that production could start in 1993.

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).

Consumption and Uses

Domestic consumption of chromite ore and concentrate was 402,290 tons in 1990. Of the total chromite consumed, the chemical and metallurgical industry used 358,620 tons, and the refractory industry, 43,670. 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.)

TABLE 10

PRINCIPAL U.S. PRODUCERS OF CHROMIUM PRODUCTS IN 1990, BY INDUSTRY

Industry and company	Plant
Metallurgical:	
Elkem AS, Elkem Metals Co.	Marietta, OH, and Alloy, WV.
Macalloy Corp.	Charleston, SC.
Satra Concentrates Inc.	Steubenville, OH.
SKW Alloys Inc.	Calvert City, KY, and Niagara Falls, NY.
Refractory:	
General Refractories Co.	Lehi, UT.
Harbison-Walker Refractories, a division of Dresser Industries Inc.	Hammond, IN.
National Refractories & Mining Corp.	Moss Landing, CA, and Columbiana, OH.
North American Refractories Co. Ltd.	Womelsdorf, PA.
Chemical:	
American Chrome & Chemicals Inc.	Corpus Christi, TX.
Occidental Chemicals Corp.	Castle Hayne, NC.

TABLE 11

PRODUCTION, SHIPMENTS, AND STOCKS OF CHROMIUM FERROALLOYS AND CHROMIUM METAL IN THE UNITED STATES

(Metric tons)

Year	Net production		Net shipments	Producer stocks, Dec. 31
	Gross weight	Chromium content		
1986	95,624	58,913	104,924	12,796
1987	106,716	68,614	114,734	5,114
1988	119,645	73,282	115,499	8,831
1989	146,844	90,073	135,361	20,475
1990	108,932	67,701	91,735	14,935

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[1]	
	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)
1986	342,281	40.3	45,303	37.1	387,584	40.2
1987	458,536	41.0	47,586	39.9	506,122	40.9
1988	494,713	42.8	55,923	38.9	550,636	42.4
1989	516,931	42.8	43,780	39.5	560,711	42.6
1990	358,620	40.5	43,670	39.7	402,290	40.1

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

Chromium has a wide range of uses in the three primary consumer groups. In the metallurgical industry, its principal use in 1990 was in stainless steel. Of the 388,916 tons of chromium ferroalloys, metal, and other chromium-containing materials reported consumed, stainless steel accounted for 78%; full-alloy steel, 9%; and other end uses, 13%. The primary use of chromium in the refractory industry was in the form of chromite to make refractory bricks to line metallurgical furnaces. Chromite consumption by the refractory industry decreased to 43,670 tons.

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.

Stocks

Reported consumer stocks of chromite in the United States decreased from 392,273 tons in 1989 to 354,661 tons in 1990. Chemical and metallurgical industry stocks decreased as did refractory industry stocks. At the 1990 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 20,475 tons in 1989 to 14,935 tons in 1990. Consumer stocks decreased from 19,486 tons in 1989 to 17,371 tons in 1990. At the 1990 annual rate of chromium ferroalloy and metal consumption, producer plus consumer stocks represented about a 5-week supply.

Prices

The price of chromite decreased steadily in 1990. The published price of the Republic of South African Transvaal chromite, 44% Cr_2O_3 (no specific chromium-to-iron ratio), decreased from a range of $60 to $65 per ton, f.o.b. the Republic of South African ports, to a range of $55 to $60 in June and a range of $50 to $55 in November, where it remained for the rest of the year. The published price of Turkish ore started the year by decreasing from a range of $175 to $185 per ton, f.o.b. Turkish ports, to a range of $160 to $170 in January. It then decreased to a range of $145 to $160

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]			
1989:					
Steel:					
Carbon	2,990	3,963	207	W	7,160
Stainless and heat-resisting	8,274	r264,933	6,837	r195	280,240
Full-alloy	4,997	25,589	1,263	W	31,849
High-strength, low-alloy and electric	1,928	r2,445	8,036	W	12,408
Tool	845	3,318	W	W	4,164
Cast irons	597	r6,500	26	W	7,123
Superalloys	r3,538	4,551	—	r3,243	11,333
Welding materials[4]	432	583	—	136	1,151
Other alloys[5]	r1,067	r772	—	r1,989	3,830
Miscellaneous and unspecified	313	131	45	410	899
Total[3 6]	r24,983	r312,786	16,415	r 75,974	r360,157
Chromium content	r17,206	r185,752	5,901	r4,776	r213,636
Stocks, Dec. 31, 1989	r4,397	r14,141	425	r 8523	r19,486
1990:					
Steel:					
Carbon	3,192	4,079	276	W	7,547
Stainless and heat-resisting	7,100	287,665	7,929	151	302,845
Full-alloy	4,171	29,326	1,325	W	34,822
High-strength, low-alloy and electric	1,977	2,905	W	W	4,882
Tool	903	2,797	W	—	3,700
Cast irons	W	5,590	26	W	5,616
Superalloys	3,856	4,443	—	3,942	12,241
Welding materials[4]	439	W	—	140	579
Other alloys[5]	1,137	385	—	1,742	3,263
Miscellaneous and unspecified	3,865	876	8,103	579	13,422
Total[3 6]	26,639	338,065	17,659	[9]6,553	388,916
Chromium content	17,927	193,944	6,347	5,552	223,770
Stocks, Dec. 31, 1990	3,280	12,923	455	[10]712	17,371

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 of converted units.
[4]Includes structural and hard-facing welding material.
[5]Includes cutting materials and magnetic, aluminum, copper, nickel, and other alloys.
[6]Includes estimates.
[7]Includes 4,290 tons of chromium metal.
[8]Includes 330 tons of chromium metal.
[9]Includes 4,920 tons of chromium metal.
[10]Includes 497 tons of chromium metal.

in June, followed by a further decrease in November to a range of $120 to $135, where it remained for the rest of the year.

Ferrochromium prices declined in 1990 as significant ferrochromium production reductions were implemented to help move ferrochromium production and consumption toward balance. The published price of domestic high-carbon ferrochromium (50% to 55% chromium) increased from 50.25 to 54.5 cents per pound (¢/lb) of chromium content in January, where it remained for the rest of the year. The published price of domestic low-carbon [0.05% and 0.015% (Simplex) carbon] ferrochromium remained unchanged. The published price of domestic chromium metal declined. The published price of electrolytic chromium metal declined from 395 ¢/lb to 350 ¢/lb in January, after which it increased to 370 ¢/lb, where it remained for the rest of the year. The price of elchrome declined from 462 ¢/lb to 422.5 ¢/lb in August, where it remained for the rest of the year. (Elchrome is a vacuum degassed chromium metal product produced by Elkem Metals Co.)

The price of imported high-carbon (50% to 55% and 60% to 65% chromium) ferrochromium declined until November, when it made a marginal recovery. The published price of imported 50% to 55% high-carbon ferrochromium started the year at a range of 50 to 52.25 ¢/lb-Cr from which it declined to a low range of 45 to 46 ¢/lb-Cr in November, after which it increased to a range of 46 to 47.5 ¢/lb-Cr. The published price of imported 60% to 65% high-carbon ferrochromium started the year at a range of 51 to 54.5 ¢/lb-Cr from which it declined to a range of 42.25 to 45.5 ¢/lb-Cr in December. The published price of imported low-carbon (0.05% carbon) ferrochromium varied throughout the year.

Foreign Trade

Chromium material exports from and imports to the United States included chromite ore and chromium metal, ferroalloys, chemicals, and pigments.

World Review

The council of the Chromium Association (Republic of South Africa) and the directors of the Chromium Centre (France) merged their respective organizations into a single organization, the International Chromium Development Association (ICDA). Each organization had been in operation for 6 years. The objective of the new organization is to promote the growth of chromium use in its traditional markets and the development of new end-use markets. Stainless steel in general and ferritic stainless steel in particular have been materials targeted for development. Structural and corrosion resistant end uses were the targeted

TABLE 14

U.S. CONSUMER STOCKS OF CHROMITE, CHROMIUM FERROALLOYS, AND METAL, DECEMBER 31

(Metric tons, gross weight)

Industry	1986	1987	1988	1989	1990
Chromite:					
Chemical and metallurgical	249,291	308,870	366,268	368,482	333,224
Refractory	35,379	23,144	23,353	23,791	21,437
Total	284,670	332,014	389,621	392,273	354,661
Chromium ferroalloy and metal:					
Low-carbon ferrochromium	4,985	3,169	5,683	r4,397	3,280
High-carbon ferrochromium	20,840	18,023	23,135	r14,141	12,923
Ferrochromium-silicon	1,324	505	647	425	455
Other[1]	1,607	826	960	r523	712
Total[2]	28,756	22,524	30,425	r19,486	17,371

rRevised.
[1]Includes chromium briquets, chromium metal, exothermic chromium additives, and other miscellaneous chromium alloys.
[2]Data may not add to totals shown because of independent rounding.

TABLE 15

PRICE QUOTATIONS FOR CHROMIUM MATERIALS AT BEGINNING AND END OF 1990

Material	January	December
	Dollars per metric ton of product	
Chromite ore:		
South Africa, Republic of	60 - 65	50 - 55
Turkey	160 -170	120 -135
	Cents per pound of chromium	
High-carbon ferrochromium:		
Domestic: 50% to 55% chromium	50.25	54.5
Imported:		
50% to 55% chromium	52 - 55.5	46 - 47.5
60% to 65% chromium	51 - 54.5	42.25- 45.5
Low-carbon:		
Domestic:		
0.05% carbon	95	95
0.015% carbon (Simplex)	166	166
Imported: 0.05% carbon	94 -105	98 -105
	Cents per pound of product	
Chromium metal (domestic):		
Electrolytic	395.0	370.0
Elchrome	462.0	422.5

Source: Metals Week.

markets. The Chromium Review and bimonthly news bulletins are the communication tools to be used by the new organization. The ICDA has offices in Paris, France, and Johannesburg, the Republic of South Africa.

The German Ministry of Economic Affairs, in cooperation with the World Mining Congress, reviewed the world chromium industry. Information on company, location, product quality, geology and resources, and mining methods were prepared by country and mine.[14]

Industry Structure.—The chromium industry is composed primarily of chromite ore producers, ferrochromium producers, and stainless steel producers. Other industry components are chromium chemical and chromite refractory producers.

Brazil, Finland, India, the Republic of South Africa, and the U.S.S.R. are countries that mine chromite, produce ferrochromium, and produce stainless steel. In Finland, Outokumpu Oy, a major share of which is state-owned, owns and operates chromite mining, ferrochromium production, and stainless steel production facilities, making it completely vertically integrated. In the Republic of South Africa, Barlow Rand, an investment company, owns chromite mining operations (Rand Mines) and ferrochromium and stainless steel production facilities (Middelburg Steel and Alloys), making it the only completely vertically integrated chromium producer in the Republic of South Africa. Gencor, an investment company, owns chromite mining operations and ferrochromium production facilities through South Africa Manganese Amcor Ltd. (Samancor). Samancor owns chromite mining operations through its subsidiary Cromore and owns ferrochromium smelters (Tubatse and Ferrometals). Anglovaal, an investment company, owns chromite mines through Associated Ore and Metal Corp., which operates a ferrochromium smelter (Feralloys) through Associated Manganese Mines. Anglo American and Johannesburg Consolidated Investment, investment companies, have shared interests in chromite mines and ferrochromium smelters (Consolidated Metallurgical Industries and Purity Ferrochrome). One other company in the Republic of South Africa, Chromecorp Technology, has chromite mining and ferrochromium production operations. Chromium chemical and chromite refractory production in the Republic of South Africa is also vertically integrated from mine production through product production. Bayer AG (Federal Republic of Germany) owns a chromite mine and chromium chemical plant. Vereening Refractories operates a chromite mine and produces chromite refractories. In the Republic of South Africa, the chromium-related companies are privately owned. Typically, major shares of a company are owned by other

TABLE 16

U.S. EXPORTS AND REEXPORTS OF CHROMITE ORE AND CONCENTRATES

Year	Exports		Reexports	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1986	83,559	$4,143	1,322	$511
1987	1,145	707	4,837	352
1988	3,931	1,430	1,032	320
1989	40,445	5,014	2,375	351
1990	6,321	1,488	4,052	513

Source: Bureau of the Census.

companies, and the remainder, if any, is openly traded. (See figure 3.)

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. (FERBASA). Stainless steel is produced primarily by Companhia Acos Especiais Itabira (ACESITA). Other chromite operations in Brazil are also vertically integrated. Bayer AG (Federal Republic of Germany) owns a chromite mine and chromium chemical plant. Refractory chromite operations are also vertically

TABLE 17

U.S. EXPORTS OF CHROMIUM MATERIALS, BY TYPE

Type	1988	1989	1990		Principal destinations, 1990
	Gross weight (metric tons)	Gross weight (metric tons)	Gross weight (metric tons)	Value (thousands)	
Chromite ore and concentrate	3,931	40,445	6,321	$1,488	Canada (78%); Mexico (11%); Pakistan (6%).
Metal and alloys:					
Chromium metal[1]	318	196	338	3,447	Japan (47%); Canada (25%); Netherlands (10%); Mexico (7%).
Chromium ferroalloys:					
High-carbon ferrochromium	[2 3]8,041	[2 4]9,464	[5]5,795	5,728	Mexico (55%); Canada (43%).
Low-carbon ferrochromium	—	—	[6]2,521	3,782	Canada (53%); Mexico (28%); Argentina (7%); Japan (3%); Venezuela (3%).
Ferrochromium-silicon	—	—	[7]802	1,027	Canada (94%); Mexico (5%).
Chemicals:					
Chromium oxides:					
Chromium trioxide[8]	4,174	3,929	4,082	9,811	Canada (33%); Japan (22%); Republic of Korea (9%); Venezuela (9%); Mexico (5%); Taiwan (5%).
Other	NA	448	1,226	4,590	Canada (31%); Mexico (24%); Japan (12%); Republic of South Africa (8%); Italy (6%); United Kingdom (6%).
Chromium sulfates	NA	1	44	68	Mexico (56%); Canada (44%).
Salts of oxometallic or peroxometallic acids:					
Zinc and lead chromate	NA	152	209	567	Mexico (42%); Canada (22%).
Sodium dichromate[9]	19,977	18,556	16,663	10,611	Italy (41%); Thailand (16%); Colombia (13%); China (7%); Republic of Korea (4%); Taiwan (4%); Mexico (3%); Indonesia (2%).
Potassium dichromate[10]	27	46	48	95	Mexico (29%); Canada (27%); Honduras (22%); Indonesia (11%); Japan (3%).
Other chromates, dichromates, and peroxochromates	NA	171	228	707	United Kingdom (61%); Canada (15%); Colombia (13%).
Pigments and preparations	3,239	2,264	2,643	9,252	Canada (22%); Philippines (21%); Singapore (11%); Federal Republic of Germany (10%).

NA Not available.
[1]Wrought and unwrought and waste and scrap in 1988. Articles thereof and waste and scrap in 1989.
[2]Includes high-, medium-, and low-carbon ferrochromium and ferrochromium-silicon.
[3]Contained 4,845 tons of chromium.
[4]Contained 5,647 tons of chromium.
[5]Contained 3,477 tons of chromium.
[6]Contained 1,517 tons of chromium.
[7]Contained 333 tons of chromium.
[8]Chromic acid in 1988.
[9]Included sodium chromate in 1988.
[10]Included potassium chromate in 1988.

Source: Bureau of the Census.

TABLE 18

U.S. IMPORTS FOR CONSUMPTION OF CHROMITE, 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)
1989:												
Canada	27	5	$2	—	—	—	18	4	$4	45	9	$6
Japan	—	—	—	—	—	—	4,498	2,024	360	4,498	2,024	360
New Caledonia	—	—	—	—	—	—	3,500	1,921	529	3,500	1,921	529
Pakistan	4,025	1,490	322	5,522	2,414	$911	3,117	1,434	608	12,664	5,338	1,841
Philippines	17,030	6,396	1,694	—	—	—	4,841	2,490	525	21,871	8,886	2,219
South Africa, Republic of	74,219	28,217	4,654	133,432	59,870	9,680	159,917	80,225	11,339	367,568	168,312	25,673
Turkey	36,500	13,185	3,412	36,450	15,222	4,783	30,732	17,159	4,290	103,682	45,566	12,485
U.S.S.R.	6,478	2,494	264	—	—	—	4,738	2,388	574	11,216	4,882	838
Total[1]	138,279	51,787	10,347	175,404	77,506	15,373	211,361	107,645	18,228	525,044	236,938	43,949
1990:												
Canada	54	15	$5	—	—	—	12	9	$5	66	24	$10
Indonesia	—	—	—	20	e8	4	—	—	—	20	e8	4
New Caledonia	—	—	—	—	—	—	2,200	1,224	413	2,200	1,224	413
Pakistan	—	—	—	—	—	—	40	24	8	40	24	8
Philippines	13,133	4,716	1,533	—	—	—	522	269	37	13,655	4,985	1,570
South Africa, Repubic of	10,806	1,859	615	129,617	59,025	9,216	120,103	55,885	8,545	260,526	116,769	18,376
Turkey	25,500	9,150	1,214	—	—	—	3,500	1,610	555	29,000	10,760	1,769
Total[1]	49,493	15,740	3,367	129,636	59,033	9,219	126,377	59,021	9,563	305,507	133,794	22,150

[e]Estimated.
[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 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 (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)
1989:												
Australia	—	—	—	—	—	—	243	149	$156	243	149	$156
Belgium[r]	48	25	$68	—	—	—	—	—	—	48	25	68
Brazil	—	—	—	—	—	—	5,803	3,130	5,236	5,803	3,130	5,236
Canada	45	26	61	—	—	—	—	—	—	45	26	61
Chile	67	44	96	40	26	$45	500	341	613	607	411	753
China	1,241	887	1,522	146	78	78	20,582	13,175	19,292	21,970	14,140	20,892
France	—	—	—	—	—	—	5	3	13	5	3	13
Germany, Federal Republic of	9,956	7,100	18,654	—	—	—	238	149	438	10,194	7,250	19,091
Greece	—	—	—	—	—	—	750	488	952	750	488	952

See footnotes at end of table.

TABLE 19—Continued

U.S. IMPORTS FOR CONSUMPTION OF FERROCHROMIUM, BY COUNTRY

Country	Low-carbon (not more than 3% carbon)			Medium-carbon (more than 3% carbon but not more than 4% carbon)			High-carbon (more than 4% carbon)			Total (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)
1989—Continued												
India	—	—	—	—	—	—	4,770	3,032	5,806	4,770	3,032	5,806
Italy	r1,328	r872	r1,972	—	—	—	2,500	1,540	2,838	r3,828	r2,412	r4,810
Japan	365	261	1,040	101	66	182	853	557	1,076	1,319	884	2,298
Mexico	—	—	—	—	—	—	3,019	1,754	2,296	3,019	1,754	2,296
Philippines	—	—	—	7,108	4,727	8,825	8,382	5,129	6,938	15,489	9,856	15,762
South Africa, Republic of	8,887	5,277	10,717	6,209	3,941	7,019	124,070	64,662	95,743	139,165	73,880	113,479
Spain	—	—	—	—	—	—	374	251	260	374	251	260
Sweden	3,797	3,006	3,982	—	—	—	8,750	5,009	7,481	12,546	8,015	11,463
Taiwan	—	—	—	—	—	—	1,215	668	1,149	1,215	668	1,149
Turkey	3,434	2,376	5,036	—	—	—	36,204	23,143	33,054	39,639	25,519	38,090
United Kingdom	73	52	128	—	—	—	34	18	22	107	70	150
Yugoslavia	256	169	363	—	—	—	30,625	19,311	30,975	30,881	19,480	31,337
Zimbabwe	7,684	5,177	7,131	17,300	11,276	19,710	26,732	17,501	29,465	51,716	33,953	56,305
Total[1]	37,181	25,272	50,769	30,903	20,114	35,858	275,650	160,010	243,800	343,733	205,396	330,427
1990:												
Albania	—	—	—	—	—	—	1,505	961	689	1,505	961	689
Australia	—	—	—	—	—	—	294	179	84	294	179	84
Brazil	300	177	321	—	—	—	1,250	659	523	1,550	836	844
Canada	1	—	2	—	—	—	44	23	23	45	23	25
China	350	225	401	—	—	—	1,270	797	766	1,620	1,022	1,167
Finland	—	—	—	—	—	—	23,849	12,530	12,067	23,849	12,530	12,067
France	90	67	149	—	—	—	884	596	591	974	663	740
Germany, Federal Republic of	11,997	8,498	22,195	—	—	—	47	29	92	12,044	8,527	22,287
Greece	—	—	—	—	—	—	240	157	224	240	157	224
Italy	955	686	1,864	—	—	—	—	—	—	955	686	1,864
Japan	364	251	865	193	131	333	387	263	720	944	645	1,918
Mexico	—	—	—	—	—	—	11	6	6	11	6	6
Norway	—	—	—	—	—	—	21,490	13,067	10,865	21,490	13,067	10,865
Philippines	2,554	1,660	1,379	—	—	—	11,793	6,781	4,826	14,347	8,441	6,205
South Africa, Republic of	9,599	5,790	9,703	19,702	10,251	9,095	143,067	74,491	63,033	172,368	90,532	81,831
Spain	—	—	—	—	—	—	1,531	1,008	961	1,531	1,008	961
Sweden	181	135	586	—	—	—	11,821	6,713	5,621	12,002	6,848	6,207
Turkey	9,670	6,716	11,424	—	—	—	35,650	22,353	19,871	45,320	29,069	31,295
United Kingdom	238	159	359	—	—	—	320	139	201	558	298	560
Yugoslavia	—	—	—	—	—	—	48,904	30,975	25,885	48,904	30,975	25,885
Zimbabwe	9,761	6,118	9,050	5,057	3,315	3,801	40,525	26,448	27,863	55,343	35,881	40,714
Total[1]	46,059	30,485	58,299	24,952	13,696	13,230	344,882	198,175	174,911	415,893	242,356	246,439

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

Source: Bureau of the Census.

TABLE 20

U.S. IMPORTS OF CHROMIUM MATERIALS, BY TYPE

Type	1988 Gross weight (metric tons)	1989 Gross weight (metric tons)	1990 Gross weight (metric tons)	1990 Value (thousands)	Principal sources, 1990
METALS AND ALLOYS					
Chromium metal:					
Waste and scrap	NA	50	85	$475	China (75%); Hong Kong (24%).
Other than waste and scrap[1]	4,101	4,152	6,579	42,686	China (30%); Japan (29%); France (19%); United Kingdom (19%).
Ferrochromium-silicon	[2]9,710	[3]6,803	[4]3,801	2,616	Zimbabwe (100%).
CHEMICALS					
Chromium oxides and hydroxides:					
Chromium trioxide[5]	1,542	661	1,677	3,502	Federal Republic of Germany (27%); Netherlands (21%); Japan (19%); United Kingdom (15%); Italy (6%).
Other[6]	NA	3,880	3,512	11,018	Federal Republic of Germany (38%); United Kingdom (19%); China (6%); Canada (4%).
Sulfates of chromium	NA	313	192	176	United Kingdom (40%); Turkey (36%); Mexico (12%); Italy (10%).
Salts of oxometallic or peroxometallic acids:					
Chromates of lead and zinc	NA	607	425	859	Poland (48%); Federal Republic of Germany (18%); Norway (17%); Japan (14%).
Sodium dichromate[7]	3,756	5,489	1,661	1,548	Mexico (37%); Republic of South Africa (31%); Turkey (12%); Spain (7%).
Potassium dichromate[7]	1,327	827	680	1,264	U.S.S.R. (34%); United Kingdom (32%); Federal Republic of Germany (28%).
Other chromates and dichromates; peroxochromates	NA	1,010	1,860	4,491	United Kingdom (63%); Italy (28%).
Chromium carbide	68	108	123	1,278	Federal Republic of Germany (62%); United Kingdom (19%); Japan (18%).
PIGMENTS AND PREPARATIONS BASED ON CHROMIUM					
Chrome yellow	3,999	3,688	3,643	7,636	Canada (72%); Hungary (19%).
Molybdenum orange	1,131	1,046	916	2,579	Canada (97%); Japan (1%); France (1%).
Zinc yellow	1,098	542	436	880	Norway (92%); Canada (4%); Poland (4%).
Other[8]	NA	687	657	2,613	Federal Republic of Germany (56%); Japan (23%); Canada (11%); Romania (6%); United Kingdom (3%).

NA Not available.
[1]Includes wrought and unwrought and waste and scrap before 1989.
[2]Contained 3,885 tons of chromium.
[3]Contained 2,756 tons of chromium.
[4]Contained 1,459 tons of chromium.
[5]Called chromic acid before 1989.
[6]Includes material reported as chromium oxide green or hydrated chromium oxide green before 1989.
[7]Included chromates before 1989 that are reported under "Other" in 1989.
[8]Includes material reported under chrome green, chromium oxide green, hydrated chromium green, or strontium chromate before 1989.

Source: Bureau of the Census.

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 one of many stainless steel producers in India that is integrated from chromite ore mining through ferrochromium and stainless steel production. In the U.S.S.R., chromite mining, ferrochromium production, and stainless steel production are state-owned.

The chromium industry of Japan consists primarily of the production of ferrochromium and stainless steel. Chromite ore production in Japan is small relative to consumption. In Japan, industrial companies may group together to meet

TABLE 21

U.S. IMPORT DUTIES FOR CHROMIUM-CONTAINING MATERIALS IN 1990

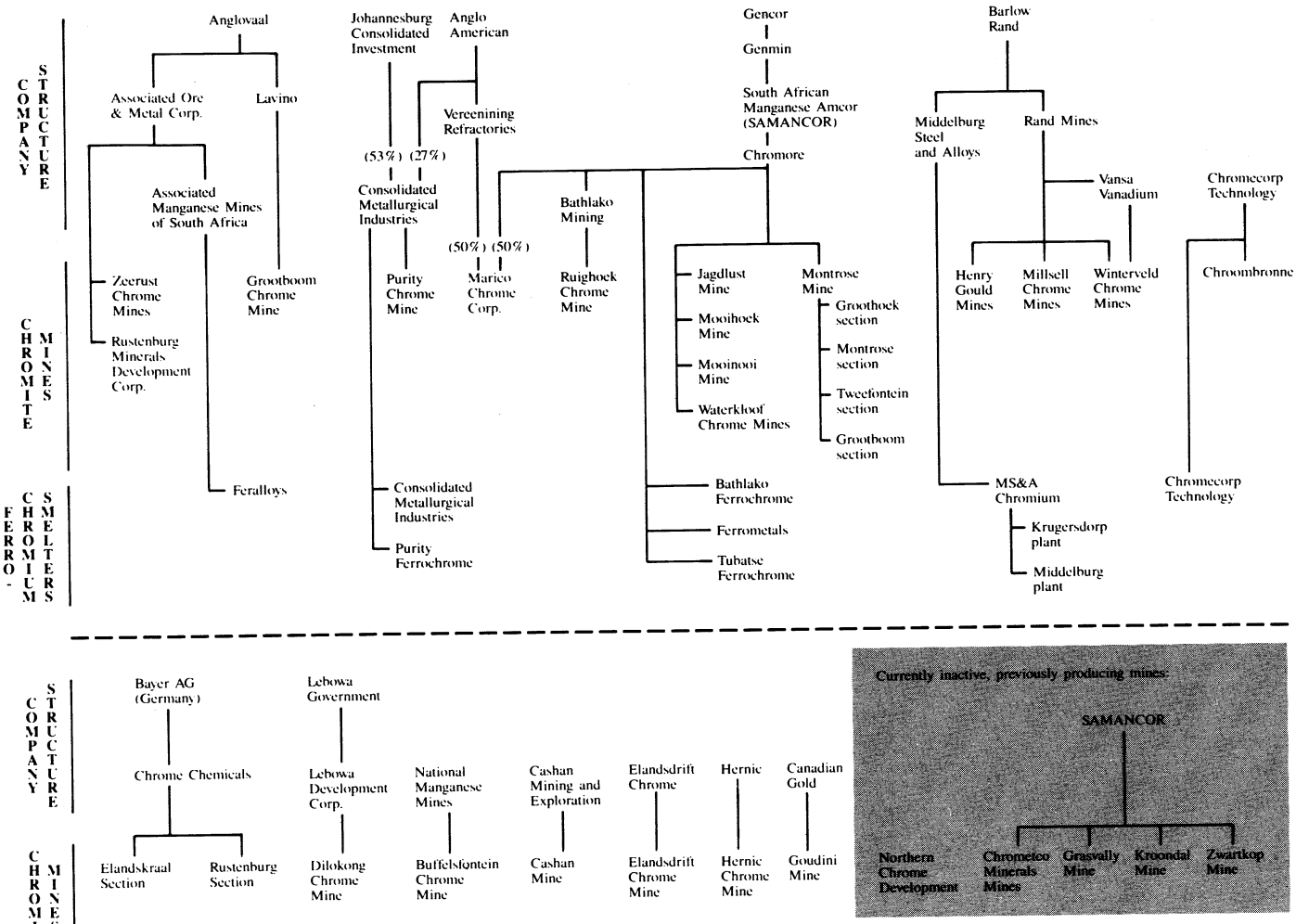
Item	Harmonized Tariff Schedule No.	Most favored nation (MFN)	Non-MFN	Special	
				CA[1]	A, E, IL[2]
Chromite ores and concentrates therefrom:					
Not more than 40% Cr_2O_3	2610.00.0020	Free	Free	NA	Free
More than 40% and less than 46% Cr_2O_3	2610.00.0040	do.	do.	Free	Do.
Not less than 46% Cr_2O_3	2610.00.0060	do.	do.	do.	Do.
Chromium oxides and hydroxides:					
Chromium trioxide	2819.10.0000	3.7% ad valorem	25% ad valorem	do.	Do.
Other	2819.90.0000	do.	do.	do.	Do.
Sulfates; alums; peroxosulfates (persulfates):					
Other sulfates: of chromium	2833.23.0000	do.	do.	1.9% ad valorem	Do.
Salts of oxometallic or peroxometallic acids:					
Chromates of zinc and lead	2841.20.0000	do.	do.	2.2% ad valorem	Do.
Sodium dichromate	2841.30.0000	2.4% ad valorem	8.5% ad valorem	1.4% ad valorem	Do.
Potassium dichromate	2841.40.0000	1.5% ad valorem	3.5% ad valorem	0.9% ad valorem	Do.
Other chromates and dichromates; peroxochromates	2841.50.0000	3.1% ad valorem	25% ad valorem	1.8% ad valorem	Do.
Carbides, whether or not chemically defined:					
Other: of chromium	2849.90.2000	4.2% ad valorem	do.	2.5% ad valorem	Do.
Pigments and preparations based on chromium:					
Chrome yellow	3206.20.0010	3.7% ad valorem	do.	2.2% 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: Ferrochromium:					
More than 4% carbon	7202.41.0000	1.9% ad valorem	7.5% ad valorem	Free	Do.
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	Do.
Other	8112.20.6000	3.7% ad valorem	30% ad valorem	2.2% ad valorem	Do.

NA Not available.
[1]United States-Canada Free Trade Agreement. These tariff values became effective Jan. 1, 1990.
[2]A—Generalized System of Preferences, E—Caribbean Basin Economic Recovery Act, IL—United States-Israel Free-Trade Area Implementation Act of 1985.
Source: U.S. International Trade Commission. Harmonized Tariff Schedule of the United States (1990). USITC Publication 2232.

common needs such as insurance, banking, transportation, international trade, real estate, etc. Companies within a group are frequently part owners of other companies within the group, but shareholding between groups is also common, especially by banking and trust companies. The Japanese ferrochromium producers are typically associated with stainless steel producers and may be part of a group. Association means the stainless steel producer takes the output of the ferrochromium producer. Because Japanese industry is typically both forward and backward integrated, stainless steel and ferrochromium may each be partial owners of one another. The chromium industry of Turkey is composed of both large and small chromite ore producers, with one major producer, Etibank, integrated from mining through ferrochromium production. The chromium industry of Zimbabwe is composed of large companies vertically integrated from chromite mine production through ferrochromium production, small independent chromite mines, and chromite mines operated independently on behalf of the large vertically integrated companies.

FIGURE 3

STRUCTURE OF THE SOUTH AFRICAN CHROMIUM INDUSTRY IN 1990



Sources: Minerals Bureau (South Africa). South Africas Minerals Industry 1989, pp. 79-85, Sept. 1990.
Minerals Bureau (South Africa). Operating Mines, Quarries and Mineral Processing Plants in the Republic of South Africa, Directory DI 90, #57-87, July 1990.
Minerals Bureau (South Africa). Ferrous Mineral Commodities produced in the Republic of South Africa, Directory D8 88, 1988, pp. 1-11, 23-28.
M. H. Silk. World Chromite Resources and Ferrochromium Production. Council for Mineral Technology Special Publication No. 11, 1988, 149 pp.
Company annual reports.

Capacity.—The data in table 15 are rated capacities for major countries that mine chromite ore and produce ferrochromium, primary chromium chemicals, and chromium metal as of December 31, 1990. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time at a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Because not all countries or producers make production capacity information available, historical chromium trade data have been used to estimate production capacity. Rated production capacity changes result both from changes in facilities and changes in knowledge about facilities.

Reserves.—The United States has no chromite ore reserves. However, the United States has a reserve base and resources that could be exploited. (For

TABLE 22

WORLD CHROMIUM RESOURCES[1] AND ANNUAL PRODUCTION CAPACITY OF CHROMITE ORE, FERROCHROMIUM, CHROMIUM METAL, AND CHROMIUM CHEMICALS IN 1990

(Thousand metric tons, contained chromium)

	Resources[2]			Annual production capacity			
	Reserves	Reserve base[3]	Identified resources	Ore	Ferro-chromium	Metal	Chem-icals
Albania	1,900	1,900	6,300	218	41	—	—
Argentina	—	—	—	—	—	—	7
Australia	—	500	500	—	—	—	—
Brazil	2,300	4,900	4,900	108	89	(4)	7
Canada	—	1,100	1,100	—	—	—	—
Chile	—	—	—	—	1	—	—
China	NA	NA	NA	13	72	2	—
Cuba	700	700	2,000	14	—	—	—
Czechoslovakia	—	—	—	—	13	—	—
Egypt	NA	NA	NA	1	—	—	—
Finland	8,900	8,900	8,900	211	105	—	—
France	—	—	—	—	24	2	—
Germany, Federal Republic of	—	—	—	—	42	1	35
Greece	400	400	800	21	19	—	—
Greenland	—	—	26,000	—	—	—	—
Hungary	—	—	—	—	—	—	2
India	18,100	23,800	23,800	241	167	(4)	5
Indonesia	200	200	200	20	—	—	—
Iran	700	700	17,700	15	—	—	—
Italy	—	—	—	—	64	—	—
Japan	(5)	100	100	3	218	5	23
Korea	—	—	—	—	—	—	4
Madagascar	2,100	2,100	2,100	45	—	—	—
Mexico	—	—	—	—	4	—	5
New Caledonia	—	NA	NA	(4)	—	—	—
Norway	—	—	—	—	88	—	—
Oman	NA	NA	NA	1	—	—	—
Pakistan	NA	NA	NA	2	—	—	1
Papua New Guinea	—	—	2,900	—	—	—	—
Philippines	2,300	2,300	2,300	60	49	—	—
Poland	—	—	—	—	35	—	5
Romania	—	—	—	—	24	—	4
South Africa, Republic of	295,200	1,704,400	2,973,700	1,505	791	—	5
Spain	—	—	—	—	9	—	6
Sudan	500	500	500	2	—	—	—
Sweden	—	—	—	—	100	—	—
Taiwan	—	—	—	—	9	—	—
Thailand	NA	NA	NA	(4)	—	—	—
Turkey	2,500	6,000	6,800	440	70	—	8
U.S.S.R.	39,600	39,600	40,600	1,100	223	6	52
United Kingdom	—	—	—	—	1	5	24
United States	—	3,100	35,000	—	83	4	58
Vietnam	NA	NA	NA	1	—	—	—

See footnotes at end of table.

TABLE 22—Continued

WORLD CHROMIUM RESOURCES[1] AND ANNUAL PRODUCTION CAPACITY OF CHROMITE ORE, FERROCHROMIUM, CHROMIUM METAL, AND CHROMIUM CHEMICALS IN 1990

(Thousand metric tons, contained chromium)

	Resources[2]			Annual production capacity			
	Reserves	Reserve base[3]	Identified resources	Ore	Ferro-chromium	Metal	Chem-icals
Yugoslavia	NA	NA	NA	3	58	—	5
Zimbabwe	43,500	285,400	285,400	169	136	—	—
Total[6]	418,900	2,086,600	3,441,600	4,193	2,535	25	257

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

further information on domestic reserves, reserve base, and resources, see Geology-Resources section of this report.)

Albania.—Albania continued construction of a ferrochromium plant at Elbasan. The plant was planned to have a production capacity in the range of 40,000 to 60,000 tons per year from three furnaces. The first of three furnaces was to have been completed in 1990. Albania produces most of its electrical energy at hydroelectric power stations that have had their output limited by water supply shortages resulting from drought. Because ferrochromium production is electrical energy intensive, ferrochromium production capacity has been limited by electrical energy supply.

Australia.—Dragon Resources Ltd. continued to develop its Range Well chromite in a laterite deposit near Cue in Western Australia. The company reported favorable results from a feasibility study for producing high-chromium cast iron grinding balls from its chromite resource. The study was carried out in cooperation with Crooks Mitchell Peacock Stewart (WA) Pty. Ltd. by shipping ore to Geraldton, where it was smelted and cast.

Bolivia.—Bolivia accepted applications for concessions for mineral exploration in the Rincon del Tigre. This 240,000-hectare area has been reported to contain chromite resources.

Brazil.—Companhia Ferroligas do Amapá's Vila Nova Mine produced chromite in Amapá Territory. The Vila Nova Mine estimated its inferred chromite reserves at 7 million tons. Chromite production capacity was 50,000 to 60,000 tons per year of beneficiated product. The company planned to increase beneficiation capacity to 120,000 tons per year when an expansion was justified by chromite demand. Open pit mining resulted in run-of-mine (ROM) ore that typically graded 35% to 44% Cr_2O_3 with a chromium-to-iron ratio of 1.7:1, while beneficiated product typically graded 50% Cr_2O_3 with a chromium-to-iron ratio in the range of 2.0:1 to 2.3:1. ROM ore was beneficiated at the mine site from which it was transported by truck to the Cupixi railroad station, then by train to Santana for export.

Cia. de Ferro Ligas da Bahia S.A. (FERBASA) planned to construct four hydroelectric powerplants. FERBASA planned to construct two of those hydroelectric powerplants on the San Francisco River in Bahia State. Each was planned to have a production capacity of 50 megawatts. The first of these plants was planned to be completed in 1993. FERBASA planned to finance this project through Federal Government financial institutions. Owing to reduced world demand relative to supply, FERBASA reduced production by about 20% (from about 110,000 tons to about 80,000 tons) in 1990.

Companhia Ferroligas do Amapá (CFA) completed construction of its ferrochromium smelter at Porto de Santana at a cost in the range of $14 to $16 million. CFA's 12-megavolt-ampere furnace has a ferrochromium production capacity of 20,000 tons per year. Ferrochromium production would be interchangeable with ferromanganese and ferrosilicon production, with the choice of product determined by market conditions.

Anuário da Indústria Brasileira de Ferroligas (ABRAFE), the Brazilian ferroalloy producers association, reported 1990 production as follows: high-carbon ferrochromium, 73,105 tons; low-carbon ferrochromium, 10,684 tons; ferrochromium-silicon, 4,973 tons; and chromium metal, 37 tons. ABRAFE reported 1990 exports as follows: high-carbon ferrochromium, 16,143 tons; low-carbon ferrochromium, 345 tons; and ferrochromium-silicon and chromium metal, none.

Canada.—Canada studied the development potential of its chromium resources. Coleraine Mining Resources Inc. evaluated the resources of the Hall deposit in Quebec. The Hall deposit was found to contain 1.04 million tons of chromite ore reserves graded at 4.5% Cr_2O_3, of which 801,400 tons grading at 4.6% Cr_2O_3 was proven. Chromium-to-iron ratio of the chromite was found to be 2.6:1. The reserve was found to be exploitable by surface mining. The deposit remains open at depth, and the company planned to continue surveying to determine the deposit's lateral extent. Coleraine Mining also planned to conduct a feasibility study for the production of ferrochromium using low-cost hydroelectric energy from Québec.

Sherwood Metallurgical Corp. continued development of a low-carbon ferrochromium smelter in Vancouver, British Columbia. The plant was planned

to have an initial production capacity of 30,000 tons per year of low-carbon ferrochromium containing 60% to 65% chromium. Producing at full capacity, the plant was planned to annually consume 300,000 megawatt hours of energy, 61,000 tons of chromite ore, 12,500 tons of low-sulfur reductant, and 22,000 tons of low-lime silica sand. A construction site was selected at Bear Cove in Port Hardy. The proposed plant was relocated to the Port Hardy area after local opposition was encountered at Mill Bay and Namaimo. The Port Hardy Ferrochromium Assessment Review Panel was expected to decide on whether or not to permit plant construction in 1991. The plant was opposed by the local Kwakiutl Indian tribe, which claims the proposed plant site and was concerned about the effect of a plant on local fishing. Sherwood also considered locating a low-carbon ferrochromium plant in New Brunswick.

Ferrochrome Canada, a joint venture including Showa Denko (Japan), Mitsui (Japan), Companhia Auxiliar Empresa Minerção SA (Brazil), and Société Général du Financement (Canada), planned an 80,000-ton-per-year-capacity high-carbon ferrochromium plant for Bécancour, Québec. The project was indefinitely postponed owing to the low price of ferrochromium (resulting from increased supply) and to the reduced likelihood of sanctions against the Republic of South African produced ferrochromium (resulting from improved performance of the South African Government in abandoning its apartheid policy).

China.—China reported chromite production from 1949 through 1988.[15]

China reported construction of the Norbusa Mine in Shannan district of Tibet Autonomous Region. Tibet has produced about 500,000 tons of chromite since 1979. The mine was planned to come into production in 1995, with an annual chromite production capacity of about 50,000 tons. The Lhobsa deposit is near the Yarlung Zangbo River. The development cost was estimated to be $12 million and was to be financed by earnings from the Dongfeng chromite mine. The Dongfeng Mine was planned to close owing to consumption of reserves. Chromite from the Norbusa Mine was planned to be smelted to ferrochromium locally, and the ore was to be processed by the Tibet Chemical Works and smelted by the Lhasa Power Bureau and the Tibet Electrical Machinery Plant. About 1,000 tons of ferrochromium was produced.

China deemphasized ferrochromium export owing to raw material supply shortages. Conversion contracts wherein foreign companies supplied ore for conversion were not effected.

The Chinese Ferroalloy Association reported Chinese high-carbon ferrochromium production in 1989 to have been in the range of 80,000 to 90,000 tons; low-carbon ferrochromium production was about 50,000 tons. Ferrochromium exports were reported to have been 8,000 tons in 1987, 24,000 tons in 1988, and 20,000 tons in 1989. Japan and the United States were the largest recipients of Chinese ferrochromium.

European Community.—European ferrochromium producers requested the European Commission to investigate U.S.S.R. and Albanian high-carbon ferrochromium imports to determine whether or not the ferrochromium was being dumped in the European Community. The European Commission opened an investigation, which it planned to complete in 1991. In July, the Council of European Communities increased the amount of high-carbon (more than 6% carbon) ferrochromium from nonmember states permitted to enter duty free from 300,000 tons to 450,000 tons.

Finland.—Outokumpu Chrome Oy operated a new concentrator at the Kemi Mine and a new pelletizing and sintering plant at its ferrochromium plant at Tornio. Construction of the new production facilities was completed in 1989, and these facilities were being brought up to full operating capacity, raising Outokumpu's sintered pellet production capacity to 300,000 tons per year and its ferrochromium production capacity to about 200,000 tons per year. The old sintering plant was to be dismantled. Outokumpu reported that Outokumpu Chrome Oy operated as an independent company and was a wholly owned subsidiary of Outokumpu Oy. Outokumpu planned to transfer ownership of Outokumpu Chrome Oy to Outokumpu Steel Oy effective January 1991. Outokumpu reported 1990 production of 1.1 million tons of chromite ore excavated (up from 0.8 million tons in 1989), 157,000 tons of ferrochromium (down from 169,000 tons in 1989), and 226,000 tons of stainless steel slab (up from 192,000 tons in 1989).

Greece.—Hellenic Ferroalloys SA (HFA) restructured its debt, power cost, and ownership. HFA renegotiated its power rate from 10.2 to 4.75 drachmas per kilowatt-hour, to become effective in 1991. Also to become effective in 1991 was the new ownership structure wherein HFA was to be owned primarily by the Greek Finance Ministry (55%) and the state-run Public Power Corp. (35%). The Greek Government expressed interest in selling publicly owned companies, such as HFA, to the private sector. Interest in HFA was reported. However, no specific offers were revealed. The Greek Government was interested in developing stainless steel production in Greece through the sale of HFA and a sister nickel-producing company.

The National Bank of Greece granted HFA exclusive rights to mine chromite deposits near Domokos in central Greece. HFA planned to start mining the 1 million ton reserve at the rate of about 50,000 tons per year.

India.—**National.**—The large amount of ferrochromium production capacity licensed in 1989 stimulated debate over the best way for India to exploit its chromium resources. Some proposed development of India's ferrochromium industry so that India could benefit from supplying a higher value added commodity (i.e., ferrochromium instead of chromite ore) on the world market. Others proposed to develop the chromite ore-producing industry, but not the ferrochromium industry, reasoning that the ferrochromium plants are not cost effective. (The purpose of development is to earn hard currency, which could then be used for other Indian needs. The cost in hard currency, it was thought, of constructing ferrochromium plants would more than offset the income gain.) Yet others proposed limiting chromite ore exports for a variety of reasons, including the following:

(1) There was not adequate chromite ore production capacity in India to supply the ore required by licensed ferrochromium producers.

(2) Limiting chromite ore export could stimulate development of the electrical energy consuming industry (i.e., ferrochromium production) in States with excess electrical energy. Unfortunately, chromite ore resources and excess electrical power were not found in the same States.

(3) Limitation of chromite ore export from the major producing area (Orissa State) would stimulate industrial growth in that State.

Many motivations and constraints are shaping the development of the Indian chromium industry.

The Indian Government announced its chromite ore export policy for April 1, 1990, through March 31, 1993. The new policy prohibits the export of either lumpy chromite ore with Cr_2O_3 content greater than 38% or friable chromite ore with Cr_2O_3 content greater than 52% and silica content lower than 4%. The Steel and Mines Minister of India introduced a new minerals policy that reserves exploration and processing of chromite for the Government. The Orissa State Government sought to have the Indian Government ban export of chromite ore from the Orissa. Orissa State holds 97% of Indian chromite reserves and accounts for more than 90% of Indian chromite ore production. Such a ban would have reduced supplies to foreign consumers, reduced the likelihood of ferrochromium plant construction outside Orissa, and favored chromite ore and ferrochromium producers in Orissa State. Orissa Mining Corp. and OMC Alloys Ltd. are the State-owned enterprises currently producing chromite ore and ferrochromium. Tata Iron and Steel Co. is the major private producer of chromite ore and new ferrochromium producer in Orissa. Ferro Alloys Corp. Ltd. (FACOR) and Indian Development Corp. are private ferrochromium producers in Orissa State.

Chromite Ore.—FACOR continued development of the Lakshmi shaft at its Boula Mine. The company planned to complete the chromite ore haulage shaft in 1992.

Tata Iron and Steel Co. (TISCO) started production from its new beneficiation plant at Sukinda chromite mine. The plant cost about $13 million[16] and has an annual production capacity in the range of 70,000 to 80,000 tons of chromite ore graded at 48% Cr_2O_3 with a chromium-to-iron ratio of 2.7:1 and 20,000 to 30,000 tons of chromite ore graded at 52% to 54% Cr_2O_3 with chromium-to-iron ratio of 3.2:1. Product size is in the range of 150 to 200 mesh. Chromite feedstock to the plant is graded in the range of 20% to 30% Cr_2O_3.

Ferrochromium.—India's consumption of chromium materials was estimated to include about 60,000 tons of high-carbon ferrochromium and 10,000 tons of low-carbon ferrochromium annually. India is virtually self-sufficient in ferrochromium supply. India operates a unique mixture of privately and publicly owned ferrochromium smelters. Larger smelters were licensed by the State, while smaller smelters operated without license. Licensed smelters are required to produce for domestic use or for export. It has been estimated that there is about 50,000 tons of ferrochromium production capacity at small (unlicensed) plants. Licensed production capacity nears 600,000 tons per year. However, substantially less production capacity is installed, and even less is available owing to insufficient electrical power availability from the national grid. India experienced electrical power shortages in Andra Pradesh and Karnataka States. Andra Pradesh reduced electrical power supply by 30% to 40%.

FACOR installed a captive electrical power generating facility (including a fuel oil storage facility) at its ferrochromium plant at Shreeramnagar in Andra Pradesh State. The electrical powerplant consisted of three 10.5-megawatt diesel-powered electrical generators. This captive power station is capable of supplying about 60% of FACOR's needs at Shreeramnagar. FACOR planned to install two 10.5-megawatt electrical generators at its charge-grade ferrochromium plant in Orissa State. FACOR added a vacuum oxygen decarburizing furnace of its own design and construction to its processing facilities to supply medium-carbon ferrochromium produced from high-carbon ferrochromium to India's steel industry.

Indian Charge Chrome Ltd. (ICCL), a subsidiary of Indian Metals and FACOR, started production operation of its 108-megawatt captive powerplant, briquetting plant, and ferrochromium smelter at Choudwar, Cuttack District, Orissa State. ICCL is an export-oriented unit with an annual production capacity of 62,500 tons. ICCL arranged for Tata Iron and Steel to supply chromite ore and to market its ferrochromium production.

Ispat Alloys Ltd. planned to construct a ferrochromium plant in Ohankale District of Orissa State, where chromite ore was readily available. Ispat Alloys planned to use a pelletizing process from Outokumpu Oy (Finland) and a 45-megavolt-ampere furnace from Demag (Germany) at the export-oriented plant. Ispat planned to complete construction of the plant in 1991.

OMC Alloys, a subsidiary of Orissa Mining Co. and a public-sector company, experienced financial difficulties. OMC identified increasing electrical power rates and inflation as the major causes of its problems. Since the plant started producing ferrochromium, electrical power cost has increased from $0.0139[17] per kilowatt hour to $0.0566[18] per kilowatt-hour. The rising cost of production and declining price of ferrochromium has resulted in unprofitable operation for OMC. Rupee value dropped by 30% to 60% due to inflation. This inflation has increased the cost of the foreign component of OMC's debt. OMC planned to improve its position by increasing production from the current 70% of capacity to the range of 80% to 85% of capacity.

TISCO converted a ferromanganese furnace to ferrochromium and constructed an export-oriented ferrochromium plant. TISCO had Elkem (Norway) renovate a 9-megavolt-ampere ferromanganese furnace at its ferromanganese plant at Joda, Kendujhar District, Orissa State, to a 12-megavolt-ampere ferrochromium furnace with an annual production capacity of 20,000 tons.

Kolmak Chemicals planned to build a ferrochromium plant at Raigarh, Madhya Pradesh. The new ferrochromium producer, Standard Chrome, was planned to have an annual production capacity of 15,000 tons. TISCO was expected to supply chromite ore, handle export sales, and cofinance the new business.

Indonesia.—Aneka Tambang, Indonesia's state-owned mining company, developed a chromite mine near Wosu Port, Sulawesi Island. Commercial production started in 1990 and included chromite ore for metallurgical use and for foundry sand use. Aneka planned to ship the metallurgical-grade chromite ore to Japan and the foundry sand-grade chromite ore to Gebe Island for cast iron production. The metallurgical-grade chromite ore graded about 41% Cr_2O_3, 17% FeO, 18% Al_3O_3, and 11% MgO, with a chromium-to-iron ratio in the range of 1:1 to 1.6:1. The foundry-sand grade chromite ore contained about 52% Cr_2O_3.

Iran.—Following the end of the Iran-Iraq war in 1988, Iran has been developing its chromium industry. Chromite ore exports have increased since the end of the war.

Italy.—Italcromo purchased a site (the Stefana di Termoli, an industrial site used

to produce steel from 1972 to 1986) at a cost of $5.4 million[19] and planned to construct four furnaces. The first two were planned to be 24-megavolt-ampere furnaces for ferrochromium production (convertible to ferromanganese). The second two furnaces, planned for construction in 1994, were planned to be for silicomanganese production (convertible to ferrosilicon). The first furnace (planned to have been purchased from Demag in Germany) was to be brought into operation in the second quarter of 1991. It was noted that Italy consumed on the order of 160,000 to 170,000 tons of ferrochromium annually, an adequate level of demand to support a domestic plant. Italcromo planned to produce high-carbon ferrochromium from Albanian ore.

Japan.—Japan operated a two-part stockpiling program, Government and private. Japan's goal is to acquire a stockpile of chromium adequate to serve its needs for 60 days, of which 42 days was to be in the Government stockpile and 18 days was to be in the private stockpile. The Metal Mining Agency of Japan, under the supervision of the Ministry of International Trade and Industry, operated the Government stockpile, while Japan Rare Metals Association operated the private stockpile. As of March 1990, Japan had acquired a stockpile of chromium adequate to serve its needs for 35.3 days in the Government stockpile and 15.1 days in the private stockpile. Japan planned to increase its Government stockpile to 2.8 days of consumption, while increasing its private stockpile to 1.2 days.

Japan reported stainless steel production of 2,410,725 tons in 1990, a decline of 11% compared with that of 1989. Japan's ferroalloy industry produced about 324,327 tons of ferrochromium, a decline of 9.0% compared with that of 1989. Japan's ferrochromium production has ranged from 260,000 tons to 360,000 tons per year in the 1980-90 time period. Japan imported 441,672 tons of ferrochromium in 1990, while it exported 2,811 tons, giving imports a 58% market share. Japan imported 789,225 tons of chromite ore with which to produce chromium ferroalloys and imported 550 tons of chromium metal.

Japanese ferrochromium producers suffered as a result of excess supply of ferrochromium in 1990. The Japan Ferroalloy Association studied the possibility of making an antidumping complaint against ferrochromium imports owing to the low price of that material relative to the cost of production in Japan.

Japanese stainless steel producers, NKK and Kawasaki Steel, reported implementing innovative production techniques. NKK started production of nickel-containing stainless steel at its Fukuyama works in September. NKK combined nickel and chromite ores with coke and blast furnace iron in a converter, then blew the mixture with oxygen and nitrogen to produce stainless steel. The stainless steel was then continuously cast. Kawasaki processed chromite ore in a kiln at its Mizushima works then supplied the chromium product to a converter at its Chiba works for the production of stainless steel. It was thought that stainless steel production by these blast furnace steel producers would increase competition and result in a lower priced and more competitive stainless steel product.

Korea, Republic of.—Korea reported 1990 ferrochromium imports of 67,162 tons, consumption of 69,363 tons, and ending stocks of 11,953 tons.

Madagascar.—Kraomita Malagasy (Kraoma) mined 192,857 tons of chromite ore from which it produced 62,540 tons of marketable concentrate in 1989. Madagascar exported 134,338 tons of chromite in 1989.

New Caledonia.—Chromical Ltd., the chromite ore mining company that operates the Tiebaghi Mine in New Caledonia, continued mining until July 1990, while it prospected to extend chromite ore reserves. New Caledonia reported mining about 11,031 tons of run-or-mine chromite ore from which it produced about 6,207 tons of marketable concentrate.

Norway.—Elkem AS (Norway) purchased the fixed assets of Norsk Ferrokrom AS effective July 1990 and named the operation Elkem Rana AS. The assets included a briquetting facility and two ferrochromium-producing electric furnaces. One electric furnace started production in September 1989. Elkem planned to start the second furnace in 1991. The briquetting facility had an annual production capacity of 300,000 to 400,000 tons of chromite ore furnace feed. The operating furnace had a capacity of 45 megavolt amperes and was operated at 40 megawatts to produce about 70,000 tons of high-carbon ferrochromium annually. Thus, with both furnaces in operation, Elkem could produce with an annual capacity of about 140,000 tons. Elkem planned to construct a concentrator to recover chromium from slag. Chromium recovery from slag would permit smelting-process-chromium recovery in excess of 80%. Norwegian sanctions against the Republic of South Africa prohibit importation of South African chromite ore.

Oman.—Oman Mining Co. (state owned) has mined chromite ore from deposits near Wadi Rajmi and exported about 8,000 tons of chromite between 1985 and 1989. Oman has identified more than 600 chromite occurrences. Detailed analysis of 36 deposits yielded 1 million tons of chromite ore reserves. Oman continues to explore for chromite in the area of Rajmi-Fizh and the Farfar-Hilti areas of northern Oman.

Philippines.—**Chromite Ore.**—At the request of the Philippine Government, the Japan International Cooperation Agency is conducting a 3-year study of chromite resources on Palawan Island. The study is funded by the Metal Mining Agency (Japan) and was estimated to cost about $2 million.

Merlin Mining Co. (Australia) acquired 24.4% interest in Acoje Mining Co., owner of the Acoje Mine in Zambales Province. Merlin also holds leases near the Acoje Mine, from which it produces chromite fines from alluvial deposits and owns leases on Dinagat Island. Acoje Mining Co. started mining in the late 1930's, from which time it has produced about 3 million tons of chromite ore. As a result of excessive debt and labor problems, production has declined to about 36,000 tons per year. Merlin planned to invest in the Acoje Mine to bring the mine's production up to about 100,000 tons per year. In situ reserves were estimated at 4 million tons.

The Philippine Government signed an agreement with Benguet Corp. to develop a refractory chromite mine from deposits owned by Consolidated Mines Inc.

The Philippine Government and the United Nations Revolving Fund for Natural Resources Exploration (UNRFNRE) agreed to develop chromite deposits on Dinagat Island. The deposit was estimated to contain in the range of 1 to 2 million tons of massive metallurgical-grade chromite ore graded at 50% Cr_2O_3.

Ferrochromium.—Ferrochrome Philippines Inc. operated a ferrochromium smelter with a production capacity of about 54,000 tons per year. Integrated Chrome Corp. operated a ferrochromium smelter with a production capacity of about 18,000 tons per year.

***South Africa, Republic of.*—Labor Relations.**—The National Union of Metalworkers of South Africa (NUMSA) represents ferrochromium workers at Consolidated Metallurgical Industries, Ferrometals, Feralloys, Middelburg Steel and Alloys, and Tubatse. Contracts were renegotiated without work interruptions at Consolidated Metallurgical Industries, Feralloys, Middelburg Steel and Alloys, and Tubatse. Ferrometals experienced a strike during part of August and September before a new contract was agreed upon. Issues included job security and pay rates.

Chromite Ore.—High demand for chromium in 1989 resulted in the creation of new, independent chromite ore mining operations in the Republic of South Africa that utilize surface mining methods. As a result, the new operations can produce chromite ore at a cost less than that of established underground operations. The cost difference is expected to last until surface minable reserves are exhausted. Established South African chromite ore producers reported that wage increases, inflation, and rail transportation cost increases contributed to the increased cost of chromite ore. South Africa's Minerals Bureau reported 1989 chromite ore production (excluding Bophuthatswana) at 4,274,700 tons, an increase of 13% over that of 1988 and a record high for the second year in a row. The Minerals Bureau reported 1989 sales to have been as follows: domestic, 2,542,000 tons (up 19% over that of 1988); and foreign, 1,371,000 tons (up 3.5% over that of 1988). Domestic sales set a record high, exceeding the previous high in 1987 by 17.8%.

Lebowa Development Corp, owner of the Dilokong Chrome Mine in Lebowa, reported mine developments raising annual production capacity to 300,000 tons effective in 1990. The production composition was to include 69,000 tons of lumpy chromite ore, 58,000 tons of small lumpy ore, and 173,000 tons of fine chromite ore.

Hernic Pty. Ltd. started production late in 1989 from reserves of about 3.052 million tons and reached full potential in 1990. Ore reserves include 1.743 million tons in the GM-1 seam (primarily metallurgical grade) and 1.309 million tons in the GM-2 seam (primarily chemical and refractory grades). Open pit mining yields a range of 30,000 to 40,000 tons of chromite ore per month after removal of 25 meters of overburden and with an eventual change to underground mining when production capacity will shift to a range of 20,000 to 30,000 tons of chromite per month. A beneficiation plant under construction, at a cost of $1.7 million,[20] was planned to produce 12,000 tons of lumpy chromite ore per month and 18,000 tons of chromite concentrate per month. A captive loading facility, under construction at Marikana station (11 kilometers from the mine), was to have a loading capacity in the range of 15,000 to 20,000 tons of chromite ore per month when completed in 1990. (Wolhuterskop station, 25 kilometers from the mine, was to be used until the Marikana facilities were completed.) Typical chromite ore specification were as follows: lumpy, 39.5% Cr_2O_3, chromium-to-iron ratio of 1.50:1; chemical grade, 46.54% Cr_2O_3, chromium-to-iron ratio of 1.55:1; concentrate, 45.0% Cr_2O_3, chromium-to-iron ratio of 1.51:1. Hernic's mine is south of Samancor's Mooinooi Mine in the Rustenburg district, Transvaal Province (western belt of the Bushweld Complex). Beneficiation includes crushing, screening, and spiral classifiers.

Goudini Mine started open pit production of chromite ore early in 1990, with reserves in the range of 70 to 75 million tons. Goudini Mine is in the western belt of the Bushweld Complex. Ore has an unusually high chromium-to-iron ratio of 2:1, with lumpy ore grading 40% Cr_2O_3 and concentrate, above 50% Cr_2O_3. Production was reported at the rate of about 80,000 tons per year in 1990, with a target production capacity of 200,000 tons per year.

Elandsdrift Chrome (Pty.) Ltd. was organized in September 1989 and started opencast mining in June 1990. The beneficiation plant was completed in February 1990. Chromite ore was mined from an inferred reserve of 1.5 million tons in the MG-1 seam. Run-of-mine ore grading 44% Cr_2O_3 was about 30% lump and 70% fines. The beneficiation plant, including a rod mill and spiral separators, produced about 9,000 tons per month, with expansion to 18,000 tons per month planned. Shipping was by rail from the nearby Marikana station.

A new process, recovery of platinum-group metals from chromite ore tailings, was being implemented. Temex, the mining exploration division of Genwest Group, erected a plant in western Transvaal Province. In addition to platinum-group metals, the new plant was to produce chromite concentrate.

Ferrochromium.—The Republic of South Africa's Minerals Bureau reported 1989 ferrochromium production at 993,920 tons, an increase of only 0.02% over that of 1988 and a record high for the third consecutive year. The Minerals Bureau reported 1989 sales to have been as follows: domestic, 59,552 tons (up 2.4% over that of 1988 and a record high); and foreign, 930,571 (down 3.6% over the record high of 1988).

Chromecorp Technology (CCT) operated the two electric arc furnaces (electrical capacity, 30 megavolt amperes and production capacity, 50,000 to 60,000 tons per year each), while it completed construction in April 1990 of a third furnace like the first two. With completion of its third furnace, CCT had a production capacity in the range of 150,000 to 180,000 tons per year. CCT also operated a captive chromite mine, the Chroombronne Mine.

Consolidated Metallurgical Industries Ltd. (CMI), a subsidiary of Johannesburg Consolidated Investment Co. Ltd., started its third 32.5-megavolt-ampere furnace at its plant near Lydenburg, Transvaal Province. The additional furnace increased CMI's production capacity from a range of 150,000 to 160,000 tons per year to a range of 200,000 to 210,000 tons per year. CMI purchased the issued share capital of Purity Chrome Pty. Ltd. (a chromite ore mining and beneficiating company) and the assets of Purity Ferrochrome Pty. Ltd. (a ferrochromium producer) for $49 million.[21] At the time of purchase, Purity Chrome Mine had a production capacity of about 250,000 tons per year of chromite ore with chromium-to-iron ratio of 1.55:1. Chromite ore production included lumpy, grading 40% to 42% Cr_2O_3, and fines, grading 45% Cr_2O_3. Purity Ferrochrome included two electric arc furnaces of 33-megavolt-ampere power capacity and 120,000 tons per year charge-grade high-carbon ferrochromium production capacity. With this purchase, CMI acquired a captive chromite mine and additional

ferrochromium production capacity, yielding a total capacity in the range of 320,000 to 330,000 tons per year for CMI and Purity combined.

Middelburg Steel and Alloys (Pty.) Ltd. reorganized itself into MS&A Chromium (Pty.) Ltd. (MS&A), responsible for the chromium ferroalloy production and marketing, and MS&A Stainless (Pty.) Ltd., responsible for stainless steel production and marketing. Middelburg Steel and Alloys (Pty.) Ltd. retains responsibility for the new companies' strategic planning. MS&A completed construction of a rotary kiln and electric arc furnace for application of the chrome direct reduction (CDR) process that MS&A developed with Krupp (Germany). The project will add 120,000 tons per year of ferrochromium production capacity during a 3-year period, while the new equipment and process is being brought to full capacity operation at a cost to MS&A of about $97 million.[22] The new process offers several cost-reducing features, including the following: (1) The CDR process uses chromite ore fines that are available at lower cost than chromite ore lumps, and (2) the CDR process uses coal as a source of energy for reducing a substantial fraction of the chromite ore before the partially reduced product is fed into an electric arc furnace for completion of the reduction process. Energy supplied from coal is less expensive than energy supplied from electricity.

Tubatse started production from its fifth furnace in February 1990. Tubatse started producing ferrochromium with three furnaces, each with electrical transformer capacity of 30 megavolt-amperes and production capacity of about 50,000 tons per year. Tubatse modified its furnaces, changing production capacity to about 60,000 tons per year for each furnace. Tubatse then added two furnaces, each with electrical transformer capacity of 37 megavolt-amperes and production capacity of about 60,000 tons per year. The fourth furnace was brought into production in 1989. Tubatse now has a production capacity of 300,000 tons per year.

South Africa Manganese Amcor Ltd. reported its analysis of the world chromium growth prospects. Samancor estimated world stainless steel production to have grown historically at a rate of 2.4%. At this growth rate, Samancor estimated the world chromium industry would be required to add about 100,000 tons of ferrochromium production capacity and about 300,000 tons of stainless steel production capacity annually. The Republic of South Africa was estimated to produce only about 1% of world stainless steel production. Samancor found these conditions encouraging to the development of stainless steel production capacity in the Republic of South Africa. Samancor and Highveld Steel & Vanadium planned a 300,000-ton-per-year capacity stainless steel plant. It was suggested that such a plant could be built at Witbank within a 3-year period. Expanded stainless steel production would be the next step in vertically integrating and expanding the Republic of South Africa's chromium industry.

Purity Ferrochrome, a subsidiary of Consolidated Metallurgical Industries Ltd., brought its first furnace into operation in June and its second in July 1990. Each furnace is of Tanabe Kakoki (Japan) design and has electrical capacity in the range of 30 to 33 megavolt-amperes and production capacity of about 60,000 tons per year. (See Consolidated Metallurgical Industries Ltd. on previous page.)

Spain.—Empresa Nacional Adaro de Investigaciones Mineras S.A. (ENADIMSA), a state-owned Spanish company, in cooperation with the University of Madrid, reported the results of minerals exploration on the northwest coast of Spain. The exploration geologists targeted chromite because the Cape Ortegal Complex is composed of rock types known to be associated with chromite. The geologists found clear indicators of chromium mineralization in northwestern Spain. The mineral rights of the area are covered by ENADIMSA claims.

Sweden.—SwedeChrome AB closed its ferrochromium plant at Malm in January 1990. The plant was closed because of the declining price of ferrochromium, an unfavorable cost position due to the Swedish embargo toward South African chromite, and, to a lesser degree, uncertainty about electrical power rates. With SwedeChrome out of production, Sweden was left with one ferrochromium producer, Vargn Alloys AB. Vargn produces high-carbon ferrochromium with an annual capacity of about 160,000 tons.

Turkey.—Mine and smelter development was planned by Egemetal Madencilik AS in cooperation with three Korean companies, Yukong Ltd., Sunkyong Ltd., and Korea Mining Promotion Corp. Mine development was planned to start in 1990 followed by smelter development in 1991, with completion in 1993 at a cost of $34 million. The ferrochromium smelter was planned to have a production capacity of about 40,000 tons per year, of which 20,000 tons was planned to be supplied to Korea to meet about 20% of Korea's ferrochromium demand. The smelter was planned to be at the mine site in Bursa Province.

Etibank, Turkey's Government-owned company that owns chromite mines and the only ferrochromium smelters in Turkey, completed construction of two new furnaces in 1989, when one of those furnaces was brought into production. The second new furnace started trial operation in 1990. When both new furnaces are operating at full capacity, Etibank will have a high-carbon ferrochromium production capacity of 150,000 tons per year. Etibank considered reorganizing its sales operation in the United States. Etibank has sold its ferrochromium product quarterly on a tender basis to U.S. merchants, who then sell the material to consumers. Etibank may enter a joint-venture arrangement to create an exclusive agent company for Etibank's ferrochromium in the United States.

U.S.S.R.—Donskoy Ore Dressing Complex is at Khromtau city, about 90 kilometers east of Aktyubinsk, Kazakhstan Republic. Ore was discovered there in 1936. The complex operated with a work force of 5,000 compared with a local population in Khromtau city of 25,000. Proven ore reserves were reported to have been 300 million tons at 43% to 44% Cr_2O_3; total ore reserves (including inferred), 1,000 million tons. Production was planned to increase to 4 million tons per year by the year 2000. Run-of-mine chromite ore was mined and then screened into lumps and fines. Tailings (material in the size range of 0 to 3 millimeters and containing 40% Cr_2O_3) were stockpiled and amounted to about 5.0 million tons by yearend. Upgrading tailings for export was planned.

Donskoy Ore Dressing Complex planned to expand its beneficiation facilities. The new beneficiation facility was planned to have a production capacity of 400,000 tons per year. Construction was planned to be completed in 1993, and shipments were planned to start in 1994. This additional production capacity

would increase the operation's production capacity from 3.6 to 4.0 million tons per year. The new beneficiation facility has been designed to utilize ore grades of 37% to 38% Cr_2O_3.

United Kingdom.—Metal Alloys Ltd. of South Wales ceased production of chromium metal when the company was sold, and its new owner elected to discontinue chromium metal production. United Kingdom is left with two chromium metal producers, London & Scandinavian Metallurgical Co. Ltd. and Murex—a division of SKW Metals UK Ltd.

Vietnam.—Vietnam operated the Nui Nua chromite mine in Than Hoa Province. Chromite was discovered there in 1927, and mining started in 1930. Production was about 8,000 tons per year until 1960. Production peaked at 36,000 tons in 1963, then dropped in 1980 to the range of 3,500 to 4,000 tons per year. Mining is from an alluvial deposit in which about 70% of the ore is in the size range of 0.07 to 0.28 millimeters. The chromite has a Cr_2O_3 content in the range of 47.3% to 51.5% and Al_2O_3 content of about 12%. Vietnam planned to replace current water-jet mining with modern dredging. There is an oversupply of modern tin dredges in Southeast Asia.

Zimbabwe.—The Government of Zimbabwe, Union Carbide (owner of Zimbabwe Mining and Smelting), and Zimbabwe Alloys are developing technology to mechanize the recovery of chromite from the narrow seams in the Mutorashanga area of the North Dyke. The objective is to make chromite recovery economic, thereby creating an estimated 500 million tons of chromite reserves for the country. The group will acquire and operate an Atlas Copco-Eikhoff (Federal Republic of Germany) roadheader on a narrow North Dyke chromite seam to test the feasibility of using such technology. The group planned to study a mechanized low-profile rock cutter for efficient stoping operations. Owing to a lack of economic recovery methods for narrow seam chromite mining, many northern Great Dyke mines are unmechanized and operated by cooperatives. Zimbabwe reviewed its chromium mining industry, reporting mine locations, cumulative production, and time period of operation.[23]

TABLE 23

CHROMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons, gross weight)

Country[2]	1986	1987	1988	1989	1990[e]
Albania[e]	850,000	830,000	750,000	r610,000	600,000
Brazil[3]	r353,000	r337,500	r410,256	r475,949	476,000
China	50,000	32,000	26,000	e25,000	25,000
Cuba	50,000	52,400	r52,200	r50,600	50,000
Finland[4]	678,091	543,000	e700,000	re498,000	500,000
Greece[5]	r60,063	63,825	r49,535	r56,000	60,000
India[6]	r629,671	623,591	r820,863	r1,002,659	995,000
Indonesia	—	—	7,636	r7,635	8,000
Iran	re54,000	re55,000	r57,000	r62,000	60,000
Japan	10,642	11,815	9,508	r11,674	7,800
Madagascar	82,910	106,600	r64,177	r62,540	62,000
New Caledonia	72,207	61,832	70,341	r60,281	76,207
Oman	4,820	—	—	—	—
Pakistan	8,299	r10,181	3,327	r27,105	20,000
Philippines	174,230	187,900	e190,000	re173,200	197,950
South Africa, Republic of[8]	3,907,000	r3,789,000	4,245,000	r4,950,854	74,497,700
Sudan	8,500	13,015	8,000	r25,000	15,000
Thailand	361	5	776	r416	500
Turkey[4]	r617,652	r762,071	r851,425	re1,000,000	850,000
U.S.S.R.	3,640,000	3,570,000	3,700,000	3,800,000	3,800,000
Vietnam[e]	4,000	4,000	4,000	r3,500	3,500
Yugoslavia	8,780	13,172	11,538	e12,000	11,000
Zimbabwe	533,105	570,298	561,477	r627,424	600,000
Total	r11,797,331	r11,637,205	r12,593,059	r13,541,837	12,845,657

[e]Estimated. [r]Revised.

[1]Table includes data available through May 7, 1991.

[2]In addition to the countries listed, Bulgaria and North Korea may also produce chromite, but output is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels. Figures for all countries represent marketable output unless otherwise noted.

[3]Average Cr_2O_3 content is as follows; 1986—40.0%, 1987—40.0%, 1988—39.0%, 1989—39.5%, 1990—not available. Brazil also reports run-of-mine crude ore production (and Cr_2O_3 content) in metric tons as follows: 1986—762,599 (173,068); 1987—829,739 (172,215); 1988—779,258 (208,812); 1989-90—not available.

[4]Direct-shipping lump ore plus concentrate and foundry sand.

[5]Exports of direct-shipping ore plus production of concentrates.

[6]India production for 1985 was, in metric tons, 569,475 (revised).

[7]Reported figure.

[8]Includes production by Bophuthatswana, which was as follows, in metric tons: 1986—451,900 (revised); 1987—522,900 (revised); 1988—536,500; 1989—676,154; and 1990—550,000 (estimated).

Current Research

U.S. Bureau of Mines research provides fundamental scientific and technical information essential for advancing mineral science, processing technology, and conserving and developing domestic mineral resources. This research is conducted in support of the Strategic and Critical Materials Stock Piling Act of 1946 as amended, the Defense Production Act of 1950 as amended, the Mining and Minerals Policy Act of 1970, and the National Materials and Minerals Policy, Research and Development Act of 1980. Recent research related to chromium includes the study of chromite recovery from domestic deposits, the development of analytic techniques to study chromium alloys, and the recovery of chromium from waste.

The Bureau studied chromite recovery from California ores using physical concentration processes. Ore from three previously producing deposits was beneficiated in laboratory and pilot plant scale studies. Laboratory beneficiation

studies included tabling, vanning, spiraling, Reichert tray concentration, and froth flotation. The results of the laboratory studies were used to design the pilot scale studies. Pilot scale overall recovery ranged from 66% to 91% concentrating chromite ore with Cr_2O_3 content in the range of 11% to 15% to a chromite ore concentrate with Cr_2O_3 content exceeding 50% Cr_2O_3 and a chromium-to-iron ratio of greater than 2:1.[24]

The Bureau, as a result of numerous chromite ore and ferrochromium analyses, has developed analytical methods that are reliable yet rapid. The Bureau documented those procedures, materials, and supplies used to analyze for chromium.[25]

The Bureau found that traditional etching methods did not yield stains satisfactory for accurate image processing system (IPS) analysis of chromium carbide volume fraction of high-chromium white cast irons. A successful etch procedure was developed by optimizing etching parameters of composition, temperature, and time to yield carbide contrast satisfactory for IPS analysis.[26]

The Bureau studied the recovery of chromium from hardface alloy grinding waste and contaminated superalloy scrap. Researchers developed a hydrometallurgical process that recovers chromium in the form of chromic chloride solution from hardface alloy grinding waste and economically evaluated the process. About 79% of chromium contained in the hardface alloy grinding waste was recovered as commercial-grade chromic chloride. Economic evaluation resulted in estimated capital cost of $4 million and operating cost of $11.70 per kilogram of feedstock for a plant processing 200,000 kilograms per year.[27] The Bureau also developed a process for the recovery of chromium as a filterable precipitate from superalloy scrap. The mixed and contaminated superalloy scrap was first pyrometallurgically treated to produce a feed material for hydrometallurgical processing that produced the chromium as filterable precipitate ferroalloy.[28] In addition, Bureau researchers developed a process to recover chromium primarily in the form of insoluble chromium carbide anode sludge from mixed and contaminated superalloy scrap. The superalloy scrap is melt carburized to produce an anode containing the chromium carbide.[29]

The Council for Mineral Technology (MINTEK) of the Republic of South Africa developed chromite ore and ferrochromium reference materials. The reference materials are produced by crushing, milling, and blending bulk samples and are distributed.[30]

Private industry researched more economic production and utilization processes. For example, private industry developed the hollow electrode system for use in the ferrochromium production process and applied it to chromite ore fines. The process was compared with other techniques for efficient fine-chromite ore consumption. In particular, the hollow electrode system was found to be a potential substitute for cost-intensive briquetting, pelletizing, or sintering processes.[31] Private industry implemented a chromium-aluminum hazardous waste recycling process. Chromium conversion chemicals are used in the aluminum metal finishing process generating a chromium-aluminum containing hazardous waste (EPA designation F019). The waste contains chromium hydroxide precipitate. About 15,000 tons of this waste, containing 3% to 15% chromium, has been generated annually. EPA permits the waste to be land filled after the contained chromium has been immobilized or fixed. However, the industry process recovers chromium from the material by first dissolving it, then precipitating chromium hydroxide, which is calcined to produce a material containing 50% to 55% chromic oxide.[32]

OUTLOOK

On the 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 the 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.[33]

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.

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.

A review of cement kiln refractories found that mag-chrome (magnesia-chromite) refractories are used in the transition zones of cement kilns because chromite is inexpensive, provides resistance to acidic slags, and moderates thermal expansion that leads to excessive spalling. U.S. specific consumption of mag-chrome refractories was estimated to average about 0.31 kilograms per metric ton of clinker product. EPA regulation of used chromium-containing refractories (see Legislation and Government Programs section) was expected to increase the life-cycle cost of those refractories by increasing disposal cost. Increased disposal cost was expected to result in substitution of magnesia-spinel refractories for the mag-chrome refractories currently used.[34]

The world chromium markets were reviewed and classified as follows: structural and utilitarian stainless steels, stainless and heat-resisting steels, other metals and alloys, alloy steels, foundry sand, chemicals, and refractories. These markets were categorized as being growth or mature markets. (A mature market is a

TABLE 24

CHROMIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons, contained chromium)

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
WORLD PRODUCTION												
Chromite ore (mine)[1]	2,807	2,981	2,736	2,553	2,472	2,943	3,295	3,497	3,450	3,730	3,993	3,784
Ferrochromium (smelter)[2]	1,707	1,632	1,510	1,314	1,354	1,613	1,695	1,689	1,794	1,866	1,874	NA
Stainless steel, Western World[3]	NA	1,171	1,084	1,049	1,185	1,364	1,343	1,343	1,561	1,788	1,734	NA
U.S. SUPPLY												
Components of U.S. supply:												
Domestic mines	—	—	—	—	—	—	—	—	—	—	—	—
Secondary	64	58	65	61	75	79	85	84	95	119	99	94
Imports:												
Chromite ore	258	254	228	130	53	83	109	133	133	185	162	92
Chromium ferroalloy	123	160	228	79	148	223	173	206	171	255	208	244
Chromium metal	3	4	3	2	3	4	4	4	4	4	4	7
Chromium chemicals	(4)	1	1	2	4	3	5	4	3	2	5	4
Chromium pigments	2	3	2	1	2	2	2	2	2	4	NA	NA
Stocks, Jan. 1:												
Government	1,301	[5]1,051	1,051	1,051	1,051	1,051	1,051	[6]1,080	[6]1,110	[6]1,079	[6]1,057	[6]1,097
Industry	399	288	219	232	181	164	114	106	102	119	137	139
Total U.S. supply	2,152	1,818	1,798	1,558	1,518	1,609	1,542	1,619	1,620	1,767	1,673	1,676
Distribution of U.S. supply:												
Exports:												
Chromite ore	4	2	18	2	3	15	27	25	(4)	1	12	2
Chromium ferroalloy	8	16	7	3	2	9	6	3	2	5	6	5
Chromium metal	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
Chromium chemicals	9	9	6	5	5	7	4	7	6	8	6	7
Stocks, Dec. 31:												
Government	1,301	1,051	1,051	1,051	1,051	1,051	1,080	1,110	1,079	1,057	1,097	1,099
Industry	288	219	232	181	164	114	106	102	119	137	139	118
Total U.S. distribution	1,610	1,297	1,314	1,243	1,226	1,197	1,223	1,247	1,207	1,208	[r]1,260	1,231
Apparent industry demand	542	521	483	315	292	412	349	402	382	537	[r]452	447

[r]Revised. NA Not available.
[1]Calculated assuming chromite ore to average 44% Cr_2O_3 that is 62.48% chromium.
[2]Calculated assuming chromium content of ferrochromium to average 57%.
[3]Calculated from World Stainless Steel Statistics, 1990 ed. reported production, assuming chromium content of stainless steel to average 17%.
[4]Less than 1/2 unit.
[5]Nonstockpile-grade material that was included before 1980 was deleted from stockpile count.
[6]Variation in stockpile quantity does not contribute to apparent industry demand because variation results from upgrading programs.

market whose growth rate is less than that of gross national product. Similarly, a growth market is a market whose growth rate is greater than that of gross national product.) Growth markets for chromium were found to be structural and utilitarian stainless steels, stainless and heat-resisting steels, and other metals and alloys. The remaining markets were found to be mature. Each of the growth markets was described.[35]

A review of the refractory and ceramic industries in the United Kingdom found that chromite ore has suffered a marked decline since 1950, when 150,000 tons was used. Chromite refractories are used primarily in steel production, but also in cement and glass production. This decline was found to be consistent with a general trend in the steel- and cement-producing industries toward smaller unit consumption of refractories (i.e., refractory consumption per unit of product). In addition to smaller unit consumption of refractories, these industries have experienced reduced growth rates in relation to gross national product. In particular, plastics have substituted for steel in automobiles and for glass in bottles.[36] A review of the foundry casting industry found the role of chromite to be particularly useful in sand casting of large castings for chilling rather than finish. It was

noted that in Europe, chromite has found a role as substitute material for zircon, the traditional material. Lack of suitable zircon has resulted in greater use of zircon-chromite blends or chromite alone in greensand casting.[37]

The world chromium metal market was reviewed and found to be a highly competitive market in which consumption and production are in near balance and production capacity far exceeds production. World production was estimated at 15,000 tons (13,500 Western World, 1,500 China and U.S.S.R.), of which about 70% was produced by the aluminothermic process and the remaining 30% by the electrolytic process. Japan was identified as the source of 37% of world production, leaving 53% for the remainder of the Western World. Consumption, however, was concentrated in the Americas (52%), Western Europe (31%), and Japan (13%). The end-use market for chromium metal was primarily superalloys (44%), aluminum alloys (16%), and welding and hard-facing materials (15%), followed by corrosion resistant alloys (9%), electrical wire (8%), and miscellaneous uses (8%). Chromium metal consumption prospects were optimistic. While there did not appear to be preeminent new uses, there also did not appear to be replacements in the traditional end user market, jet engines. In the United Kingdom, consumption prospects were optimistic because vacuum induction melting (the production route by which chromium metal is used to make superalloy castings) capacity was expected to increase. A significant change in the chromium metal industry has been the recent introduction of upgraded aluminothermic chromium metal, which now accounts for 5% of the world market. The price of high-grade electrolytic chromium metal has lead the price structure for chromium metal. The impact of this new upgraded aluminothermic chromium metal has been to reduce the high end price of chromium metal. The price of low-graded chromium metal has been pressured further downward by Chinese and Soviet produced material.[38]

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[17]Value has been converted from Indian Rupees (Rs) to U.S. dollars (US$) at the rate of Rs1.00 = US$0.0578 (Rs17.3 = US$1.00).

[18]Value has been converted from Indian Rupees (Rs) to U.S. dollars (US$) at the rate of Rs1.00 = US$0.0578 (Rs17.3 = US$1.00).

[19]Value has been converted from Italian Lire (L) to US dollars (US$) at the rate of L1.00 = US$0.0008347 (L1,198 US$1.00).

[20]Value has been converted from South African Rand (R) to U.S. dollars (US$) at the rate of R1.00 = US$0.386 (Rs2.59 = US$1.00).

[21]Value has been converted from South African Rand (R) to U.S. dollars (US$) at the rate of R1.00 = US$0.386 (Rs2.59 = US$1.00).

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CLAYS

By Robert L. Virta

Mr. Virta, a physical scientist with 15 years of U.S. Bureau of Mines experience, has been the acting commodity specialist for clays since 1991. Domestic survey data were prepared by Rosa McGee, supervisory mineral data assistant. The international tables were prepared by Harold Willis and Virginia Woodson, international data coordinators.

The amount of clay sold or used by domestic producers increased slightly in tonnage to 43 million metric tons and 7% in value to $1.6 billion. Production of bentonite, fuller's earth, and kaolin increased in 1990. Ball clay, common clay and shale, and fire clay production decreased. Common clays accounted for 61% of the tonnage, and kaolin accounted for 66% of the value of clays produced in 1990. Imports increased 7% in tonnage to 29,550 tons and 10% in value to $12.0 million. Exports increased 10% in tonnage to 4.1 million tons and 6% in value to $584.4 million. Clays were produced in 44 States and Puerto Rico. The seven leading producer States, in descending order, were Georgia, Wyoming, Ohio, California, Texas, Alabama, and North Carolina.

DOMESTIC DATA COVERAGE

Domestic production data for clays are developed by the U.S. Bureau of Mines from one voluntary survey of U.S. operations. Of the 1,080 operations covered by the survey, 944 responded, representing 88% of the total clay and shale production sold or used shown in table 1.

BACKGROUND

Definitions, Grades, and Specifications

Clays are categorized into six groups by the U.S. Bureau of Mines. The categories are kaolin, ball clay, fire clay, bentonite, fuller's earth, and common clay and shale. The definitions listed in this work for the high-alumina clays, kaolin, ball clay, and fire clay are similar to those in U.S. Bureau of Mines Information Circular 8335.[1]

Kaolin, or china clay, is defined as a white, claylike material composed mainly of kaolinite and other kaolin-group minerals, such as halloysite and dickite. Kaolin has a specific gravity of 2.6 and a fusion point of 1,785° C. Kaolin is classified according to the method of preparation (crude, air-separated, water-washed, delaminated, air-dried, calcined, slip, pulp, slurry, or water suspension) and on specific physical and chemical properties.

Ball clay is a plastic, white-firing clay used mainly for bonding in ceramicware. The clays are of sedimentary origin and consist mainly of the kaolinite, sericite mica, and organic matter. Ball clays usually are much finer grained than kaolins

TABLE 1

SALIENT U.S. CLAYS AND CLAY PRODUCTS STATISTICS[1]

(Thousand metric tons and thousand dollars)

	1986	1987	1988	1989	1990
Domestic clays sold or used by producers:					
Quantity	40,479	43,234	44,515	42,254	42,904
Value	$1,095,179	$1,202,284	r$1,390,908	$1,515,300	$1,619,824
Exports:					
Quantity	2,643	3,023	3,535	3,755	4,123
Value	$351,161	$512,964	$516,566	$550,343	$584,404
Imports for consumption:					
Quantity	34	34	33	28	30
Value	$7,501	$9,392	$8,835	$10,928	$11,988
Clay refractories shipments: Value	$529,268	$617,493	$1,950,032	$2,055,784	NA
Clay construction products shipments: Value	$1,601,640	$1,782,023	$1,927,000	$1,786,000	$1,775,000

rRevised. NA Not available.
[1]Excludes Puerto Rico.

TABLE 2

CLAYS SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1990, BY STATE[1]

(Metric tons unless otherwise specified)

State	Ball clay	Bentonite	Common clay and shale	Fire clay	Fuller's earth	Kaolin	Total	Total value
Alabama	—	W	1,953,519	96,257	—	W	2,258,154	$37,189,360
Arizona	—	37,643	102,519	—	—	—	140,162	2,318,185
Arkansas	—	—	705,469	—	—	283,914	989,380	21,577,837
California	—	153,450	1,888,032	—	W	122,033	[2]40,217,102	[2]41,217,102
Colorado	—	272	262,020	—	—	—	262,292	1,868,241
Connecticut	—	—	W	—	—	—	W	W
Florida	—	—	W	—	352,890	38,444	521,192	41,243,955
Georgia	—	—	1,546,304	—	648,009	7,660,935	9,855,248	1,060,539,776
Idaho	—	—	W	—	—	W	W	W
Illinois	—	—	598,479	—	W	—	[2]598,479	[2]2,515,844
Indiana	W	—	1,051,703	—	—	—	[3]1,051,703	[3]3,272,624
Iowa	—	—	423,227	—	—	—	423,227	1,376,264
Kansas	—	—	625,969	—	—	—	625,969	4,056,062
Kentucky	W	—	826,205	—	—	—	[3]826,205	[3]8,282,322
Louisiana	—	—	368,322	—	—	—	368,322	1,066,295
Maine	—	—	W	—	—	—	W	W
Maryland	—	—	338,755	—	—	—	338,755	1,711,599
Massachusetts	—	—	W	—	—	—	W	W
Michigan	—	—	1,201,542	—	—	—	1,201,542	4,093,649
Minnesota	—	—	W	—	—	W	W	W
Mississippi	W	289,372	528,456	—	W	—	[2 3]817,828	[2 3]16,195,868
Missouri	—	—	1,064,884	282,674	W	—	[2]1,347,558	[2]12,863,415
Montana	—	W	29,741	—	—	—	[4]29,741	[4]192,682
Nebraska	—	—	227,292	—	—	—	227,292	1,685,241
Nevada	—	34,625	—	—	W	W	111,854	8,992,928
New Hampshire	—	—	W	—	—	—	W	W
New Jersey	—	—	W	W	—	—	W	W
New Mexico	—	—	27,994	W	—	—	[5]27,994	[5]74,250
New York	—	—	490,552	—	—	—	490,552	2,906,006
North Carolina	—	—	2,179,428	—	—	W	[6]2,179,428	[6]9,355,674
North Dakota	—	—	50,485	—	—	—	50,485	W
Ohio	—	—	2,320,354	225,797	—	—	2,546,151	13,333,596
Oklahoma	—	—	631,302	—	—	—	631,302	3,155,987
Oregon	—	24,563	198,889	—	—	—	223,452	1,390,822
Pennsylvania	—	—	840,646	W	—	W	[5 6]840,646	[5 6]2,899,788
Puerto Rico	—	—	147,721	—	—	—	147,721	W
South Carolina	—	—	831,763	—	—	1,231,061	2,062,824	44,485,828
South Dakota	—	—	W	—	—	—	W	W
Tennessee	543,693	—	482,496	—	W	34,473	[2]1,060,662	[2]25,775,522
Texas	55,610	W	2,106,485	—	W	W	2,303,458	26,145,493
Utah	—	W	277,795	—	—	—	[4]277,795	[4]1,773,740
Virginia	—	—	882,383	—	W	—	[2]882,383	[2]3,740,806
Washington	—	—	158,257	—	—	—	158,257	1,356,945
West Virginia	—	—	164,257	—	—	—	164,257	383,710
Wyoming	—	2,523,573	W	—	—	—	2,523,573	76,082,575
Undistributed	188,360	410,097	562,595	21,080	1,306,577	390,916	[7]2,322,795	[7]128,910,450
Total	787,663	3,473,595	26,095,840	625,808	2,307,476	9,761,775	43,052,156	1,620,414,502

W Withheld to avoid disclosing company proprietary data; included with "Total" and/or "Undistributed."
[1]Includes Puerto Rico.
[2]Excludes fuller's earth.
[3]Excludes ball clay.
[4]Excludes bentonite.
[5]Excludes fire clay.
[6]Excludes kaolin.
[7]Incomplete total; difference included with individual State totals.

TABLE 3

NUMBER OF MINES FROM WHICH PRODUCERS SOLD OR USED CLAYS IN THE UNITED STATES IN 1990, BY STATE[1 2]

State	Ball clay	Bentonite	Common clay and shale	Fire clay	Fuller's earth	Kaolin	Total
Alabama	—	1	24	6	—	16	47
Arizona	—	3	8	—	—	—	11
Arkansas	—	—	16	2	—	3	21
California	1	5	41	—	2	5	53
Colorado	—	1	28	2	—	—	31
Connecticut	—	—	2	—	—	—	2
Florida	—	—	3	—	5	1	9
Georgia	—	—	14	—	9	77	100
Idaho	—	1	1	—	—	2	4
Illinois	—	—	9	—	2	—	11
Indiana	—	—	13	—	—	1	14
Iowa	—	—	11	—	—	—	11
Kansas	—	1	21	—	—	—	22
Kentucky	7	—	13	1	—	—	21
Louisiana	—	6	8	—	—	—	8
Maine	—	—	2	—	—	—	2
Maryland	—	—	7	—	—	—	7
Massachusetts	—	—	2	—	—	—	2
Michigan	—	—	6	—	—	—	6
Minnesota	—	—	1	—	—	2	3
Mississippi	1	3	15	—	3	—	22
Missouri	—	1	9	40	2	—	52
Montana	—	4	5	1	—	—	10
Nebraska	—	—	5	—	—	—	5
Nevada	—	6	—	—	2	2	10
New Hampshire	—	—	1	—	—	—	1
New Jersey	—	—	1	1	2	—	2
New Mexico	—	—	4	2	—	—	6
New York	—	—	9	—	—	—	9
North Carolina	—	—	47	—	—	2	49
North Dakota	—	—	3	—	—	—	3
Ohio	—	—	47	7	—	—	54
Oklahoma	—	—	15	—	—	—	15
Oregon	—	4	7	—	—	—	11
Pennsylvania	—	—	30	4	—	1	35
Puerto Rico	—	—	2	—	—	—	2
South Carolina	—	—	27	—	1	17	45
South Dakota	—	—	1	—	—	—	1
Tennessee	17	—	6	—	3	—	26
Texas	1	3	63	3	1	1	72
Utah	—	3	10	—	—	—	13
Virginia	—	—	14	—	1	—	15
Washington	—	—	7	3	—	—	10
West Virginia	—	—	3	—	—	—	3
Wyoming	—	94	3	—	—	—	97
Total	27	130	563	72	31	130	953

[1]Includes both active and idle operations.
[2]Includes Puerto Rico.

and are reknowned for their plasticity. They are classified according to the method of preparation (crude, shredded, air-floated, water-washed, or slurry) and specific physical and chemical properties.

Fire clay is defined as detrital material, either plastic or rocklike, that commonly occurs as underclay below coal seams. Low concentrations of iron oxide, lime, magnesia, and 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 diaspore, burley, burley-flint, ball clay, and bauxitic clay and shale. Fire clays generally are used for refractories or to raise vitrification temperatures in heavy clay products. The fired colors of fire clays range from buffs to grays. Fire clays are classified according to their physical and chemical properties and the characteristics of the products made from them.

Bentonite is a clay composed primarily of smectite minerals. The primary smectite mineral is usually montmorillonite. Swelling-type bentonite has a high-sodium ion concentration. Its volume increases 15 to 20 times its dry volume when wetted with water. Nonswelling bentonites usually are high in calcium. Bentonite is classified according to its physical and chemical properties, with particular emphasis on particle size and swelling index.

The term "fuller's earth" is derived from the first major use of the material, which was for cleaning textiles by fullers. Fuller's earth does not refer to a clay with a specific composition or mineralogy. It is defined as a nonplastic clay or claylike material, usually high in magnesia, that is suitable for decolorizing and purifying mineral and vegetable oils. They are composed mainly of the needle- and/or lath-shaped clay mineral attapulgite or varieties of montmorillonite. Fuller's earths containing opal or other forms of colloidal silica also are produced. Fuller's earths are classified according to their physical and chemical properties. Sepiolite-type clays are grouped with fuller's earths under the Bureau classification system.

Common clay is defined as a clay or claylike material that is plastic enough to mold easily. Its vitrification point is usually below 1,100° C. Shale is a laminated sedimentary rock that is formed by the consolidation of clay, mud, or silt. The common clays and shales are composed mainly of illite or chlorite. They also may contain kaolin and montmorillonite. Common clays and shales usually contain more alkali, alkaline earth, and ferruginous minerals and less aluminum than high-quality kaolins, fire clays, and ball clays. Iron present in the clay usually imparts a reddish color to the final product after firing. There is no formal classification of common clays and shales, although a clay may sometimes be referred to as common, brick, sewer pipe, or tile clay. Clay and shale are used in the manufacture of structural clay products such as brick, drain tile, portland cement clinker, and expanded lightweight aggregates.

The American Society for Testing and Materials, American Foundrymen's Association, American Oil Chemist's Society, American Petroleum Institute, Technical Association of the Pulp and Paper Industry, and other national organizations have developed tests and set standards for some applications. Many producers and consumers, however, use nonstandardized tests that are applicable to their specific needs. Individual companies often set the acceptable limits of mineralogical composition, particle size, and other physical and chemical properties. Detailed data on specifications have been published by the U.S. Bureau of Mines.[2]

Products for Trade and Industry

Because of the many types of clay and different qualities within each type, the consumption pattern and the products for trade and industry are constantly changing. Consumption of kaolin in refractories has been growing since 1970 because of the increasing popularity of castable, ramming, gunning, and plastic mixes that use calcined kaolin aggregates (grog) in their formulations.[3] The consumption of calcined kaolin grogs also has increased in refractory brick manufacturing, replacing imported calcined refractory-grade bauxite grogs. Consumption of bentonite has decreased for iron ore pelletizing and for more expensive drilling mud and foundry uses. 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 350 companies operating more than 1,000 clays pits or mines reported production in 1990; of these, 50 companies, most with multiple operations, accounted for approximately 50% of the tonnage and 80% 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, 9.9 million tons; Ohio, 2.5 million tons; Wyoming, 2.5 million tons; Texas, 2.3 million tons; Alabama, 2.3 million tons; North Carolina, 2.2 million tons; and California, 2.2 million tons. Most of the clay is mined by open pit methods. Less than 2% of U.S. clay output is from underground mines in 1990. Most of the underground production is in Pennsylvania, Ohio, and West Virginia, where the clays are mainly underclays associated with coal and suitable for refractory uses.

Forty-three firms operated 130 kaolin mines in 13 States. In 1990, three large, diversified firms accounted for about 60% of total domestic kaolin output. Most large kaolin producers have operations in Georgia, which accounted for 78% of the kaolin production.

The ball clay industry is small, with 6 producers operating 27 mines in 5 States in 1990. Three of the producers were large, diversified firms with widespread foreign and domestic mineral interests. Tennessee ball clay production represented about 69% of the total output.

Fireclay producers were mostly refractories manufacturers that used the clays in firebrick and other refractories. Seventy-two mines were operated in 1990 by 26 firms in 6 States.

Firms producing bentonite operated 132 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 73% of the total output. Swelling-type bentonite is produced mainly in Wyoming and Montana, and nonswelling-type bentonite is produced in Mississippi and Texas. The United States is the world's largest producer and exporter of bentonitic clays.

Fourteen companies produced fuller's earth from 29 mines in 10 States. Fourteen of the mines were in the attapulgite-fuller's earth areas of Florida and Georgia. These two States accounted for 43% of domestic production. Most producers were small, independent firms, but three were large, diversified corporations with international

mineral interests. The world's fuller's earth needs are supplied from relatively few areas. The United States is the world's largest producer and user of fuller's earth.

Firms producing common clay and shale in 1990 were manufacturers of structural clay products, clay pipe, lightweight aggregates, and cement. Most companies mined the clays used in making their products. Private mining contractors and haulers were employed in many of the operations. Some producers were diversified firms having interests in metals and other nonclay products. Some companies owned and operated several clay pits and plants in order to cover a large market area. The economic radius for shipment of common clay or shale products is usually 200 miles or less. The high cost of transport promotes the development of local ownership companies, or in the case of a large firm, the ownership and operation of several strategically located pits and associated fabricating plants.

Geology-Resources

Clay is formed by the mechanical and chemical breakdown (weathering) of rocks. The weathering products consist of mineral grains and rock fragments of different size and different physical and chemical properties. The nonplastic portion consists of altered and unaltered rock fragments (grit), which are usually quartz, micas, feldspar, and iron oxides. The plastic portion usually is composed of clays and is low in grit.

Clays may be classified as residual or sedimentary. Residual clays are deposited in the same location in which they were formed. Sedimentary clays are those that have been transported, usually by water, and deposited elsewhere.[4] Sedimentary clays often undergo further alteration and classification during transport. Kaolin deposits in Georgia and South Carolina are sedimentary. Kaolin deposits in North Carolina and English china or kaolin clay deposits are residual.[5] The Kentucky and Tennessee ball clays and the Missouri fire clays are sedimentary deposits. Most bentonites, montmorillonites, and fuller's earth were formed in place through the weathering of volcanic ash or tuff. The attapulgite-type fuller's earth deposits of Florida and Georgia were probably not formed from volcanic ash or tuff. Geologists have never found any evidence of volcanic materials associated with these deposits.[6]

The definitions of reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals." Reserves are the part of an ore body that can be economically extracted at the time of evaluation. Reserve base is the part of an ore body that meets specified minimum physical and chemical criteria related to current mining and production practices. Reserve base includes reserves, marginal reserves, and subeconomic resources.

Common clays and shale deposits are found throughout the United States. Clays and shale were mined commercially in 44 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 deliniate the size and shape of the deposit and to obtain material for testing.

Kaolins usually are evaluated for filler and ceramic applications. The grit, particle size, brightness, and leachability are determined. Air-floated clays normally require only grit and brightness determinations. Kaolin, ball clay, and fire clay for ceramic and/or refractory applications are analyzed for grit, brightness, green and dry strengths, fired color, and iron and alumina contents. The common clays and shales usually are tested according to the intended end use, such as brick, structural-drain tile, or lightweight aggregate. Usually, prepared specimens are tested for plasticity, green strength, shrinkage, vitrification temperature range, etc. For lightweight aggregates, the bloating range is determined. Bentonites and fuller's earth clays are difficult to evaluate because there is no standard testing procedures or specifications. Generally, they are processed to meet the purchaser's specifications.

Mining.—Most clays are mined from open pits using modern surface mining equipment such as draglines, power shovels, front-end loaders, backhoes, scraper-loaders, and shale planers. Some kaolin is extracted by hydraulic mining and dredging. A few clay pits are operated using crude hand-mining methods. A small number of clay mines, principally in underclays in coal mining areas, are mined underground using room-and-pillar methods. Clays usually are transported by truck from the pit or blending areas to the processing plants. Rail, conveyor belt, and in the case of kaolin, pipelines also are used.

About 100% of the clay is recovered from the minable beds in most open pit operations. Approximately 75% is recovered in underground operations. The waste-to-clay ratio is highest for kaolin, about 7:1, and lowest for common clay and shale, about 0.25:1.

Processing.—Clays are used in a large number of products so they must be treated in many different ways. Processing can consist of very simple and inexpensive crushing and screening for some common clays. It also can consist of very elaborate and expensive grinding, sizing, bleaching, delamination, etc., for paper-coating clays and high-quality filler clays for use in rubber, paint, plastic, and other products. In general, processing does not appreciably alter the chemical or mineralogical characteristics of the clays. The two exceptions are calcining and cation exchange.

Significant processing losses occur with kaolin and fuller's earth. About 40% of the kaolin and 30% of the fuller's earth delivered to the processing plants is discarded. Waste material from processing consists mostly of off-grade clays and small quantities of quartz, mica, feldspar, and iron-bearing minerals.

Kaolin.—Processing involves one or more of the following: crushing, blunging with dispersant, rough sedimentation, water fractionation, magnetic separation, ultraflotation, acid treatment, calcination, air floating, and attrition grinding, slurrying, and delaminating. Kaolins used for paper-coating applications may be bleached and further delaminated by grinding, deflocculation, and elutriation to special sizes. Ultraflotation or wet magnetic separation treatment may be used to remove iron- or titanium-bearing minerals to obtain a whiter product.

Ball Clay.—Processing involves drying, shredding, pulverizing, air floating, and slurrying.

Fire Clay.—Processing involves crushing, calcining, and blending.

Bentonite.—Processing involves weathering, drying, grinding, sizing, granulation, and the use of additives for cation exchange.

Fuller's Earth.—Processing involves blunging, extruding, drying, crushing, grinding, sizing, and dispersing.

Common Clay and Shale.—Processing involves crushing, blunging, extruding, and drying. Common bricks, tile, lightweight aggregate, etc., require firing in a kiln. The kiln firing or drying operation produces a finished manufactured product.

Processing costs for clays range from a few cents per ton for some common clays to more than $400 per ton for some special paper-coating clays and high-quality clays that require very elaborate and expensive treatments.

Price schedules, although not complete, are available and are published regularly in trade journals such as the American Paint and Coatings Journal, Chemical Marketing Reporter, and Industrial Minerals (London).

Federal tax laws allow clay producers a depletion allowance on both domestic and foreign gross income not to exceed 50% of net income with depletion deduction. Depletion allowances are as follows: ball clay, bentonite, kaolin or china clay, sagger clay, and clay used or sold for purposes dependent on its refractory properties, 14% domestic and 14% foreign; fuller's earth, 14% domestic and 14% foreign; clay used for extraction of alumina or aluminum compounds, 22% domestic; clay used or sold for use in manufacturing drainage and roofing tile, flower pots, and kindred products, 5% domestic and 5% foreign; and clay and shale used for making brick, tile, and lightweight aggregate, 7.5% domestic and 7.5% foreign. Severance taxes are levied by some producing States.

Byproducts and Coproducts

Firms in California, Florida, and Texas produce silica glass sand as a coproduct of its kaolin production. Flake mica is a byproduct in one kaolin operation in North Carolina. Bauxite is a coproduct in kaolin operations in Alabama and Georgia. Clay and limestone for cement manufacture are often produced from the same property and reported as coproducts or byproducts even though they are usually mined separately from different formations or beds. Sand, gravel, and stone aggregates are occasionally produced together with common clays.

Economic Factors

Economic factors affecting clays vary in importance with type, quality, and intended end use. The cost of transportation is an important factor for the common clay and fire clay industries; mines must be close to consumers to be cost competitive. Other types of clays are less abundant and have higher unit values. They can be shipped greater distances from the mines and still be cost competitive. For example, paper-coating clay from Georgia and 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 above $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 1990 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 regula-

tions and land use changes sometimes force a mine to close or relocate to a more distant deposit. Moving to a more distant deposit increases costs to the community because of increased transportation charges.

Another important issue concerns crystalline silica. The World Health Organization classified crystalline silica as a possible human carcinogen in 1987. Additionally, the Occupational Safety and Health Adminstration (OSHA) must include crystalline silica under its Hazard Communication Standard (HCS). Products containing 0.1% or more crystalline silica must be labeled in accordance to the HCS, and employers must comply with the terms of HCS with regard to worker training. The Mine Safety and Health Administration has proposed a similar regulation. There is concern that States will consider crystalline silica a proven, rather than a possible, carcinogen when enacting legislation as a result of these findings.

Although domestic clay resources are more than adequate and clay is a mature industry, the average price for clays is expected to rise steadily. The increased prices reflect the demand for higher quality specialty clay by consumers and increased costs associated with land acquisition, severance taxes, land rehabilitation, energy requirements, and environmental factors. These rising prices, if unchecked, will have an adverse effect on the clay industry by making competing materials more cost competitive.

Production, Prices, and Foreign Trade

Two articles reviewed clay production in the Southwest United States and Georgia. The article on the Southwest United States discussed the common clay and shale, kaolin, bentonite, and hectorite industries, including producers and end uses.[7] The article on Georgia discussed the history of the clay industry within the State, the geology of deposits, end uses, and the outlook for the State's clay industry.[8]

Kaolin.—Domestic production of kaolin increased 9% to 9.8 million tons. The value of production increased 5% to $1.07 billion. The unit value of kaolin decreased 4% to $110 per ton. Filler- and refractory-grade kaolin had the highest reported values. Kaolin was produced in 13 States. Georgia accounted for 78%, and South Carolina accounted for 13% of total production. Georgia accounted for more than 91% of the total production value. Filler, refractory, chemical- and water-washed, air-floated, and unprocessed grades were produced in Georgia. South Carolina produced only air-floated and unprocessed grades of kaolin. Arkansas and California produced refractory- and chemical-grade kaolins. Kaolin producers reported major domestic end uses as paper-coating, 28%; paperfilling, 15%; refractories, 9%; fiberglass and insulation, 5%; face brick and rubber, 4% each; and paint and chemicals, 3%.

Despite the overall slow economy, kaolin production increased. Sales of paper-, plastic-, and paint-grade kaolin increased. Exports also increased because of a continued weak U.S. dollar. Sales of kaolin for refractory grogs and calcines, and firebrick also increased. Sales to cement manufacturers decreased because of continued lower construction rates. Production of paper-grade kaolin increased slightly in 1990. U.S. sales of unprocessed kaolin almost doubled because large tonnages of low-value unprocessed kaolin were required for a special project in the Southeastern United States. Calcined, water-washed, and delaminated kaolin production increased 5%, 2%, and 13%, respectively. Air-float kaolin production decreased 8%.

The geology, mineralogy, and classification of major occurrences were dis-

FIGURE 1

KAOLIN SOLD OR USED BY DOMESTIC PRODUCERS FOR SPECIFIED USES

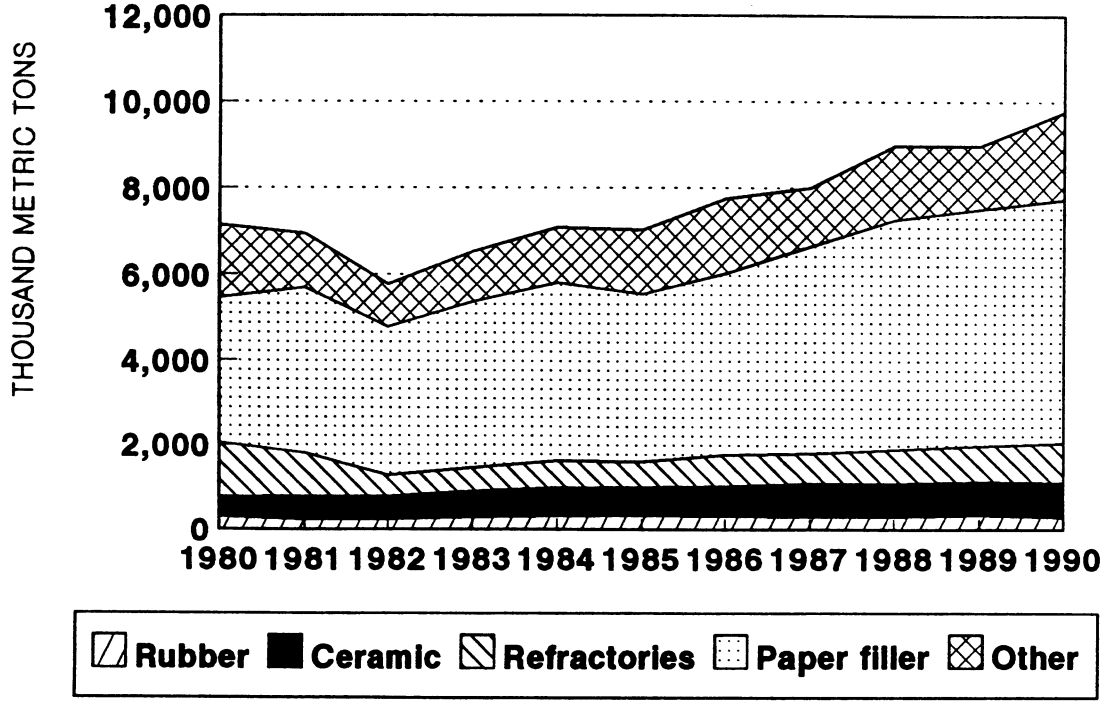

TABLE 4

KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1989		1990	
	Metric tons	Value	Metric tons	Value
Alabama	66,828	$4,097,222	W	W
Arkansas	243,488	15,716,778	283,914	$18,779,800
California	122,996	5,089,029	122,033	4,995,020
Colorado	9,378	131,603	—	—
Florida	42,632	3,911,500	38,444	W
Georgia	7,494,522	944,862,508	7,660,935	980,795,070
North Carolina	65,767	1,929,558	W	W
South Carolina	659,651	36,471,151	1,231,061	42,408,909
Other[1]	268,406	10,377,057	425,388	25,388,161
Total[2]	8,973,670	1,022,586,406	9,761,775	1,072,366,960

W Withheld to avoid disclosing company proprietary data; included in "Other."
[1]Includes Idaho, Minnesota, Nevada, Pennsylvania, Tennessee, and Texas.
[2]Data do not add to total shown because of independent rounding.

TABLE 5

KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY KIND

State	1989		1990	
	Metric tons	Value	Metric tons	Value
Air-float	1,571,082	$86,081,048	1,450,690	$84,576,484
Calcined[1]	1,437,639	307,291,330	1,504,956	340,891,985
Delaminated	1,179,899	142,158,224	1,328,401	160,519,721
Unprocessed	650,101	15,559,669	1,245,783	17,337,375
Waterwashed	4,134,947	471,496,135	4,231,945	469,040,395
Total	8,973,668	1,022,586,406	9,761,775	1,072,365,960

[1]Includes both low-temperature filler and high-temperature refractory grades.

TABLE 6

CALCINED KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	High-temperature		Low-temperature	
	Metric tons	Value	Metric tons	Value
1989				
Alabama and Georgia	508,931	$61,260,150	[1]585,836	[1]$222,549,571
Other	[2]297,361	[2]17,213,208	[3]45,511	[3]6,268,401
Total	806,292	78,473,358	631,347	228,817,972
1990				
Alabama and Georgia	553,220	70,362,060	[1]592,260	[1]241,209,457
Other	[2]211,406	[2]17,889,788	[3]148,069	[3]11,511,680
Total	764,626	88,251,848	740,329	252,721,137

[1]Excludes Alabama.
[2]Includes Arkansas, California, Colorado, Idaho, and South Carolina.
[3]Includes Alabama, Arkansas, Pennsylvania, and South Carolina.

TABLE 7

GEORGIA KAOLIN SOLD OR USED BY PRODUCERS, BY KIND

State	1989		1990	
	Metric tons	Value	Metric tons	Value
Air-float	1,023,746	$45,949,035	863,403	$40,346,252
Calcined[1]	1,043,964	278,297,221	1,094,678	306,059,017
Delaminated	1,179,899	142,158,224	1,328,401	160,519,721
Unprocessed	180,052	8,465,799	231,102	9,139,540
Waterwashed	4,066,860	469,992,229	4,143,351	464,730,540
Total[2]	27,494,522	944,862,508	7,660,935	980,795,070

[1]Includes both low-temperature filler and high-temperature refractory grades.
[2]Data do not add to total shown because of independent rounding.

TABLE 8

GEORGIA KAOLIN SOLD OR USED BY PRODUCERS, BY USE

(Metric tons)

Use	1989				1990			
	Air-float	Unprocessed[1]	Waterwashed[2]	Total[3]	Air-float	Unprocessed[1]	Waterwashed[2]	Total[3]
Domestic:								
Adhesives	9,220	—	17,139	26,359	20,738	—	20,997	41,735
Aluminum sulfate and other chemicals	6,560	167,104	—	173,664	—	W	—	W
Asphalt tile and linoleum	3,425	—	—	3,425	W	—	—	W
Catalysts (oil-refining)	11,858	—	40,670	52,528	8,185	—	38,039	46,224
Face brick	—	—	—	—	—	8,895	—	8,895
Fiberglass and mineral wool	249,899	—	43,124	293,023	199,937	—	43,817	243,754
Fine china and dinnerware; crockery and earthenware	22,462	—	—	22,462	12,051	—	—	12,051
Firebrick, blocks and shapes	27,267	4,536	—	31,803	W	6,728	—	6,728
Grogs and calcines, refractory	36,495	390,027	424	426,946	W	W	W	496,453
Medical, pharmaceutical, cosmetic	369	—	420	789	W	—	W	815
Paint	18,757	—	199,649	218,406	19,160	—	206,716	225,879
Paper coating	—	—	2,568,846	2,568,846	54,197	—	2,698,974	2,753,171
Paper filling	229,758	—	1,312,644	1,542,402	146,957	—	1,305,658	1,452,615
Plastics	370	—	40,177	40,547	14,335	—	40,571	54,906
Pottery	26,324	—	—	26,324	24,883	—	—	24,883
Refractories[4]	12,707	6,350	5,741	24,798	14,971	—	—	14,971
Roofing granules	10,143	—	—	10,143	W	W	—	W
Rubber	77,630	—	19,556	97,186	13,297	—	45,606	58,903
Sanitaryware	33,018	—	—	33,018	39,042	—	—	39,042
Miscellaneous, air-float:								
Common brick, fertilizers, gypsum products, pesticides and related products, roofing and structural tile, other uses not specified	172,726	—	—	172,726	206,655	—	—	206,655
Miscellaneous, unprocessed:								
Fertilizers, pesticides and related products, other uses not specified	—	37,624	—	37,624	—	717,756	—	717,756
Miscellaneous, waterwashed:								
Gypsum products, ink, pesticides and related products, waterproofing and sealing, fertilizers, other uses not specified	—	—	147,516	147,516	—	—	162,193	162,193
Total[3]	948,988	605,641	4,395,906	5,950,535	774,408	733,379	4,562,571	6,567,629

See footnotes at end of table.

TABLE 8—Continued

GEORGIA KAOLIN SOLD OR USED BY PRODUCERS, BY USE

(Metric tons)

Use	1989				1990			
	Air-float	Unprocessed[1]	Water-washed[2]	Total[3]	Air-float	Unprocessed[1]	Water-washed[2]	Total[3]
Exports:								
Paint	—	—	27,115	27,115	—	—	25,857	25,857
Paper coating	20,650	—	1,074,973	1,095,623	20,894	—	1,135,074	1,155,968
Paper filling	32,479	—	262,155	294,634	38,306	—	266,330	304,635
Refractories	—	32,540	—	32,540	—	—	—	—
Rubber	—	—	17,451	17,451	—	—	17,953	17,953
Undistributed	21,629	—	54,995	76,624	29,795	142	56,216	86,153
Total[3]	74,758	32,540	1,436,689	1,543,987	88,995	142	1,501,430	1,590,566
Grand total[3]	1,023,746	638,181	5,832,595	7,494,522	863,403	733,520	6,064,012	7,660,935

W Withheld to avoid disclosing company proprietary data; with "Miscellaneous."
[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; and refractory mortar and cement.

TABLE 9

SOUTH CAROLINA KAOLIN SOLD OR USED BY PRODUCERS, BY KIND

State	1989		1990	
	Metric tons	Value	Metric tons	Value
Air-float	494,563	$35,383,831	497,067	$37,372,439
Unprocessed	165,088	1,087,320	733,994	5,036,470
Total	659,651	36,471,151	1,231,061	42,408,909

TABLE 10

SOUTH CAROLINA KAOLIN SOLD OR USED BY PRODUCERS, BY KIND AND USE

(Metric tons)

Kind and use	1989	1990
Air-float:		
Adhesives	13,084	12,116
Animal feed and pet waste absorbent	3,480	3,491
Ceramics[1]	5,354	6,299
Fertilizers, pesticides and related products	19,053	19,068
Fiberglass	137,754	134,923
Paint	542	W
Paper coating and filling	17,658	17,479
Plastics	8,275	W
Rubber	160,524	148,008
Refractories[2]	8,667	6,900
Other uses[3]	59,161	88,439
Exports[4]	61,009	60,344
Total	494,563	497,067
Unprocessed: Face brick and other uses	165,088	733,994
Grand total[5]	659,651	1,231,061

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

cussed in a paper on kaolin. Mining methods and processing technology (including flotation, fractionation, bleaching, magnetic separation, flocculation, delamination, calcination, and surface treatment) were discussed. Applications and specifications also were featured.[9]

The Minnesota Department of Natural Resources collected mineralogical and geological data on clay deposits in the southwest section of the State for its data base on kaolin. The State is gathering the information to encourage exploration activities by mining companies. There are three operating kaolin mines in the region. The kaolin produced is for brick and cement manufacturing.[10]

The Minnesota Valley Railroad (MNVA) announced plans to purchase a kaolin operation from Nova Natural Resources. The mine is near Belview and produces kaolin used in the production of cement. MNVA plans to expand the mine to include a higher grade deposit.[11] Minnesota Valley Minerals, Inc. announced

TABLE 11

KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Metric tons)

Use	1989				1990			
	Air-float	Unprocessed[1]	Water-washed[2]	Total[3]	Air-float	Unprocessed[1]	Water-washed[2]	Total[3]
Domestic:								
Adhesives	22,304	—	17,198	39,502	32,855	—	21,935	54,789
Aluminum sulfate and other chemicals	4,536	208,290	—	212,826	—	136,078	71,577	207,655
Animal feed	3,480	—	4,091	7,571	W	W	W	W
Brick, extruded and other	49,431	193,910	59,875	303,216	W	219,946	W	290,711
Catalysts (oil and gas refining)	50,420	—	42,888	93,308	50,515	—	40,257	90,772
Cement, portland	—	188,286	—	188,286	—	176,003	—	176,003
China and dinnerware	15,172	—	—	15,172	17,711	—	—	17,711
Crockery and other earthenware	16,815	1,139	—	17,954	2,998	—	—	2,998
Electrical porcelain	13,066	—	2,218	15,284	13,965	—	2,218	16,183
Fertilizers[4]	40	—	2,250	2,290	W	—	W	2,725
Fiberglass, mineral wool and other insulation	387,653	13,517	71,499	472,669	369,333	—	84,798	454,131
Firebrick, blocks and shapes	50,681	59,788	4,823	115,292	62,790	67,112	W	129,902
Floor and wall tile, ceramic; glazes, glass, enamels	17,660	1,605	4,497	23,762	W	W	W	W
Flue linings, high-alumina brick and specialities	762	69,639	—	70,401	W	W	W	W
Foundry sand	524	145	—	669	W	W	W	536
Grogs and calcines, refractory	39,726	588,800	424	628,950	W	756,190	W	759,246
Gypsum products and wallboard	7,700	2,380	122	10,202	W	W	W	W
Ink	—	—	2,025	2,025	—	—	W	W
Kiln furniture; refractory mortar and cement	4,689	1,344	1,244	7,277	W	—	W	W
Linoleum and asphalt tile	4,085	—	—	4,085	W	—	W	W
Medical, pharmaceutical, cosmetic	369	—	2,972	3,341	2,735	—	383	3,118
Paint	19,299	5,429	201,667	226,395	19,620	3,200	238,400	261,219
Paper coating	—	—	2,568,846	2,568,846	54,197	—	2,698,974	2,753,171
Paper filling	247,417	—	1,313,577	1,560,994	164,435	—	1,306,863	1,471,298
Pesticides and related products	19,309	—	383	19,692	19,204	—	31,105	50,309
Plastics	8,645	—	40,177	48,822	21,330	—	40,571	61,901
Pottery	30,147	—	—	30,147	27,852	—	—	27,852
Roofing granules	10,677	—	—	10,677	W	W	—	9,114
Rubber	238,153	1,155	19,556	258,864	161,305	822	45,606	207,733
Sanitaryware	35,131	—	—	35,131	40,947	—	—	40,947
Waterproofing and sealing	4,536	—	527	5,063	—	—	W	W
Miscellaneous	127,956	120,006	113,823	361,785	222,196	647,092	219,150	1,002,237
Total[3]	1,430,383	1,455,433	4,474,682	7,360,498	1,283,988	2,006,443	4,801,837	8,092,261
Exports:								
Ceramics	17,014	—	—	17,014	21,315	—	—	21,315
Foundry sand, grogs and calcines; other refractories	—	32,540	—	32,540	—	—	—	—
Paint	—	—	27,115	27,115	—	—	25,857	25,857
Paper coating	22,696	—	1,074,973	1,097,669	20,894	—	1,135,074	1,155,968
Paper filling	32,917	—	262,155	295,072	38,617	—	266,330	304,947
Rubber	60,068	—	17,451	77,519	59,676	—	17,953	77,630
Miscellaneous	8,004	960	57,277	66,241	26,202	142	57,454	83,798
Total[3]	140,699	33,500	1,438,971	1,613,170	166,704	142	1,502,668	1,669,515
Grand total[3]	1,571,082	1,488,933	5,913,653	8,973,668	1,450,692	2,006,585	6,304,505	9,761,776

[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 soil conditioners and mulches.

plans to mine and process kaolin in Belview, MN. The kaolin will be sold as a filler for soybean meal.[12]

Combustion Engineering Inc., a subsidiary of Asea Brown Boveri Inc., sold a portion of its Georgia Kaolin Co. to ECC Group. The sale included its mine and plants near Sandersville and Wrens, GA, and the Carbonate Div., which produced precipitated calcium carbonate. Combustion Engineering is the parent company of Georgia Kaolin Co., a major producer of water-washed and air-floated kaolins in Georgia.[13] Combustion Engineering sold C-E Minerals Co. to IMETAL SA of France. C-E Minerals operates mines near Anersonville, GA, and is the world's largest calcined refractory clay producer.[14] Asea Brown Boveri retained ownership of Georgia Kaolin's Dry Branch kaolin operation. Dry Branch Kaolin Co., a newly formed company, will operate the Dry Branch mine.[15]

Despite strong foreign competition and a fluctuating U.S. dollar, exports of kaolin, reported as clays by the U.S. Department of Commerce, increased 21% to 2.83 million tons valued at $428 million. The unit value of the exported clay decreased 5% to $151.41 per ton. Kaolin, including calcined material, was exported to 67 countries. The major importers, in descending order, were Japan, Canada, Italy, the Netherlands, Finland, and Mexico. Exports to Finland increased 21% to 192,000 tons. Kaolin producers reported end uses for their exports as follows: paper-coating, 69%; paper-filling, 18%; rubber, 5%; paint, 2%; and other, including ceramics and refractories, 6%.

Kaolin imports for consumption decreased about 10% to 3,067 tons valued at $1.4 million. The unit value increased about 8% to $443.43 per ton, reflecting the continuing strong worldwide demand for premium-quality kaolin.

Kaolin prices quoted in the trade journals generally were unchanged from those of the previous year.

TABLE 12

PRICE QUOTATIONS FOR KAOLIN AND BALL CLAY, 1990

	Per ton
Kaolin:	
Waterwashed, fully calcined bags, carload lots, f.o.b. Georgia per ton	$323.00
Calcined, paper-grade, same basis, per ton	470.00
Paper-grade, uncalcined, bulk, carload lots, f.o.b. Georgia, per ton:	
No. 1 coating	110.00
No. 2 coating	87.00
No. 3 coating	85.00
No. 4 coating	82.00
Filler, general purpose, same basis per ton	64.00
Delaminated, waterwashed, uncalcined, painted-grade, 1-micrometer average, same basis, per ton	284.00
Dry-ground, air-floated, soft, same basis per ton	52.00
National Formulary, powder, collodial, bacteria controlled, 50-pound bags, 5,000-pound lots, per ton	273.00
Ball clay:	
Domestic, air-floated, bags, carload lots, Tennessee, per ton	49.00
Domestic, crushed, moisture-repellent, bulk carload lots, Tennessee, per ton	24.00

Source: Chemical Marketing Reporter, V. 238, No. 27, Dec. 31, 1990, pp. 34-36.

Ball Clay.—Production of domestic ball clay decreased 13% to 788,000 tons valued at about $33 million. Tennesse supplied 69% of the Nation's output, followed by, in descending order of production, Kentucky, Mississippi, Texas, and Indiana. Production decreased in all the major producing States. The principal ball clay markets were dinnerware, floor and wall tile, pottery, and sanitaryware. Sales decreased because the slow overall economy depressed construction rates and housing starts.

United Clays Inc. of Tennessee announced that it would open a mine in Tennessee. The company will produce clay for the manufacture of ceramic fixtures and fiberglass.[16]

TABLE 13

BALL CLAY SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	Air-float		Water-slurried		Unprocessed		Total	
	Metric tons	Value	Metric tons	Value	Metric tons	Value	Metric tons	Value
1989								
Tennessee	346,250	$16,423,013	104,752	$4,422,232	189,636	$5,446,538	640,638	$26,291,783
Other[1]	179,410	10,208,186	W	W	W	W	2262,842	214,551,372
Total	525,660	26,631,199	104,752	4,422,232	189,636	5,446,538	2903,480	240,843,155
1990								
Tennessee	260,873	$12,903,847	130,316	$5,475,849	152,503	$4,290,932	543,692	$22,670,628
Other[1]	160,064	8,106,330	—	—	83,907	2,679,200	243,971	10,785,530
Total	420,937	21,010,177	130,316	5,475,849	236,410	6,970,132	787,663	33,456,158

W Withheld to avoid disclosing company proprietary data.
[1]Includes Indiana, Kentucky, Mississippi, and Texas.
[2]Includes data indicated by symbol W.

TABLE 14

BALL CLAY SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1989				1990			
	Air-float	Water-slurried	Un-processed	Total	Air-float	Water-slurried	Un-processed	Total
Ceramics[1]	W	W	W	62,600	W	—	W	11,780
Dinnerware[2]	102,960	1,297	82,640	186,897	99,640	—	W	99,640
Fillers, extenders, and binders[3]	W	W	W	92,043	101,187	—	1,478	102,665
Floor and wall tile	34,124	19,140	108,460	161,724	34,550	11,938	111,837	158,325
Refractories[4]	33,739	1,829	25,364	60,932	39,292	W	548	39,840
Sanitaryware	122,636	66,422	5,019	194,077	W	106,598	51,633	158,231
Miscellaneous	32,701	—	5,125	37,826	72,321	W	54,290	126,611
Exports	83,218	—	24,163	107,381	73,947	—	16,624	90,571
Total	545,609	104,702	253,169	903,480	420,937	130,316	236,410	787,663

W Withheld to avoid disclosing company proprietary data; included in "Total."
[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 (1989); asphalt tile; pesticides and related products; rubber; wallboard (1989); other uses not specified.
[4]Includes electrical porcelain; firebrick, block and shapes; high-alumina brick and specialties.

The average unit value for ball clay reported by domestic producers increased 17% to $52.77 per ton. Listed prices in the Chemical Marketing Reporter, January 7, 1991, per short ton, were unchanged from those of 1989.

Ball clay exports decreased 56% to 69,000 tons valued at $3.1 million. Unit value increased to $45.14 from $43.62. Shipments were made to 24 countries, 1 less than in 1989. The major importer was Mexico, with 86% of the exports. The expanding Mexican ceramic markets continued to be supplied largely with domestic clays because of international financial difficulties. Mexican ceramic exports, mostly to the United States, are made chiefly with U.S. and domestic clays.

Ball clay imports for consumption, almost entirely from the United Kingdom, also decreased 4% to 1,417 tons valued at $299,000. The unit value of these clays increased more than 12% to $286.58 per ton.

Fire Clay.—Fire clay sold or used by domestic producers decreased 24% in tonnage to 625,808 tons and 23% in value to $16.1 million. Missouri was the leading producing State followed by Ohio, Alabama, New Jersey, Pennsylvania, and New Mexico.

The clay refractory industry had been in a period of low production because of decreased demand brought about by technological changes and lower consumption levels by its major users—steel, non-ferrous metals, ceramics, glass, and minerals processing industries. The technological changes in steelmaking, away from integrated pig iron systems and toward electric furnaces and/or minimills, further compounded the problem by employing shapes and specialty refractories requiring less fire clay.

Radex Heraklith of Austria signed an agreement to acquire 50% ownership of National Refractories and Minerals Corp.

TABLE 15

FIRE CLAY[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1989		1990	
	Metric tons	Value	Metric tons	Value
Alabama	108,241	$4,052,254	96,257	$3,980,540
Colorado	7,477	63,054	—	—
Missouri	431,084	10,785,153	282,674	7,651,531
New Jersey	18,492	399,700	W	W
New Mexico	3,125	24,090	W	W
Ohio	222,931	4,695,895	225,797	4,038,024
Pennsylvania	14,459	488,506	W	W
Texas	2,348	35,947	—	—
Washington	2,787	68,159	—	—
Other	14,986	264,361	21,080	457,780
Total	825,930	20,877,119	625,807	16,127,875

W Withheld to avoid disclosing company proprietary data included in "Other."
[1]Refractory uses only.

of California. National Refractories produces clays for refractory applications.[17]

Fire clay was produced again from mines in six States. Missouri, Ohio, and Alabama, in descending order of volume, accounted for more than 97% of the total domestic production. Output decreased in other producing States.

Exports of fire clay decreased 14% to 245,000 tons. The unit value of exported clay increased 3% to $87.45 per ton. Fire clay was exported to 33 countries, 1 less than in 1989. The major recipients, in descending order, were the Netherlands, Japan, Mexico, Australia, and Canada. Fire clay imported from three countries amounted to 185 tons valued at $16,200.

The unit value for fire clay, reported by producers, ranged from about $25 to $77 per ton.

Bentonite.—Bentonite production increased more than 12% to 3.5 million tons, while the value decreased 2% to $123.0 million. Wyoming was the largest bentonite producer, accounting for 73% of production. Wyoming also was the leading producer of swelling bentonite. The three major end uses were drilling mud, foundry sand, and iron ore pelletizing with 24%, 32%, and 20%, respectively, of total sales. Consumption of bentonite for foundry sand and iron ore pelletizing applications increased in 1990.

Bentonite was produced in 11 States. Most of the high-swelling or sodium bentonite was produced in Wyoming. Mines in Alabama and Mississippi produced more than one-half of the low-swelling or calcium bentonite. Calcium bentonite produced in Alabama and Mississippi was suitable for the production of absorbent, acid-activated, and foundry products.

American Colloid Co.'s request for bentonite mining in Thunder Basin National Grassland in Wyoming was still under review. American Colloid purchased the Thunder Basin bentonite operations owned by Federal Ore and Chemicals Inc. The company applied for permission to mine an additional 179 acres that had previously been disturbed by mining.[18]

A new plant that produces mats of bentonite sheeting was planned for Spearfish, SD. The company will use locally produced bentonite to produce the mats, which consist of bentonite sandwiched between layers of thick plastic. The company estimates that it will use approximately 500 tons of bentonite per month.[19]

The quoted price in the Chemical Marketing Reporter, January 7, 1991, for domestic bentonite, carload lots, f.o.b. mines, was $28.60 per ton. The average unit value reported by domestic producers decreased 12% to $35.42 per ton.

Bentonite exports increased 4% to 699,000 tons valued at $57.1 million. The unit value of exported bentonite increased about 4% to $81.71 per ton. Bentonite was exported to 68 countries, 18 less than in 1989. The five major recipients, in descending order, were Japan, Canada, Singapore, Taiwan, and the Federal Republic of Germany. Domestic bentonite producers reported their exports were foundry sand, 55%; drilling mud, 24%; and others, 21%.

Bentonite imports for consumption consisted mostly of untreated bentonite clay and chemically or artificially activated materials. Bentonite imports increased 5% to 17,000 tons. Canada was the largest supplier of bentonite. The chemically activated category increased 15% to 15,000 tons valued at $6.2 million. Mexico accounted for 92% of the chemically activated bentonite imported into the United States. This was an increase of 7% over that of 1989.

Fuller's Earth.—Production of fuller's earth increased 23% to 2.31 million tons valued at $224 million. Reported production of fuller's earth is greater than that of 1989 because two producers were included under the fuller's earth category for the first time. They were reported under other clay categories in the past. The average unit value increased 10% to $96.92 per ton. Production was reported in 10 States. Florida and Georgia accounted for nearly one-half of domestic production. Increases in consumption occurred in every

FIGURE 2

BENTONITE SOLD OR USED BY DOMESTIC PRODUCERS FOR SPECIFIED USES

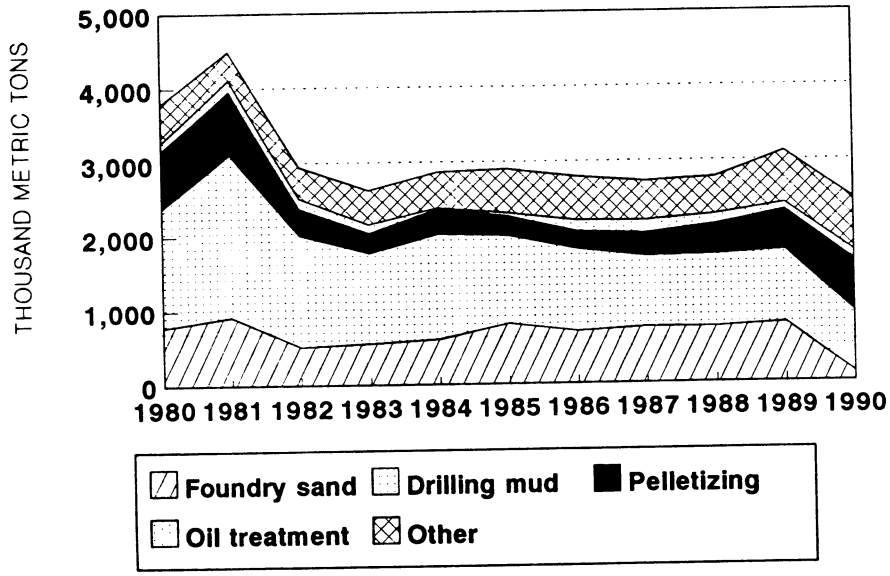

TABLE 16

BENTONITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	Nonswelling		Swelling		Total	
	Metric tons	Value	Metric tons	Value	Metric tons	Value
1989						
Alabama and Mississippi	528,807	$26,323,541	—	—	528,807	$26,323,541
Arizona	36,830	1,742,432	23	$882	36,853	1,743,314
California	133,958	11,278,648	18,705	1,656,600	152,663	12,935,248
Colorado	—	—	272	3,361	272	3,361
Nevada	—	—	40,045	3,626,319	40,045	3,626,319
Oregon	2,858	132,300	9,146	415,993	12,004	548,293
Texas	38,972	1,589,001	1,087	32,659	40,059	1,621,660
Utah	647	33,540	45,003	800,496	45,650	834,036
Wyoming	—	—	2,166,497	74,697,299	2,166,497	74,697,299
Other[1]	106	121,277	89,409	2,626,392	89,515	2,747,669
Total	742,178	41,220,739	2,370,187	83,860,001	3,112,365	125,080,740
1990						
Alabama and Mississippi	411,244	17,217,383	—	—	411,244	17,217,383
Arizona	37,622	W	21	W	37,643	W
California	136,118	11,402,895	17,331	1,618,286	153,450	13,021,181
Colorado	—	—	272	4,200	272	4,200
Nevada	W	W	W	W	34,625	4,097,723
Oregon	—	—	24,562	1,063,343	24,562	1,063,343
Texas	W	W	W	W	W	W
Utah	W	W	W	W	W	W
Wyoming	—	—	2,523,572	76,082,575	2,523,572	76,082,575
Other[1]	47,008	2,954,481	275,845	12,648,139	300,930	11,504,897
Total	631,992	31,574,759	2,841,603	91,416,543	3,473,595	122,991,302

[1]Includes Kansas (1989), Montana, and uses indicated by symbol W.

TABLE 17

BENTONITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1989			1990		
	Nonswelling	Swelling	Total[1]	Nonswelling	Swelling	Total[1]
Domestic:						
Absorbents	287,747	1,110	288,857	W	W	W
Adhesives	—	8,074	8,074	—	4,410	4,410
Animal feed	20,527	73,410	93,937	14,589	90,991	105,580
Catalysts (oil-refining)	12,220	—	12,220	W	—	W
Drilling mud	6,750	839,833	846,583	1,773	711,200	712,973
Filtering, clarifying, decolorizing:						
Animal oils, mineral oils and greases, and vegetable oils	76,699	1,776	78,475	58,548	4,226	62,775
Desiccants	24,141	—	24,141	W	—	W
Foundry sand	209,970	400,003	609,973	226,260	638,420	864,680
Medical, pharmaceutical, cosmetic	W	9,169	9,169	W	16,008	16,008
Paint	—	9,984	9,984	—	5,747	5,747
Pelletizing (iron ore)	—	477,275	477,275	—	682,878	682,878
Pesticides and related products	9,617	1,814	11,431	W	W	W
Water treatment and filtering	3,853	930	4,783	W	W	W
Waterproofing and sealing	1,639	87,050	88,689	14,850	141,097	155,947
Miscellaneous[2]	31,815	81,863	113,678	275,338	124,774	400,112
Total[1]	684,978	1,992,293	2,677,271	591,358	2,419,753	3,011,112

See footnotes at end of table.

TABLE 17—Continued

BENTONITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1989			1990		
	Nonswelling	Swelling	Total[1]	Nonswelling	Swelling	Total[1]
Exports:						
Drilling mud	1,649	133,439	135,088	—	113,079	113,079
Foundry sand	2,012	147,899	149,911	2,400	251,944	254,344
Other[3]	53,538	96,556	150,095	38,234	56,825	95,056
Total[1]	57,200	377,894	435,094	40,634	421,850	462,483
Grand total	742,178	2,370,187	3,112,365	631,992	2,841,603	3,473,595

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

major absorbent product line. The two major end uses were pet waste and oil and grease absorbents.

Production from the region that includes Attapulgus, Decatur County, GA, and Quincy, Gadsden County, FL, is composed predominantly of the lath-shaped amphibolelike clay mineral attapulgite. Most of the fuller's earth produced in other areas of the United States contains varieties of montmorillonite and/or other clays.

Attapulgite, a fuller's earth-type clay, finds wide application in both absorbent and gelling and/or thickening areas. The thixotropic properties of attapulgite clays provide the important thickening and viscosity controls necessary for suspending solids. Mineral thickeners are used in such diverse markets as paint, joint compound cement, and saltwater drilling mud.

Fuller's earth was exported to 30 countries, 4 more than in 1989. The quantity decreased 50% to 46,000 tons. The unit value of exported fuller's earth rose 45% to $129.07. The increase was attributed to a larger percentage of high-cost gelling and drilling mud grades shipped. Most of the fuller's earth was shipped to Canada (15%) and the Netherlands (43%). Small amounts of decolorizing fuller's earth were imported from Canada and the Federal Republic of Germany.

Common Clay and Shale.—Domestic sales or use of common clay and shale decreased 2% in tonnage to 26.1 million tons and increased 8% in value to $152 million. Of the nine major producing States, production increased in Alabama, Indiana, and Missouri, and decreased in California, Georgia, Michigan, 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.

FIGURE 3

FULLER'S EARTH SOLD OR USED BY DOMESTIC PRODUCERS FOR SPECIFIED USES

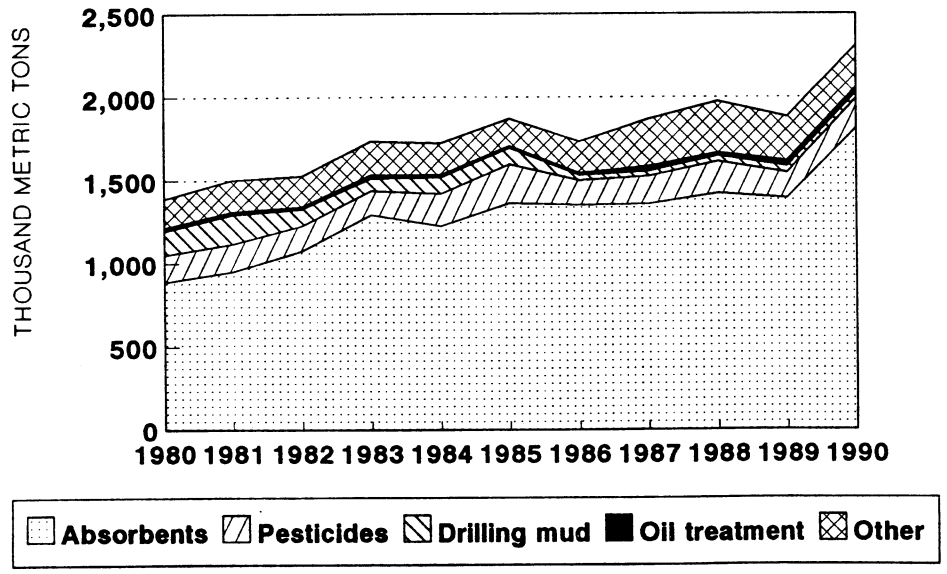

TABLE 18

FULLER'S EARTH SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	Attapulgite		Montmorillonite		Total	
	Metric tons	Value	Metric tons	Value	Metric tons	Value
1989						
Florida	405,069	$43,029,400	—	—	405,069	$43,029,400
Georgia	471,711	40,191,539	195,533	$13,057,401	667,244	53,248,940
Southern[1]	—	—	278,260	23,879,062	278,260	23,879,062
Western[2]	17,219	1,830,826	513,719	43,706,682	530,938	45,537,508
Total[3]	893,999	85,051,765	987,512	80,643,145	1,881,511	165,694,910
1990						
Florida	352,890	35,928,117	([3])	([3])	352,890	35,928,117
Georgia	460,543	59,242,731	187,469	13,486,716	648,009	72,729,447
Southern[1]	—	—	508,972	33,970,190	508,972	33,970,190
Western[2]	([4])	([4])	797,605	81,017,614	797,605	81,017,614
Total[5]	744,757	95,170,848	1,562,718	128,474,520	2,307,476	223,645,368

[1]Includes Mississippi, South Carolina (1989), Tennessee, and Virginia.
[2]Includes California, Illinois, Missouri, Nevada, and Texas.
[3]Included under attapulgite.
[4]Included under montmorillonite.
[5]Data may not add to totals shown because of concealments for proprietary coverage of individual kinds.

TABLE 19

FULLER'S EARTH SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Metric tons)

Use	1989			1990		
	Attapulgite	Montmorillonite	Total[1]	Attapulgite	Montmorillonite	Total[1]
Domestic:						
Adhesives	118	907	1,025	W	—	W
Drilling mud	35,181	—	35,181	34,150	—	34,150
Fertilizers	45,723	2,361	48,084	43,893	W	43,893
Filtering, clarifying, decolorizing mineral oils and greases	3,834	—	3,834	23,237	—	23,237
Medical, pharmaceutical, cosmetic	1,395	—	1,395	W	—	W
Oil and grease absorbents	170,003	128,007	298,009	150,597	219,181	369,778
Paint	19,341	907	20,248	W	—	W
Pesticides and related products	97,452	43,711	141,163	84,592	83,128	167,720
Pet waste absorbents	297,026	718,166	1,015,192	219,720	1,127,549	1,347,270
Portland and other cement	—	43,551	43,551	—	W	W
Other[2]	4,536	—	4,536	W	—	W
Miscellaneous[3]	109,423	20,291	129,714	94,790	86,430	181,220
Exports	109,968	29,611	139,579	93,778	46,430	140,208
Grand total[1]	893,999	987,512	1,881,512	744,757	1,562,718	2,307,476

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.

Domestic clay and shale are generally mined and used captively to fabricate or manufacture products. Less than 10% of the total output is usually sold. The average unit value for all common clay and shale produced in the United States and Puerto Rico increased 11% to $5.82 ton. The reported unit value ranged from $5 per ton to $36 per ton.

The Department of Commerce reviewed ceramic tile imports from Mexico for January 1, 1987, to December 31, 1987. It concluded that duties will be zero for 47 companies and 1.29% ad valorem for all other firms. The Agency also reviewed brick imports for January 1, 1986, to August 23, 1986. It concluded that duties will be zero for 22 firms and

TABLE 20

COMMON CLAY AND SHALE SOLD OR USED BY PRODUCERS IN THE UNITED STATES,[1] BY STATE

State	1989		1990	
	Metric tons	Value	Metric tons	Value
Alabama	1,703,001	$10,388,283	1,953,519	$23,766,026
Arizona	151,358	763,412	102,519	470,140
Arkansas	627,825	1,673,881	705,467	2,799,037
California	1,919,694	21,212,742	1,888,032	22,200,901
Colorado	248,308	1,866,343	262,020	1,864,041
Connecticut and New Jersey	195,539	2,455,353	165,148	2,293,793
Florida	115,981	W	W	W
Georgia	1,606,546	6,841,777	1,546,304	7,015,259
Illinois	142,207	641,237	598,479	2,515,844
Indiana	871,179	3,835,574	1,051,703	3,272,624
Iowa	439,323	1,772,934	423,227	1,376,264
Kansas	533,099	2,699,864	625,969	4,056,062
Kentucky	716,990	3,357,200	826,205	8,282,322
Louisiana	233,992	6,114,609	368,322	1,066,295
Maine and Massachusetts	96,064	474,755	52,107	237,067
Maryland	351,464	1,882,283	338,755	1,711,599
Michigan	1,249,198	4,598,922	1,201,542	4,093,649
Mississippi	497,625	2,591,061	528,456	2,568,130
Missouri	1,048,814	3,880,428	1,064,884	5,211,884
Montana	30,176	79,887	29,741	192,682
Nebraska	224,624	879,546	227,292	1,685,241
New Mexico	27,887	70,119	27,994	74,250
New York	531,559	3,428,813	490,552	2,906,006
North Carolina	2,204,617	13,599,134	2,179,428	9,355,674
Ohio	3,296,737	10,287,176	2,320,354	9,295,572
Oklahoma	565,956	1,618,977	631,302	3,155,987
Oregon	198,889	327,479	198,889	327,479
Pennsylvania	1,035,514	4,447,350	840,646	2,899,788
Puerto Rico	136,873	310,888	147,721	W
South Carolina	931,059	2,214,064	831,763	2,076,919
South Dakota and Wyoming	196,466	865,197	162,657	775,876
Tennessee	496,514	W	482,496	W
Texas	2,203,895	11,965,200	2,106,485	13,057,548
Utah	276,299	1,799,103	277,795	1,773,740
Virginia	1,001,394	6,302,335	882,383	3,740,806
Washington	230,480	1,522,712	158,257	1,356,945
West Virginia	251,385	553,474	164,257	383,710
Other[2]	105,657	3,206,571	233,168	3,968,679
Total	26,694,188	140,528,683	26,095,840	151,827,839

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Includes Puerto Rico.
[2]Includes Idaho, Minnesota, New Hampshire, and North Dakota.

4.44% ad valorem for all other firms. The decision is based on benefits received by these companies under Government financial aid programs.[20]

S.V. Farming Corp. submitted a proposal to expand its clay operation to approximately twice its current size of 59 acres. S.V. Farming produces clay for lining and capping landfills.[21]

Western Aggregates Inc. announced a $14 million reconstruction of its lightweight aggregate plant in Colorado. Plant capacity will be 500,000 cubic yards of aggregate for construction applications.[22]

Carolina Solite Corp. was the center of controversy as residents protested its burning of chemical wastes as fuel. The company produces lightweight aggregate for cement and concrete applications. Caroline Solite uses approximately 6 million gallons of waste per year.[23]

Consumption and Uses

The manufacture of heavy clay products, including (1) building brick; sewer pipe; and drain, roofing, structural, terra

TABLE 21

CLAYS SOLD OR USED BY PRODUCERS ON THE UNITED STATES[1] IN 1990, BY USE

(Metric tons)

Use	Ball clay	Bentonite	Common clay and shale	Fire clay (refractor only)	Fuller's earth	Kaolin	Total
Absorbents:							
Oil and grease	—	W	W	—	350,804	—	350,804
Pet waste absorbents	—	W	W	—	1,347,270	—	1,347,270
Other[2]	W	196,684	165,184	—	W	—	362,168
Ceramics and glass:							
Catalysts (oil-refining)	—	W	—	—	W	90,772	90,772
Crockery and other earthenware	—	—	—	—	—	2,998	2,998
Electrical porcelain	22,665	—	—	—	W	16,183	38,848
Fine china and dinnerware	W	—	—	—	—	17,711	17,711
Glazes, glass and enamels	—	W	—	W	—	W	788
Mineral wool and insulation, fiberglass	—	W	—	—	—	454,131	454,131
Pottery	118,519	W	150,440	W	—	27,852	296,811
Roofing granules	—	—	102,290	—	2,887	9,114	114,291
Sanitaryware	176,809	—	—	—	—	40,947	217,755
Other[2]	14,926	47,619	—	W	15,046	83,886	161,477
Chemical manufacturing	—	10,082	—	—	W	218,170	228,252
Civil engineering and sealing	11,793	181,149	598,234	—	—	584,331	1,375,507
Drilling mud	—	712,973	—	—	34,150	—	747,123
Fillers, extenders and binders:							
Adhesives	W	4,410	—	—	W	54,789	65,549
Animal feed	21,661	105,580	W	—	W	W	127,241
Fertilizers	—	W	—	—	43,893	2,725	63,936
Gypsum products and wallboard	W	—	—	—	31,510	W	34,002
Ink	—	W	—	W	—	W	W
Medical, pharmaceutical, cosmetic	—	16,045	—	—	W	3,118	19,163
Paint	W	5,747	W	—	W	261,219	266,966
Paper coating	—	W	—	—	—	2,753,171	2,753,171
Paper filling	W	W	—	—	—	1,471,298	1,471,298
Pesticides and related products	W	8,394	W	—	167,720	50,309	226,423
Plastics	W	W	—	—	W	61,901	61,901
Rubber	W	W	—	—	W	207,733	207,733
Other[2]	93,562	18,993	123,288	—	83,822	187,756	491,253
Filtering, clarifying, decolorizing:							
Animal oils, mineral oils and greases, and vegetable oils	—	62,775	—	—	23,237	458	86,470
Desiccants	—	W	—	—	—	—	W
Floor and wall tile:							
Ceramic	158,325	11	212,665	—	—	13,816	384,817
Quarry tile	W	—	530,662	—	—	—	530,662
Other[2]	W	—	—	—	—	29,946	29,946
Heavy clay products:							
Brick, extruded	W	W	10,540,509	17,822	—	256,724	10,815,055
Brick, other	—	—	1,837,495	—	—	33,987	1,871,482
Drain tile	—	—	9,604	—	—	—	9,604
Flower pots	—	—	68,026	—	—	—	68,026
Flue linings	—	—	22,140	5,842	—	W	27,982
Portland and other cements	—	W	7,095,811	—	—	176,003	7,271,814
Roofing tile	—	W	W	—	—	—	W
Sewer pipe, vitrified	—	—	107,986	227	—	W	108,213
Structural tile	—	—	54,122	—	—	—	54,122

See footnotes at end of table.

TABLE 21—Continued

CLAYS SOLD OR USED BY PRODUCERS ON THE UNITED STATES[1] IN 1990, BY USE

(Metric tons)

Use	Ball clay	Bentonite	Common clay and shale	Fire clay (refractor only)	Fuller's earth	Kaolin	Total
Heavy clay products—Continued							
Terra cotta	—	—	W	—	—	—	W
Other[2]	W	5,177	96,439	2,098	—	32,168	135,882
Lightweight aggregate:							
Concrete	—	—	2,523,507	—	—	—	2,523,507
Highway surfacing	—	W	267,861	—	—	—	267,861
Structural concrete	—	—	786,084	W	—	—	786,084
Other[2]	—	7,194	226,879	W	—	—	234,073
Pelletizing iron ore	—	682,878	W	—	—	—	682,878
Refractories:							
Firebrick, blocks and shapes	W	W	98,321	453,024	—	129,902	686,272
Foundry sand	—	864,680	—	7,739	—	536	872,955
Grogs and calcines	—	—	—	20,208	—	759,246	779,454
High-alumina brick and specialties	—	—	—	41,192	—	W	41,192
Kiln furniture	15,814	W	—	—	—	W	15,814
Mortar and cement, refractory	852	—	407,145	—	—	—	407,997
Other[2]	W	49,386	W	44,469	34,948	41,108	169,907
Other[3]	62,167	31,039	52,538	23,822	23,629	10,799	203,993
Exports	90,570	462,483	18,606	9,364	140,210	1,669,515	2,390,748
Total	787,663	3,473,595	26,095,808	625,808	2,307,476	9,761,775	43,052,152

W Withheld to avoid disclosing company proprietary data; included with "Total" and/or "Other."
[1]Includes Puerto Rico.
[2]Includes uses indicated by symbol W.
[3]Uses not specified.

cotta, and other tile; (2) portland cement clinker; and (3) lightweight aggregate, accounted for 47%, 17%, and 10%, respectively, of total domestic consumption.

Kaolin has many industrial applications, and many grades are specifically designed for use as a filler in paper, paint, rubber, plastics,[24] and ceramics.[25] 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.[26]

Ball clays are extremely refractory and their use, largely in whitewares, imparts a high green strength as well as plasticity to the bodies. Although white-firing ball clays are preferable, fired products that range to cream or buff colors do not generally impair the quality of the whiteware products.

Fire clays are used mostly in commercial refractory products such as firebrick and block of many shapes, insulating brick, saggers, refractory mortars and mixes, ramming and gunning mixes, grog and crude aggregates, and many other products. Fire clays are also added to common clays to increase the vitrification range of sewer pipes and bricks.

The swelling sodium bentonites are used largely in drilling muds, in foundry sands, and in pelletizing taconite iron ores. The nonswelling or calcium bentonites are used mostly in conjunction with the swelling bentonites in foundry sand mixes in which the sodium bentonites provide dry strength and the calcium bentonites provide high green strength. Fuller's earth and calcium bentonites find application in decolorizing and purifying mineral, vegetable, and animal oils. Clays used to process animal or vegetable oils usually are activated by acid treatment. Acid treatment produces a highly absorbent sievelike structure. Attapulgite is used in drilling muds instead of sodium bentonites for drilling saltwater formations. Sodium bentonite "breaks the emulsion" or flocculates in brine, thereby destroying the gellike colloidal suspension required for drilling. The major uses for attapulgite and montmorillonite types of the fuller's earths are in pet waste and oil and grease absorbents because of their absorbent properties.

Bentonite also is used for foundry casting by the steel, iron, and nonferrous casting. The bentonite provides good green strength and desirable dry strength characteristics. Sodium bentonites are used in steel casting. Ion-exchanged bentonites are used for iron and nonferrous casting. There is increased use of mixtures of ion exchanged and sodium bentonites to meet the more stringent demands of the casting industry.[27]

Construction.—Common clays and shales are used to manufacture a wide variety of construction materials such as structural clay products, cement, and expanded aggregates.

Structural Clay Products.—Structural clay products such as building brick, drain

TABLE 22

SHIPMENTS OF PRINCIPLE STRUCTURAL CLAY PRODUCTS IN THE UNITED STATES

Product		1986	1987	1988	1989	1990
Unglazed common and face brick:						
Quantity	million standard brick	7,204	7,313	7,811	6,698	6,783
Value	million	$972	$1,060	$1,188	$1,000	$1,014
Unglazed structural tile:[1]						
Quantity	thousand metric tons	65	84	53	W	W
Value	million	$28	$50	$6	W	W
Vitrified clay and sewer pipe fittings:						
Quantity	thousand metric tons	270	295	286	232	220
Value	million	$66	$74	$74	$64	$60
Unglazed, salt-glazed, ceramic-glazed structural facing tile including glazed brick:						
Quantity	million standard brick	W	32	26	35	31
Value	million	W	$11	$18	$15	$14
Clay floor and wall tile including quarry tile:						
Quantity	million square feet	444	462	488	545	509
Value	million	$536	$587	$641	$707	$687
Total value[2]	do.	$1,602	$1,782	$1,927	$1,786	$1,775

W Withheld to avoid disclosing individual company proprietary data.
[1]Includes first 9 months only, 1987.
[2]Data do not add to total shown because of independent rounding.
Source: Bureau of the Census Report Form M32-D(90), Current Industrial Reports—Clay Construction Products.

tile, and vitrified sewer pipe are used in building construction, for sewer systems, to drain farmers' fields, and for many other uses. Other clays, such as kaolin, fire clay, or ball clay, could in many cases be used to produce equally suitable "heavy clay" products, but they are generally more refractory and valuable for other uses. Of the total clay produced, about one-third is consumed in the manufacture of these structural products.

Hydraulic Cement.—The portland cement industry requires alumina and silica as constituents in the manufacture of portland cement. Common clays provide a low-cost source of these materials.

Expanded Clay and Shale.—For this purpose, certain bloating qualities and strength are required. Lightweight concrete blocks, floors, walls, and other shapes made from expanded clay and shale have a lower overall weight, which results in savings in the design of the supporting framework. Also, products made from expanded clay and shale have better insulating qualities than equivalent products made with sand and gravel and crushed stone aggregates.

Refractories.—Refractories require strength at high temperatures, resistance to corrosion, low coefficient of expansion, and many other physical and chemical properties, depending on application. Clays with physical properties most suitable for general refractory use have been classed as fire clays. The current trend is for refractories designed for a specific use and castable mixes containing refractory aggregates and calcium aluminate cements.[28]

Paper Products.—Demand for clays for use as filler and coater in paper has followed the rapid increase in demand for paper. Kaolin is the principal clay used.

Other Uses.—Pottery and related products require good ceramic qualities, including plastic formation, desirable firing temperatures, color, etc. The principal clays meeting these and other specifications are ball clay and kaolin. Kaolin also is used as a raw material feed in formulating bottle and plate glass batches. Drilling mud is a scientifically designed mixture of several items. It contains, in addition to bentonite or attapulgite, ground barite for its high specific gravity.[29] Demand for bentonite in iron and steel production is based on its ability to form strong iron ore pellets from fine-grained taconite concentrates. Easily handled hard pellets are essential for efficient blast furnace operation.

Heavy Clay Products.—The value reported for shipments by the Bureau of the Census for heavy clay products remained the same at $1.8 billion. The million standard brick count for building or common face brick increased slightly. Shipments of clay floor and wall tile decreased 6% while vitrified clay and sewer pipe fittings decreased 5%.

Lightweight Aggregates.—Consumption of clay and shale in the production of lightweight aggregate increased 12% to 3.8 million tons. Concrete block, the largest category (66% of total production), increased 22% while the second biggest consuming area, structural concrete (22% of total production), increased only slightly. The third largest segment, highway surfacing (7% of production), declined significantly. The other category, the smallest segment consisting essentially of market areas such as recreational and horticultural uses, increased 5%.

Refractories.—All types of clay, except for fuller's earth, were used in manufacturing refractories. Kaolin, bentonite, and fire clay accounted for 32%, 31%, and 19%, respectively, of total clay used for this purpose. The remainder, ball clay and common clay and shale, was used chiefly as bonding agents. Bentonite, both swelling and nonswelling, was used as a bonding agent in proprietary foundry formulations imparting both hot and green strength to the sand.

The tonnage of clays used for refractories increased 6% and constituted 8% of

TABLE 23

COMMON CLAY AND SHALE USED IN BUILDING BRICK PRODUCTION IN THE UNITED STATES, BY STATE[1]

State	1989		1990	
	Metric tons	Value	Metric tons	Value
Alabama	794,960	$4,514,209	952,605	$13,425,302
Arizona[2] and New Mexico[2]	59,309	220,616	59,862	153,286
Arkansas	277,670	712,893	322,033	757,072
California	369,030	2,574,965	400,233	6,931,117
Colorado	229,158	1,766,510	229,349	1,564,481
Connecticut, New Jersey,[2] and New York[2]	294,593	2,570,000	351,521	2,267,258
Georgia	1,178,307	4,474,571	976,652	3,594,974
Idaho, Washington, and Wyoming[2]	187,561	1,111,775	96,922	579,862
Illinois	113,755	542,500	109,229	534,740
Indiana and Iowa	322,891	1,421,015	405,286	1,237,258
Kansas	156,012	555,925	158,255	553,265
Kentucky[2]	323,284	2,343,967	372,501	6,780,768
Louisiana	75,235	266,109	83,146	254,450
Maine, Massachusetts,[2] and New Hampshire[2]	113,073	585,192	63,447	279,927
Maryland and West Virginia[3]	390,113	1,943,866	355,245	1,539,692
Michigan[2] and Minnesota[2]	166,047	550,328	163,113	413,611
Mississippi	402,111	2,207,152	374,489	2,183,499
Missouri	86,610	444,578	172,830	529,112
Nebraska and North Dakota[2]	183,058	557,667	176,327	459,876
North Carolina	1,872,337	9,537,777	1,844,384	5,180,550
Ohio	968,224	4,036,590	1,055,211	4,626,044
Oklahoma	220,372	861,955	286,630	4,940,632
Oregon	20,286	67,601	20,286	61,327
Pennsylvania	886,255	3,719,253	749,164	2,163,840
South Carolina	664,823	1,795,906	576,570	1,593,997
Tennessee[2]	384,976	1,088,435	370,958	946,721
Texas	788,464	4,520,965	896,280	11,258,501
Utah[2]	150,853	1,248,268	127,310	985,265
Virginia	753,998	2,933,106	628,166	2,095,534
Total[4] [5]	12,433,366	59,173,694	12,378,004	77,891,961

[1]Include extruded and other brick.
[2]Extruded brick only.
[3]Other brick only.
[4]Includes 1.5 million tons used in other brick production.
[5]Data may not add to totals shown because of independent rounding.

total clay produced. The continued use of high-alumina clay-base refractories, mostly calcined kaolin grogs in monoliths, and the upturn in demand for the more conventional refractory bricks and shapes were largely responsible. The major refractory consuming industries—cement, foundry, glass, and ferrous and nonferrous metals—continued to undergo major changes in technology and production levels for their products.

Filler.—Bentonite, fuller's earth, and kaolin are the principal filler clays. Kaolin, either air-floated, water-washed, low-temperature calcined, and/or delaminated, was used in the manufacture of adhesives, paint, paper, plastics, and rubber. Fuller's earth was used primarily in pesticides and fertilizers. Clays were used in pesticides and fertilizers as either thickeners, carriers, diluents, or prilling agents. Bentonites were used mainly in animal feeds.

Of the total clay produced, 13% was used in filler applications; of this, kaolin accounted for 87%; fuller's earth, 6%; bentonite, 3%; and ball clay, common clay and shale, and fire clay, 4%. Kaolin consumed as fillers increased 3% to 5.1 million tons. Use of paper-coating-grade kaolin increased 7%, and the use of paper-filler-grade kaolin decreased 6%. These two categories accounted for 84% of the total filler and extender category.

Absorbent Uses.—Absorbent uses for clays accounted for about 2.1 million tons or 5% of total clay consumption. Demand for absorbents increased 10%. Fuller's earth was the principal clay used for absorbent purposes. This application accounted for 83% of its entire output. Demand for clays in pet waste absorbents increased. The use of fuller's earth in floor or oil and grease absorbents, chiefly to absorb hazardous oily substances, accounted for 17% of the absorbent demand.

Drilling Mud.—Demand for clays in rotary-drilling muds decreased to about

TABLE 24

COMMON CLAY AND SHALE USED IN LIGHTWEIGHT AGGREGATE PRODUCTION IN THE UNITED STATES, BY STATE

State	Metric tons					Total value
	Concrete block	Structural concrete	Highway surfacing	Other	Total	
1989						
Alabama and Arkansas	487,191	85,411	11,301	10,705	594,608	$4,679,265
California	67,813	42,698	—	—	110,511	913,596
Florida and Indiana	213,345	26,082	—	—	239,427	1,539,773
Kansas, Kentucky, and Louisiana	218,632	92,533	10,886	53,506	375,557	7,222,558
Mississippi	49,137	5,830	8,330	111,018	174,315	1,483,883
New York	215,239	140,527	—	—	355,766	2,489,218
North Carolina	230,000	80,000	—	—	310,000	3,200,000
Ohio, Oklahoma, and Pennsylvania	240,244	14,000	2,386	—	256,630	727,340
Texas	98,791	236,232	288,240	—	623,263	2,595,150
Utah and Virginia	246,088	49,739	5,738	40,020	341,585	3,493,119
Total	2,066,480	773,052	326,881	215,249	3,381,662	28,343,902
1990						
Alabama and Arkansas	707,627	85,121	11,336	—	804,084	9,732,809
California	78,131	98,727	—	—	176,858	656,295
Florida and Indiana	254,153	29,484	—	—	283,637	1,752,382
Kansas, Kentucky, and Louisiana	245,984	228,661	14,646	67,303	556,594	1,579,347
Mississippi and Missouri	127,793	10,777	15,397	118,606	272,573	1,569,533
New York and Montana	259,283	40,823	—	—	300,106	1,876,954
North Carolina	244,940	81,647	—	—	326,587	3,319,616
Ohio, Oklahoma, and Pennsylvania	246,209	37,145	1,102	—	284,456	1,826,995
Texas	65,596	156,943	222,260	30,844	472,643	2,284,427
Utah and Virginia	296,791	16,756	3,120	10,126	326,793	1,635,545
Total	2,523,507	786,084	267,861	226,879	3,804,331	26,233,903

747,000 tons and accounted for 2% of total clay production. Oil- and gas-well-drilling activity increased at the end of the year because of firmer oil prices brought about by Middle Eastern difficulties. Swelling-type bentonite remained the principal clay used in drilling mud mixes, although fuller's earth, used mostly in saltwater drilling techniques, and non-swelling sodium-activated bentonites were also used to a limited extent. Bentonite and fuller's earth accounted for 100% of the total amount of clay used in this category.

Floor and Wall Tile.—Common clay and shale, ball clay, and kaolin, in order of volume, were used in manufacturing floor, wall, and quarry tile. This end-use category accounted for 2% of the total clay production.

Pelletizing Iron Ore.—Bentonite continued to be used as a binder in forming indurated iron ore pellets. Demand increased 32% to 732,000 tons.

Ceramics and Glass.—Total demand for clay in the manufacture of pottery, sanitaryware, china and dinnerware, and related products (excluding clay flower pots) accounted for 1% of the total clay output. This demand, principally ball and kaolin clays, increased 3% to 1.41 million tons. The downturn in new residential housing construction, large consumers of whiteware and sanitaryware, was partially offset by the strong demand for these products in the remodeling areas.

World Review

Capacity.—The data in tables 27, 28, 29, 30, and 31 are rated capacity for mines as of December 31, 1990. Rated capacity is defined as the maximum quantity of product that can be produced on a normally sustainable long-term operating rate based on physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Mine capacity for domestic clay production was aggregated from data voluntarily supplied by producers. The rated capacity data for the foreign mines were estimated from previous years' production in cooperation with the Division of International Minerals.

Algeria.—A 50,000-ton-per-year kaolin processing plant will be constructed at El Milia by the State Organization for Non-Ferrous Minerals and Useful Substances. Approximately one-half of the production will be used in sanitaryware, one-fourth in tableware, and one-fourth in paper.[30]

Australia.—Commercial Minerals Ltd.

TABLE 25

SHIPMENTS OF REFRACTORIES IN THE UNITED STATES, BY PRODUCT

Product	Unit of quantity	1989		1990	
		Quantity	Value (thousands)	Quantity	Value (thousands)
CLAY REFRACTORIES					
Superduty fire clay brick and shapes	1,000 9-inch equivalent	52,365	48,608	58,773	48,510
Other fire clay, including semisilica brick and shapes, glasshouse pots, tank blocks, feeder parts, upper structure parts used only for glass tanks	do.	104,867	184,488	103,855	175,975
High-alumina (50% to 60% Al_2O_3) brick and shapes made of calcined diaspore or bauxite	do.	39,558	45,734	38,512	50,307
Insulating firebrick and shapes	short tons	W	W	W	W
Ladle brick					
Sleeves, nozzles, runner brick, tuyeres					
Hot-top refractories					
Kiln furniture, radiant heater elements, potter's supplies, other miscellaneous-shaped refractory items	do.	W	W	W	W
Refractory bonding mortars	do.	80,978	42,287	80,332	72,830
Plastic refractories and ramming mixes, containing up to 87.5% Al_2O_3	do.	221,568	86,896	228,301	92,939
Castable mixes	do.	276,689	119,566	302,069	131,444
Gunning mixes	do.	182,149	46,117	171,836	49,168
Other clay refractory materials sold in lump or ground form	do.	584,635	75,220	660,114	98,153
Miscellaneous refractories	do.	XX	37,879	XX	39,431
Total clay refractories	do.	XX	813,739	XX	847,086
NONCLAY REFRACTORIES					
Silica brick and shapes	1,000 9-inch equivalent	23,472	22,339	25,293	24,112
Magnesite and magnesite-chrome brick and shapes	do.	112,712	138,724	103,028	141,797
Chrome and chrome-magnesite brick and shapes	do.	115,313	101,258	102,542	91,217
Shaped refractories containing natural graphite	short tons	28,852	57,576	24,091	46,162
Zircon and zirconia brick and shapes; other carbon refractories: Forsterite, pyrophyllite, dolomite-magnesite molten-cast, other brick and shapes	1,000 9-inch equivalent	W	176,138	W	184,709
Other mullite, kyanite, sillimanite, or andalusite brick and shapes	do.	4,770	34,396	3,550	32,776
Other extra-high (over 60% alumina) brick and fused bauxite, fused alumina, dense-sintered alumina shapes	do.	3,583	85,217	3,989	100,615
Silicon carbide brick, shapes, kiln furniture	do.	1,886	61,868	1,961	69,198
Refractory bonding mortar	short tons	W	12,147	W	11,278
Hydraulic-setting nonclay refractory castables	do.	33,223	28,428	30,403	32,790
Plastic refractories and ramming mixes	do.	133,005	96,393	134,091	99,202
Gunning mixes	do.	W	W	W	W
Dead-burned magnesia or magnesite	do.	450,358	104,186	451,189	106,474
Dead-burned dolomite	do.	226,541	12,171	186,265	11,080
Other nonclay refractory material sold in lump ground form	do.	260,973	71,481	284,323	104,755
Miscellaneous nonclay refractories	do.	XX	37,721	XX	40,167
Total nonclay refractories	do.	XX	1,136,293	XX	1,208,698
Grand total refractories	do.	XX	1,950,032	XX	20,557,784

W Withheld to avoid disclosing company proprietary data, value included in total. XX Not applicable.

Source: Bureau of Census Report Form MQ MA32C(89), Current Industrial Reports—Refractory.

TABLE 26

U.S. EXPORTS OF CLAYS IN 1990, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	Ball clay		Bentonite		Fire clay		Fuller's earth		Kaolin		Clays, n.e.c.[1]		Total[2]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Argentina	—	—	(3)	67	(3)	3	(3)	3	7	1,605	(3)	345	7	2,023
Australia	(3)	17	10	968	32	2,499	(3)	24	13	2,658	4	1,806	59	7,972
Belgium-Luxemburg	—	—	2	611	10	725	(3)	37	87	14,301	4	5,366	103	21,040
Brazil	(3)	(2)	14	1,485	—	—	(3)	35	2	1,656	1	1,829	17	5,026
Canada	—	—	164	8,900	15	2,178	7	736	694	65,404	111	19,408	991	96,626
Chile	(3)	(2)	2	390	—	—	(3)	22	36	5,067	1	330	39	5,830
Colombia	—	—	7	437	—	—	—	—	9	2,453	1	516	17	3,406
Ecuador	—	—	2	336	—	—	—	—	2	343	1	496	5	1,175
Finland	—	—	—	—	—	—	(3)	88	192	30,854	19	1,392	211	32,334
France	—	—	2	465	(3)	260	(3)	55	6	1,774	1	751	9	3,305
Germany, Federal Republic of	—	—	32	1,976	(3)	178	(3)	40	50	8,515	5	4,101	87	14,810
Hong Kong	(3)	26	1	391	(3)	12	(3)	5	4	930	1	126	6	1,490
Italy	—	—	4	1,289	2	240	(3)	171	212	26,271	2	686	220	28,657
Japan	(3)	208	210	17,079	45	4,067	(3)	38	778	132,396	16	4,835	1,049	158,623
Korea, Republic of	(3)	52	9	2,295	(3)	13	(3)	41	99	21,793	2	1,767	110	25,961
Mexico	59	2,026	4	455	41	2,828	2	179	109	13,316	9	1,488	224	20,292
Netherlands	(3)	39	15	1,243	52	4,697	20	1,352	210	29,089	9	2,566	306	38,986
Peru	—	—	1	119	—	—	—	—	1	203	1	136	3	458
Philippines	1	117	4	561	—	—	(3)	4	5	783	3	640	13	2,105
Saudi Arabia	—	—	24	597	(3)	73			(3)	97	(3)	250	24	1,017
Singapore	(3)	10	50	3,767	—	—	5	651	1	430	2	911	58	5,769
South Africa, Republic of	(3)	29	1	110	—	—	(3)	30	16	3,944	1	450	18	4,563
Spain	—	—	1	110	—	—	3	251	5	1,335	(3)	36	9	1,732
Sweden	—	—	(3)	40	—	—	—	—	65	15,067	11	1,913	76	17,020
Switzerland	—	—	—	—	(3)	2,279	—	—	(3)	9	1	169	32	2,457
Taiwan	(3)	3	45	3,530	8	664	(3)	20	100	18,807	5	1,517	158	24,541
Thailand	(3)	3	18	1,157	(3)	22	(3)	25	11	2,752	(3)	156	29	4,115
United Kingdom	—	—	27	3,872	3	262	1	260	26	6,152	9	6,752	66	17,298
Venezuela	(3)	5	9	613	(3)	33	—	—	19	2,283	5	1,777	33	4,711
Other	8	538	41	4,248	5	413	7	723	65	17,603	15	6,413	141	31,062
Total[2]	69	3,073	699	57,112	213	21,446	46	4,790	2,826	427,890	238	68,928	4,123	584,404

[1]Also includes chamotte or dinas earth, activated clays and earths, and artifically activated clays.
[2]Data may not add to totals shown because of independent rounding.
[3]Less than 1/2 unit.

Source: U.S. Department of Commerce.

acquired Australian China Clays Ltd. The purchase enables Commercial Minerals to offer a full range of dry processed and wet refined kaolin and ball clays.[31]

Brazil.—Companhia Vale do Rio Roce and Caulim da Amazonia (Cadam) announced plans to mine kaolin in eastern Para. The deposits have an estimated reserve of 300 to 400 million tons.[32]

Chile.—Minera Pacifico provided all of the kaolin for the paper industry. The kaolin produced is suitable only as a filler. Ball clay and kaolin for the ceramics industry is provided by Ceramicas Cordillera SA (Eternit Group). The clay is produced near Pichilemu.[33]

China.—A large kaolin deposit was discovered in Shaanix Province. Reserves are estimated at 360 million tons.[34] A large bentonite deposit was discovered in Xianjiang. The deposit has reserves of 1.2 billion tons.[35]

Denmark.—Denmark is the only producer of moler, which is a mixture of diatomite and plastic clay. The clay acts as a binder, while the diatomite acts as an insulator. Moler is used to make insulating bricks. In powder and granular form, some of its uses are in animal feed, for filtration, as a chemical carrier, for acid treatment, as an insulating board, as a pet litter, and in fertilizers. Denmark also produces kaolin for the tile industry.[36]

Iraq.—The Ina-Petrokemija enterprise of Yugoslavia will develop a bentonite deposit and build a 50,000-ton-per-year processing plant in Iraq.[37]

Japan.—Hojun Kogyo built a new bentonite processing plant in Chiba pre-

TABLE 27

U.S. IMPORTS FOR CONSUMPTION OF CLAYS IN 1990, BY KIND

Kind	Quantity (metric tons)	Value (thousands)
China clay or kaolin:		
China	233	$166
Brazil	1	2
Canada	38	19
France	80	24
Germany, Federal Republic of	45	31
Ireland	3	4
Japan	15	24
Mexico	25	9
Netherlands	18	9
New Zealand	36	20
United Kingdom	2,573	1,052
Total	3,067	1,360
Fire clay:		
Canada	168	34
Germany, Federal Republic of	10	11
Total	178	45
Decolorizing earths and fuller's earth:		
Canada	45	9
Germany, Federal Republic of	24	10
Total	69	19
Bentonite:		
Canada	1,165	570
Germany, Federal Republic of	160	519
Japan	153	276
Mexico	417	50
United Kingdom	150	120
Total	2,045	1,535
Common blue clay and other ball clay:		
Taiwan	11	40
United Kingdom	1,406	359
Total	1,417	399
Other clay:		
Austria	9	11
Canada	1,095	941
El Salvador	57	71
France	105	48
Germany, Federal Republic of	6	26
Japan	1	2
Portugal	17	30
Thailand	6,973	1,314
Singapore	16	26
United Kingdom	8,279	2,469
Total		
Chamotte or dina's earth:		
France	4	4
Germany, Federal Republic of	80	22
Japan	12	7
Total	96	33
Artificially activated clay and activated earth:		
Canada	336	134
Denmark	31	10

See footnotes at end of table.

fecture. The plant, which has a capacity of 5,000 tons per month, will process high-grade sodium bentonite from Wyoming for foundry and soil sealing and other civil engineering applications.[38]

Malaysia.—The ball clay, common clay, and kaolin industries were reviewed. The country produces medium-grade ball clay and common clay for manufacturing pipe, tile, brick, sanitaryware, etc. Malaysia produces kaolin for the ceramics, paint, rubber, and fertilizer industries. The outlook for these industries is good because of anticipated expansion of the Malaysian ceramics industry and increased exports of ore and finished products.[39]

New Zealand.—A report covered the halloysite, common clay, and bentonite industries. Halloysite is produced from two mines on the North Island. The deposit is approximately 50% halloysite and 50% silica. A 142-hectare deposit currently is being investigated. Halloysite is used primarily in porcelain.[40]

Philippines.—A clay deposit that is suitable for whiteware production was discovered. The deposit is in an altered gabbroic rock. Further exploration will be undertaken to determine if the deposit has sufficient reserves to be mined economically.[41]

South Africa, Republic of.—A new deposit of kaolin was discovered at Klipheuwel. Preliminary study indicates that the deposit may contain up to 40 million tons of kaolin.[42]

United Kingdom.—ECC Group announced plans to reduce its work force and focus on its kaolin, ball clay, calcium carbonate, and aggregates industries. The company will phase out its activities in other industries. The reduction in work force is not expected to affect production capacity.[43]

Current Research

A paper reviewed the use of superconducting separators for processing kaolin. The report covered applications, superconductivity, magnet design, power requirements, cycling, and reliability.[44]

A report reviewed the acid-activated bleaching industry. The report covered the activating process, worldwide pro-

TABLE 27—Continued

IMPORTS FOR CONSUMPTION OF CLAYS IN 1990, BY KIND

Kind	Quantity (metric tons)	Value (thousands)
Artificially activated clay and activated earth—Continued		
Germany, Federal Republic of	605	1,245
Italy	14	18
Japan	1	10
Mexico	13,390	4,562
Netherlands	—	4
Spain	4	13
Thailand	6	10
United Kingdom	69	140
Venezuela	39	10
Total[1]	14,497	6,161
Grand total[1]	29,550	11,988

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

Source: U.S. Department of Commerce.

ducers of activated clays, the refining processes (chemical process, physical process, and hydrogenation), and desirable properties of bleaching clays.[45]

The sorption of hydrophobic organic compounds (HOC's) onto humic-coated minerals may affect the concentration of HOC's in low-carbon aquifer materials. A study investigated how humic and fulvic acid affected the sorption of HOC's on kaolin. The sorption of HOC on kaolin was greater for kaolin treated with humic acid than with untreated kaolin or kaolin treated with fulvic acid. The sorption of HOC's was different for kaolin and hematite.[46]

Treated bentonite may increase the sorption of nonionic organic contaminants when used as a liner at waste-disposal facilities. The sorption of tetrachloromethane by Wyoming bentonite treated with 10 ammonium compounds was tested. Bentonite treated with tetramethyl-, tetraethyl-, benzyltrimethyl-, and benzyltriethylammonium exhibited the greatest sorption.[47]

Montmorillonite treated with alkylammonium compounds may be suitable for sampling organic vapors from the air. The tetramethylammonium montmorillonite exhibited better characteristics than the other treated montmorillonite samples and some other adsorbents. It exhibited favorable breakthrough and sampling volumes. The recovery and desorption efficiencies were comparable to those of a reference adsorbent.[48]

TABLE 28

CLAYS: U.S. ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990, BY KIND AND TYPE

(Thousand metric tons)

Kind and type	Rated capacity[1]
Ball clay:	
Air-float	635
Waterslurried	115
Unprocessed	300
Total	1,050
Bentonite:	
Nonswelling	555
Swelling	2,000
Total	2,555
Common clay and shale	38,000
Fire clay	1,100
Fuller's earth:	
Attapulgite	700
Montmorillonite	2,250
Total	2,950
Kaolin:	
Air-float	1,500
Calcined[2]	555
Calcined[3]	700
Delaminated	1,100
Unprocessed	1,000
Waterwashed	4,100
Total	8,955
Grand total	54,610

[1]Includes capacity at operating plants and at plants on standby basis.

[2]Low-temperature, filter.

[3]High-temperature, refractory.

TABLE 29

KAOLIN: WORLD ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990, RATED CAPACITY[1]

(Thousand metric tons)

Country	Capacity
Argentina	140
Australia	230
Austria	110
Bangladesh	14
Belgium	73
Brazil	820
Bulgaria	300
Burundi	e6
Chile	54
Colombia	1,360
Costa Rica	1
Czechoslovakia	730
Denmark	14
Ecuador	3
Egypt	140
Ethiopia (including Eritrea)	e5
France	1,450
Germany, Federal Republic of:	
Eastern states	650
Western states	180
Greece	160
Guatemala	5
Hong Kong	9
Hungary	41
India	740
Indonesia	150
Iran	e120
Israel	32
Italy	90
Japan	230
Kenya	e1
Korea, Republic of	910
Madagascar	6
Malaysia	115
Mexico	270
Mozambique	e1
Nigeria	1
Pakistan	45
Paraguay	64
Peru	9
Poland	55
Portugal	110
Romania	450
South Africa, Republic of	200
Spain	500
Sri Lanka	11
Sweden	1

See footnotes at end of table.

TABLE 29—Continued

KAOLIN: WORLD ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990, RATED CAPACITY[1]

(Thousand metric tons)

Country	Capacity
Taiwan	90
Tanzania	e2
Thailand	275
Turkey	e250
U.S.S.R.	3,100
United Kingdom	3,700
United States	8,955
Venezuela	27
Vietnam	1
Yugoslavia	270
Zimbabwe	e1
Total	27,293

eEstimated.
[1]Includes capacity at operating plants as well as at plants on standby basis.

TABLE 30

FULLER'S EARTH: WORLD ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990, RATED CAPACITY[1]

(Metric tons)

Country	Capacity
Algeria	4,000
Argentina	2,300
Australia (attapulgite)	16,000
Italy	41,000
Mexico	55,000
Morocco (smectite)	55,000
Pakistan	23,000
Sendgal (attapulgite)	120,000
Spain (attapulgite)	70,000
United Kingdom	300,000
United States	2,950,000
Total	3,636,300

[1]Includes capacity at operating plants as well as at plants on standby basis.

A heat-storage facility consisting of a thick clay bed is being planned in the United States for the first time. The solar collectors for the system will cover 7 acres. About 85% of the stored heat will be recovered up to 7 months later.[49]

TABLE 31

BENTONITE: WORLD ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990, RATED CAPACITY[1]

(Metric tons)

Country	Capacity
Algeria	36,000
Argentina	150,000
Australia	41,000
Brazil	250,000
Burma	1,000
Cyprus	e80,000
Egypt	5,500
France	14,000
Greece	1,400,000
Guatemala	4,500
Hungary	91,000
Iran	e30,000
Israel	6,000
Italy	360,000
Japan	500,000
Kenya	e200
Mexico	275,000
Morocco	4,000
Mozambique	e1,500
New Zealand	4,500
Pakistan	45,000
Peru	27,000
Philippines	27,000
Poland	77,000
Romania	190,000
South Africa, Republic of	75,000
Spain	140,000
Tanzania	e100
Turkey	e100,000
U.S.S.R.	3,000,000
United States	2,555,000
Zimbabwe	e120,000
Total	9,610,300

eEstimated.
[1]Includes capacity at operating plants as well as at plants on standby basis.

OUTLOOK

U.S. clay demand between 1980 and 1990 has rebounded slowly from the recessionary years of 1981-82 to 43 millon tons. Despite the rebound, production still is well below the levels of the early 1970's. In general, there has been a decrease in construction activity in the public, private, and commercial sectors. Higher mortgage rates in the late 1970's and early 1980's and the limited availability of affordable housing and funds for public and business ventures contributed to the problem. The slow economy of recent years continued to depress construction activities despite declining interest rates and increased availability of capital. Demand for common clay and shale, which are strongly tied to the construction industry, has declined over the past 10 years. Kaolin, ball clay, and fuller's earth have fared better than their common clay and shale counterparts because they are used in more diversified applications and industries. Domestic demand for specialty clays should remain strong in the near future.

The weakening U.S. dollar in the latter part of the decade encouraged specialty clays producers to expand their share of export markets. Exports of domestic clays, mostly kaolin, bentonite, ball clay, and fuller's earth, are restricted to the higher valued specially treated varieties for use in drilling muds, paper-coating, and iron ore pelletizing and by the foundry industry. Export markets should continue to remain strong in the near future. Imports of clays, except for English china and ball clays and acid-activated bentonites, are minor. The English clays enjoy a small prestige-dictated market, while the activated clays are confined to use in the Southern and Northern States.

[1]U.S. Bureau of Mines. Potential Sources of Aluminum. BuMines IC 8335, 1967, 148 pp.

[2]Hamlin, H. P., and G. Templin. Evaluating Raw Materials for Rotary-Kiln Production of Lightweight Aggregate. BuMines IC 8122, 1962, 23 pp.

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TABLE 32

KAOLIN: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

	1986	1987	1988	1989	1990
Algeria	14,200	16,000	17,800	r e18,000	18,000
Argentina	117,378	128,455	125,195	185,075	150,000
Australia[3]	185,617	176,958	159,067	e185,000	200,000
Austria (marketable)	46,291	92,186	89,491	157,258	155,000
Bangladesh[4]	2,695	12,272	10,097	7,092	7,000
Belgium[e]	40,000	45,000	40,000	35,000	35,000
Brazil (beneficiated plus direct sales and direct use)	r754,893	r802,586	940,518	r e990,000	975,000
Bulgaria	265,000	281,000	220,000	r e220,000	5186,467
Burundi	5,113	5,290	4,021	4,305	55,281

See footnotes at end of table.

TABLE 32—Continued

KAOLIN: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

	1986	1987	1988	1989	1990
Chile	42,170	44,533	54,464	58,512	532,416
Colombia	r346,580	r366,300	408,141	540,000	540,000
Czechoslovakia	546,101	697,000	685,958	698,000	5670,550
Denmark (sales)	10,404	9,304	39,324	16,029	517,423
Ecuador	e2,000	1,600	5,000	22,576	515,580
Egypt	127,784	125,256	124,122	121,515	549,032
Ethiopia (including Eritrea)[e 6]	90	2,500	750	400	400
France[e 7]	51,350,000	1,400,000	1,400,000	1,400,000	1,400,000
Germany, Federal Republic of:					
Eastern states (marketable)[e]	165,000	150,000	165,000	150,000	115,000
Western states (marketable)	512,000	588,000	673,000	777,000	780,000
Greece	141,210	144,634	r e150,000	67,234	100,000
Guatemala	2,017	1,880	3,459	2,573	52,050
Hong Kong	850	—	—	—	—
Hungary	29,837	33,289	29,572	24,824	18,000
India:					
Salable crude	r647,000	r602,000	471,000	464,000	450,000
Processed	100,647	93,720	107,381	110,505	100,000
Indonesia	132,240	122,046	147,109	157,122	5112,423
Iran[e]	70,000	70,000	70,000	80,000	80,000
Israel[e]	27,000	27,000	27,000	27,000	27,000
Italy:					
Crude	35,132	57,054	70,585	69,267	567,803
Kaolinitic earth	21,110	22,194	18,626	20,044	517,946
Japan	203,983	172,781	157,771	165,696	5165,532
Kenya	2,000	40	42	42	[5]—
Korea, Republic of	849,742	630,945	832,110	1,219,174	51,446,598
Madagascar	e6,000	1,427	365	1,315	5485
Malaysia	85,052	96,882	116,869	108,347	5152,972
Mexico	276,400	151,104	162,415	141,519	5151,967
Mozambique[e]	r230	r151	200	r200	[5]—
New Zealand	28,464	25,548	29,649	26,324	30,000
Nigeria[e]	250	250	250	5550	51,356
Pakistan	37,056	32,208	41,968	39,907	561,630
Paraguay	r55,000	72,000	76,000	74,000	74,000
Peru	6,328	626	8,849	r e7,000	6,000
Poland[e]	549,200	49,000	50,000	50,000	50,000
Portugal	54,841	66,763	71,200	58,297	573,849
Romania[e]	410,000	400,000	400,000	400,000	400,000
South Africa, Republic of	126,124	151,730	175,033	139,711	5132,421
Spain (marketable)[8]	375,082	433,077	438,160	e440,000	435,000
Sri Lanka	6,260	6,869	7,100	7,761	57,731
Sweden	60	100	92	e100	100
Taiwan	63,228	67,525	81,879	98,115	106,000
Tanzania	2,270	1,446	528	1,554	1,500
Thailand	7132,155	206,568	269,976	328,824	5347,690
Turkey	r91,893	r126,119	204,478	257,389	5230,000
U.S.S.R.[e]	2,000,000	2,000,000	2,000,000	2,000,000	1,800,000
United Kingdom	2,912,607	3,058,821	3,276,795	3,140,000	3,037,000
United States[9]	7,755,970	8,007,919	8,973,097	8,973,668	59,761,775

See footnotes at end of table.

TABLE 32—Continued

KAOLIN: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

	1986	1987	1988	1989	1990
Venezuela	15,000	r30,000	78,000	15,000	512,000
Vietnam[e]	1,000	1,000	r700	r750	750
Yugoslavia	204,311	218,851	218,673	218,000	210,000
Zimbabwe	901	780	95	15	[5]—
Total	r21,491,766	r22,128,587	23,928,974	24,521,589	25,023,727

[e]Estimated. [p]Preliminary. [r]Revised.
[1]Table includes data available through July 26, 1991.
[2]In addition to the countries listed, China, Lebanon, Morocco, and Suriname may also have produced kaolin, but information is inadequate to make reliable estimates of output levels.
[3]May include ball clay and other clays grouped for statistical purposes as kaolin.
[4]Data for year ending June 30 of that stated.
[5]Reported figure.
[6]Data for year ending July 6 of that stated.
[7]Includes kaolinitic clay.
[8]Includes crude and washed kaolin and refractory clays not further described.
[9]Kaolin sold or used by producers.

TABLE 33

BENTONITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Algeria[e 3]	[4]30,000	30,000	30,000	30,000	30,000
Argentina	146,191	108,595	173,930	[e]150,000	150,000
Australia[3]	39,933	30,392	35,671	[e]35,000	35,000
Brazil	r229,371	r216,591	110,893	146,550	175,000
Burma	r853	r297	418	711	700
Chile	—	—	529	2,005	[4]1,262
Cyprus	55,000	79,600	90,300	60,000	[4]82,000
Egypt	5,126	3,827	3,166	3,512	3,500
France[e]	10,000	8,000	8,000	8,000	10,000
Germany, Federal Republic of: Western states	179,000	167,000	197,000	200,000	220,000
Greece	1,317,825	1,300,525	730,501	587,000	800,000
Guatemala	3,836	r24,782	973	8,236	9,000
Hungary	79,888	98,331	66,014	59,973	36,600
Indonesia	5,730	7,962	8,266	3,863	[4]5,914
Iran[5]	52,000	52,500	37,000	31,500	35,000
Israel (metabentonite)[e]	6,000	6,000	6,000	6,000	6,000
Italy	299,638	313,094	301,434	220,000	205,000
Japan	478,254	468,705	455,137	526,131	[4]549,414
Kenya[e]	200	200	200	—	—
Mexico	136,500	129,596	163,916	123,927	[4]143,922
Morocco	3,834	2,948	3,445	3,970	3,900
Mozambique	1,112	936	986	126	190
New Zealand (processed)	3,140	—	1,255	1,342	1,500
Pakistan	r1,282	2,537	4,880	5,466	[4]3,235
Peru	33,080	16,194	50,741	[e]20,000	30,000
Philippines	1,800	759	2,030	2,782	[4]16,484
Poland[e]	75,000	75,000	80,000	80,000	80,000
Romania[e]	185,000	180,000	180,000	180,000	175,000
South Africa, Republic of	48,265	48,953	66,750	62,987	[4]66,059

See footnotes at end of table.

TABLE 33—Continued

BENTONITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Spain	114,972	103,420	103,753	[e]100,000	104,000
Tanzania[e]	75	75	75	75	75
Turkey	[r]62,367	[r]89,262	80,218	90,336	100,000
U.S.S.R.[e]	2,900,000	2,900,000	2,900,000	2,900,000	2,700,000
United States	2,551,950	2,545,775	2,870,971	3,112,365	[4]3,473,595
Yugoslavia	148,447	154,288	125,069	[r e]120,000	120,000
Zimbabwe[6]	71,987	116,802	113,157	104,865	[4]99,854
Total	[r]9,277,656	[r]9,282,946	9,002,678	8,986,722	9,472,204

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through July 26, 1991.

[2]In addition to the countries listed, Canada, China, and the U.S.S.R. 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]Year beginning Mar. 21 of that stated.

[6]May include other clays.

TABLE 34

FULLER'S EARTH: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Algeria[e]	3,500	3,500	3,500	3,500	3,500
Argentina[e]	2,000	2,000	2,000	2,000	2,000
Australia (attapulgite)	47,376	10,960	[e]15,000	[e]15,000	20,000
Germany, Federal Republic of: Western states (unprocessed)	680,000	677,000	670,000	665,000	655,000
Italy	30,960	40,150	38,955	43,550	45,000
Mexico	52,200	49,112	37,226	24,603	324,000
Morocco (smectite)	35,100	46,271	52,694	48,820	345,230
Pakistan	15,228	[r]17,945	12,395	15,436	316,489
Senegal (attapulgite)	81,857	111,048	118,725	98,882	100,000
South Africa, Republic of (attapulgite)	10,125	6,026	7,161	6,609	37,628
Spain (attapulgite)	67,820	40,818	43,585	[e]45,000	40,000
United Kingdom[e]	202,000	213,000	210,000	210,000	205,000
United States[4]	1,732,703	1,865,890	1,792,232	1,881,511	2,307,476
Total	2,960,869	[r]3,083,720	3,003,473	3,059,911	4,401,323

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Excludes centrally planned economy countries, some of which presumably produce fuller's earth, but for which no information is available. Table includes data available through July 26, 1991.

[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, a physical scientist with more than 11 years of U.S. Bureau of Mines experience, has been the commodity specialist for cobalt since 1988. Domestic survey data were prepared by Jo-Ann S. Sterling, supervisory mineral data assistant, and trade data were prepared by Barbara J. McNair, mineral data assistant, Section of Ferrous Data. International production tables were prepared by William Zajac, Chief, Section of International Data.

Cobalt is a strategic and critical metal used in many diverse industrial and military applications. The largest use of cobalt is in superalloys, which are alloys designed to resist stress and corrosion at high temperatures. The main use for superalloys is in jet engine parts. Another important use of cobalt is to make permanent magnets, which are used in a wide range of electrical devices. Cobalt acts as a binder in cemented carbides and diamond tools, which are used for metal cutting and forming, mining, and oil and gas drilling. Cobalt chemicals have diverse uses, including catalysts for the petroleum and chemical industries; drying agents for paints, varnishes, and inks; additives to ground coats for porcelain enamels; and pigments for ceramics, paints, and plastics.

The United States is the world's largest consumer of cobalt, but has no domestic production, so it relies on imports to meet its primary cobalt needs. The United States stocks significant quantities of cobalt metal in the National Defense Stockpile (NDS) for military, industrial, and essential civilian use during a national emergency.

U.S. cobalt demand remained strong in 1990. For the third year in a row, Western World cobalt demand exceeded Western World production, resulting in a further reduction in producers' stocks. Concerns over adequate supply caused market prices to rise significantly in 1990, ending a period of market stability that began in late 1986. This increase was followed by a 31% increase in the producer price late in the year.

DOMESTIC DATA COVERAGE

Domestic data on cobalt processing and consumption are developed by the U.S. Bureau of Mines from three separate, voluntary surveys of U.S. operations. In the cobalt processors survey, seven of the eight companies canvassed responded. Most of the data on cobalt used in chemicals were obtained from this survey. The second survey covers a broad range of metal-consuming companies, such as superalloy producers, magnetic alloy producers, and tungsten carbide producers. The U.S. Bureau of Mines also surveys superalloy scrap recyclers to determine the consumption of secondary cobalt in superalloy producers. The data in tables 3 through 6 contain estimates to account for nonrespondents.

BACKGROUND

Definitions, Grades, and Specifications

Cobalt is a metallic element. It is silvery gray in color, hard, ductile, somewhat malleable, and magnetic. Other properties include atomic number, 27; atomic weight, 58.93; melting point, 1,493° C; boiling point, 3,100° C; and Curie temperature, 1,121° C. Cobalt-60 (^{60}Co) is produced by irradiating cobalt metal in a nuclear reactor. This radioactive isotope is used in radiation therapy and sterilization of medical supplies.

Currently there are no internationally recognized specifications for cobalt metal. The two leading Western World producers, 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

More than one-half of the cobalt used in the United States is consumed as primary cobalt metal. This is either in the form of electrolytic cobalt (cathode or rounds), granules (shot), or metal powder. Secondary cobalt is cobalt recovered from scrap. Purchased scrap constitutes about 16% of U.S. consumption. The remainder of the cobalt used, about 30% is in the form of cobalt chemical compounds. This includes cobalt oxide, which can be either gray oxide, with 75% to 78% cobalt content, or black oxide, with 70% to 74% cobalt content. The percent cobalt content in the oxides depends on the relative amounts of cobalt(II)oxide and cobalt(II)dicobalt(III)tetroxide present. Commercially available inorganic cobalt compounds include carbonate, chloride, hydroxide, nitrate, and sulfate (either as heptohydrate or monohydrate). Most of the inorganic compounds are sold in crystalline form, but some are also available in solution. A variety of organic cobalt compounds are also available.

Industry Structure

Cobalt mine and refinery production are limited to a few countries. The United States is not currently a cobalt producer. U.S. mine production of cobalt ceased at the end of 1971, and the sole U.S. cobalt refinery discontinued processing imported nickel-cobalt matte in late 1985. In 1990,

Zaire was the world's leading producer of refined cobalt, followed by Zambia, the U.S.S.R., Canada, Norway, and Finland. These six countries represented 95% of world cobalt refinery production. Zairian and Zambian production was from domestic ores. Canada and the U.S.S.R. produced cobalt from both domestic and imported raw materials. All of the cobalt produced in Norway and most of the cobalt produced in Finland was from imported raw materials. World producers of refined cobalt and producers of intermediate cobalt-containing products are listed in tables 1 and 2.

Cobalt processors represent an important source of supply for various industries. Processors differ from producers primarily in the feed materials they use. Cobalt producers refine cobalt from ores, concentrates, mattes, or residues originating from mining or refining operations. Some refiners also use scrap as a feed material. Producer products include cobalt cathode, granules, metal powder, oxide, and salts. In contrast, cobalt processors begin with refined cobalt metal or cobalt-containing scrap and make metal powder, oxide, and/or salts, but not cathode or granules. The world's largest cobalt processor is Metallurgie Hoboken-Overpelt S.A. (MHO) in Belgium. Other cobalt processors are in Europe and the United States (see Production section of this report).

TABLE 1

WORLD PRODUCERS OF REFINED COBALT[1]

Country	Company	Cobalt products
Albania	Government-owned	Oxide.
Brazil	Companhia Niquel Tocantins	Cathode.
Canada	Inco Ltd.	Cathode, oxide.
Do.	Sherritt Gordon Ltd.	Metal powder.
China	Government-owned	NA.
Finland	Outokumpu Oy	Metal powder, oxide, salts.
France	Eramet-SLN	Chloride.
Japan	Sumitomo Metal Mining Co. Ltd.	Cathode, oxide, salts.
Norway	Falconbridge Ltd.	Cathode.
South Africa, Republic of	Impala Platinum Ltd.	Metal powder.
Do.	Rustenberg Base Metal Refiners Pty. Ltd.	Sulfate.
U.S.S.R.	Government-owned	NA.
Zaire	La Générale des Carrières et des Mines.	Cathode, granules.
Zambia	Zambia Consolidated Copper Mines Ltd.	Cathode.

NA Not available.
[1]Companies with production during 1990.

TABLE 2

WORLD PRODUCERS OF INTERMEDIATE COBALT PRODUCTS[1]

Country	Company	Cobalt-containing products
Australia	Queensland Nickel Pty. Ltd.	Cobalt sulfide.
Do.	Western Mining Corp.	Nickel-cobalt sulfide.
Do.	Pacific Smelting and Mining Co. Ltd.	Impure cobalt oxide.
Botswana	BCL Ltd.	Nickel-copper matte.
Cuba	Union de Empresas del Niquel	Nickel-cobalt oxide,[2] nickel-cobalt sulfide.
Morocco	Compagnie de Tifnout Tiranimine	Cobalt concentrate.
New Caledonia	Société Metallurgique le Nickel	Nickel matte.
South Africa, Republic of	Western Platinum Ltd.	Nickel sulfate.
Zimbabwe	Bindura Nickel Corp. Ltd.	Cobalt-nickel hydroxide.
Do.	Rio Tinto (Zimbabwe) Ltd.	Do.

[1]Companies with production during 1990; excludes companies producing refined cobalt.
[2]Cobalt may not be recovered.

Byproducts and Coproducts

Cobalt is rarely produced as a primary product from a mining operation. Most of Western World cobalt supply is produced as a byproduct of copper production in Zaire and Zambia. With the exceptions of Morocco, where small amounts of cobalt are produced as a primary product, and the Republic of South Africa, where cobalt is produced as a byproduct of platinum mining and refining, cobalt production in most other countries is a byproduct of nickel production.

Economic Factors[2]

Most of cobalt's production costs are attributed to the primary metal produced at a given operation. The incremental costs applied to cobalt production include costs to separate cobalt from the primary metal, usually during the refining stage; transportation costs; and marketing costs. The U.S. Bureau of Mines Minerals Availability Program estimated 1989 direct operating costs for cobalt refining in market economy countries to range from less than $1.00 per pound for cobalt cathode production at Falconbridge Ltd.'s Kristiansand, Norway, refinery to about $3.00 per pound for production of cobalt powders at Sherritt Gordon Ltd.'s refinery in Alberta, Canada. Cobalt refining costs in Zaire and Zambia are estimated to average about $2.50 per pound. However, additional capital improvements, transportation, and marketing expenses in these two countries may increase total costs to about $4.00 per pound. Most of the nonproducing properties evaluated in the study would require a total cost per pound, including a 15% discounted cash-flow rate of return, in excess of January 1989 market prices for the primary commodity (copper, nickel, or cobalt).

Operating Factors

Environmental Requirements.—The Environmental Protection Agency (EPA) regulates releases of cobalt into the environment under various programs. The Occupational Safety and Health Admin-

istration (OSHA) regulates workplace exposures by setting permissible exposure limits for cobalt metal, dust, and fume; cobalt carbonyl; and cobalt hydrocarbonyl.

Toxicity.—The International Agency for Research on Cancer (IARC) adopted a classification for cobalt and its compounds at a meeting in Lyon, France, during the week of July 12-19, 1990. The IARC classifies materials into one of four groups: group 1, sufficient evidence of carcinogenicity in humans; group 2A, probably carcinogenic to humans; group 2B, possibly carcinogenic to humans; and group 3, not classifiable as to carcinogenicity to humans. The IARC classified cobalt as group 2B, possibly carcinogenic to humans.[3]

TABLE 3

SALIENT COBALT STATISTICS

(Metric tons cobalt content unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Consumption:					
Reported	6,483	6,645	r7,286	r7,152	7,472
Apparent	7,649	7,986	7,824	7,164	7,885
Imports for consumption	5,574	8,832	7,051	5,793	6,529
Stocks, December 31[1]	1,355	2,043	1,766	1,439	1,851
Price: Metal, per pound[2]	$7.49	$6.56	$7.09	$7.64	$10.09
World: Production					
Mine	50,199	40,902	r43,639	p43,030	e37,136
Refinery	31,399	27,956	r26,700	p25,516	e25,775

eEstimated. pPreliminary. rRevised.

[1]Stocks held by consumers and chemical processors.

[2]Market price based on weighted average of Metals Week prices.

ANNUAL REVIEW

Legislation and Government Programs

The NDS cobalt inventory did not change significantly during 1990. The only stockpile activity was the fulfillment of the cobalt upgrading contract awarded to Sherritt Gordon Ltd. the previous year. Under the contract, the Defense Logistics Agency (DLA) shipped 148 metric tons, contained cobalt, of cobalt metal from the stockpile to Sherritt in Canada. In return, Sherritt supplied 186 metric tons, gross weight, of cobalt cathode from Falconbridge's Kristiansand refinery in Norway. Sherritt provided cobalt from Falconbridge because the DLA contract required cobalt cathode, which Sherritt does not produce. The DLA reported a yearend cobalt inventory of 23,940 metric tons, contained cobalt. This inventory did not include the cobalt received from Sherritt, which was on hand but awaiting a final accounting transfer. The NDS goal of 38,737 metric tons cobalt metal remained in effect during 1990. No actions were taken during the year to increase the inventory level to meet the goal.

The General Accounting Office (GAO) reviewed DLA's 1989 contract with Sherritt in response to a protest from The Hall Chemical Co.[4] The GAO determined that the contract had been properly awarded to Sherritt. While Sherritt was the highest bidder, it was also the only company to offer cobalt from a designated country, as required by the Trade Agreements Act.

In August, the Minerals Management Service and the State of Hawaii completed a final Environmental Impact Statement (EIS) for the possible future development of cobalt-rich manganese crusts in the Exclusive Economic Zone (EEZ). The EIS evaluated 26,910 square kilometers of EEZ lands adjacent to Hawaii and Johnston Island for a proposed lease sale and gave the following preliminary estimates of potential metal resources: 2.6 million metric tons of cobalt, 1.6 million metric tons of nickel, and 81 million metric tons of manganese. The pollution risks of exploration and development of the areas were addressed in the EIS, and several alternatives to the proposed lease were presented. No date was set for the lease sale.

On November 15, Congress amended the Clean Air Act (Public Law 101-549), completely revising the act's hazardous air pollutants program. As part of the new program, Congress established a list of hazardous air pollutants to be regulated. Cobalt compounds—defined as any unique chemical substances that contain cobalt as part of their infrastructure (composition)—were included on the list. Congress instructed EPA to establish emission standards for sources that emit hazardous air pollutants, rather than for the pollutants themselves. Congress required EPA to develop a list of source categories by November 15, 1991. The act included a provision for EPA to review petitions to delete specific chemicals or pollution sources from the lists.[5]

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 1990, the United States consumed 31% of estimated world refinery production. There was no domestic production, so demand was met primarily from imports, with the exception of about 16% 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. Upgrading of stockpile cobalt began in 1990. (See the Legislation and Government Programs section of this report.)

World cobalt production is concentrated in a limited number of geographic areas. More than one-half of the world's supply of refined cobalt comes from cen-

tral Africa, primarily Zaire and Zambia. Since 1987, all of the cobalt produced in Zaire has been transported through the Republic of South Africa. Cobalt produced in Zambia was formerly transported through the Republic of South Africa, but has been exported through Dar es Salaam, Tanzania, in recent years. Therefore, while the Republic of South Africa is not a major cobalt producer, its potential influence on supply is great because of the large amounts of cobalt exported using its transportation system. As part of the Comprehensive Anti-Apartheid Act of 1986 (Public Law 99-440), the United States prohibits imports of products "produced, manufactured by, marketed, or otherwise exported by a parastatal organization of South Africa." Because of our high reliance on cobalt imports from southern Africa, the U.S. State Department has certified cobalt as a strategic mineral so that it is exempt from this prohibition.[6]

An overview of the issues related to U.S. supplies of strategic minerals was published in 1990.[7] Many interesting points were addressed regarding the U.S. dependence on foreign supplies; ways to reduce disruptions in strategic mineral supplies; and the quality, quantities, and management of materials in the NDS. Articles by individuals from private industry and the Government were included in the text.

Production

There was no domestic mine or refinery production of cobalt in 1990. Plans by Blackbird Metals Inc. to initiate U.S. cobalt production were delayed. Delays in obtaining financing resulted from the economic slowdown. A second complicating factor was an ongoing environmental lawsuit by the State of Idaho against Noranda Mining Inc. and the M. A. Hanna Co., current owners of the Blackbird cobalt mine in Lemhi County, ID.

Black Hawk Mining Inc., of Toronto, Canada, bought China First Capital Corp., owner of a nickel-copper deposit near Warren, ME. The deposit, formerly known as the Union or Crawford Pond deposit, was renamed the Knox deposit. During 1990, Black Hawk spent $400,000 on core drilling and metallurgical testing. The company estimates reserves at 3 million metric tons ore grading 1.47% nickel, 0.66% copper, and 0.1% cobalt.[8] Annual production was anticipated to be 3,600 to 4,000 metric tons (8 million to 9 million pounds) nickel, 2,500 metric tons (5.5 million pounds) copper, and 400 metric tons (900,000 pounds) cobalt. Late in the year, Black Hawk began a feasibility study on mine and mill design and cost estimates. At yearend, the company was awaiting new State of Maine mining regulations before proceeding.

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 plant in Braithwaite, LA, and at Gulf Chemical and Metallurgical Corp. in Freeport, TX.

Two cobalt processors produced extra-fine cobalt metal powder in the United States. Carolmet, owned by MHO of Belgium, produced extra-fine powder from imported primary metal at its Laurinburg, NC, plant. GTE Products Corp. produced extra-fine powder from recycled materials in Towanda, PA. Production and shipments of extra-fine cobalt metal powder are withheld to avoid disclosing company proprietary data.

Domestic chemical processors produced 2,123 metric tons of cobalt oxide, cobalt hydroxide, inorganic cobalt compounds, and organic cobalt compounds in 1990. 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 1990, domestic chemical processors shipped 1,963 metric tons of cobalt oxide, cobalt hydroxide, inorganic cobalt compounds, and organic cobalt compounds. Production and shipments in 1990 are not comparable with those published for prior years because of a correction in survey response that began in 1990.

Consumption and Uses

Apparent consumption, as calculated from net imports, consumption from purchased scrap, and changes in Government and industry stocks, was 7,885 metric tons. Total U.S. reported consumption of cobalt increased 4% in 1990 compared with that of 1989. Consumption of cobalt in superalloys, the largest

TABLE 4

U.S. REPORTED CONSUMPTION OF COBALT,[1] BY END USE

(Metric tons cobalt content)

End use	1988	1989	1990
Steel:			
Full-alloy	W	W	W
High-strength, low-alloy	W	—	—
Stainless and heat-resisting	26	74	41
Tool	180	219	123
Superalloys	r2,926	r2,898	3,391
Alloys (excludes alloy steels and superalloys):			
Cutting and wear-resistant materials[2]	704	654	677
Magnetic alloys	869	861	700
Nonferrous alloys	W	27	31
Welding materials (structural and hard-facing)	W	W	29
Other alloys	25	17	27
Mill products made from metal powder	W	W	W
Drier in paint or related usage	892	718	[3]751
Miscellaneous and unspecified[4]	1,664	1,684	1,702
Total[5]	r7,286	r7,152	7,472

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

[1]Includes estimates.

[2]Includes wear-resistant alloys, diamond bit matrices, cemented and sintered carbides, and cast carbide dies or parts.

[3]Data not comparable with those prior to 1990 because of a change in reporting method.

[4]Includes catalysts, feed or nutritive additive, glass decolorizer, ground coat frit, pigments, and data indictated by symbol "W."

[5]Data may not add to total shown because of independent rounding.

TABLE 5

U.S. REPORTED CONSUMPTION OF COBALT,[1] BY FORM

(Metric tons cobalt content)

	1986	1987	1988	1989	1990
Chemical compounds (organic and inorganic)[2]	r1,778	r1,802	r2,020	r2,067	2,177
Metal	r3,507	r3,819	r4,247	r3,901	4,070
Purchased scrap	1,196	1,025	1,018	1,184	1,225
Total[3]	6,483	6,645	r7,286	r7,152	7,472

rRevised.
[1]Includes estimates.
[2]Includes oxides.
[3]Data may not add to total shown because of independent rounding.

cobalt-consuming industry, increased significantly in 1990. Consumption of cobalt in paint driers and in cutting and wear-resistant materials also increased. In contrast, cobalt use in tool steels and magnetic alloys decreased.

Stocks

Total yearend cobalt stocks held by U.S. chemical processors and consumers were higher than 1989 yearend stocks. The increase paralleled a gradual rise in cobalt metal inventories during 1990. Yearend stocks of cobalt chemicals and cobalt-containing scrap were lower than 1989 yearend stocks (table 6).

Markets and Prices

The producer price of $8.40 per pound of electrolytic cobalt established in November 1988 was maintained during 1989 and 1990. On September 27, Gécamines and ZCCM, the Western World's two largest cobalt producers, announced a 31% increase in the producer price to $11.00 per pound, to be effective for 1 year beginning January 1, 1991.

The free market price for cobalt metal (also referred to as market, merchant, or spot price) increased significantly during the second half of 1990, ending a period of relative stability that began in late 1986. Market analysts suggested that much of the increase was trader-driven, with many of the transactions at the high prices between traders, as opposed to sales to consumers. The price increases were fueled by press reports emphasizing a decrease in availability of free market cobalt coupled with concerns over adequacy of supply and possible supply disruptions during a period of steady demand. Early in the year, reports focused on delayed shipments from African producers, the effect that planned cutbacks in nickel production by Canadian nickel-cobalt producers would have on cobalt output, and tightening of supplies on the free market. Market prices during this period gradually increased from $7.50 per pound in January to approach the producer price of $8.40 per pound in April. In July, the market price jumped above the producer price following reports of strikes in Zaire and political unrest in Zambia. Market prices increased steadily over the summer, approaching $13.00 per pound by late August. Following the announcement of the new producer price in late September, news of a cave-in at one of Gécamines' copper-cobalt mines caused the market price to jump again, exceeding $14.00 per pound. Between mid-October and early December, the market price decreased steadily to approximately $12.50 per pound. However, in December, prices increased again, and the year ended with a market price range of $15.25 to $15.75 per pound. The weighted average market price for the year was $10.09 per pound. Prices for cobalt-containing materials are presented in tables 3 and 7.

A significant change in the world cobalt market was noted.[9] During 1990, Western World cobalt sales to Eastern Europe and the U.S.S.R. decreased as a result of reduced consumption during economic and political restructuring in those countries. A 50% decrease in exports to Eastern Europe and the U.S.S.R. was reported. In addition to reducing their consumption of imported cobalt, the Soviets also exported cobalt ingot produced in the U.S.S.R.[10] to Europe, the Far East, and the United States (see table 9).

Foreign Trade

U.S. imports of unwrought cobalt and cobalt chemicals increased 13% to an estimated 6,529 metric tons, valued at $119 million. One-third of these imports was from Canada and Norway. Much of the cobalt produced in Norway was from Canadian ores. Fifty-nine percent of U.S. cobalt imports in 1990 was from ores originating in the south-central African countries of Zaire and Zambia. This includes cobalt imported from Belgium, where Zairian cobalt metal is processed into metal powder, oxides, and salts by MHO.

In 1990, the United States began importing minor amounts of cobalt metal from Brazil and the U.S.S.R. Brazil is a new cobalt producer. Its production of cobalt metal began in 1989 with the installation of an electrolytic cobalt circuit at Cia. Niquel Tocantins' nickel refinery.

TABLE 6

U.S. REPORTED STOCKS OF COBALT MATERIALS,[1] DECEMBER 31

(Metric tons cobalt content)

	1986	1987	1988	1989	1990
Chemical compounds (organic and inorganic) other than oxide	263	282	249	[2]393	[2]378
Metal	977	1,486	1,278	860	1,341
Oxide	W	105	76	([3])	([3])
Scrap	W	171	162	186	132
Total[4]	1,355	2,043	1,766	1,439	1,851

W Withheld to avoid disclosing company proprietary data; included in "Total."
[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	1986	1987[2]	1988	1989	1990
Cobalt metal:					
Cathode or granules (shot)[3 4]	7.00	7.50	8.40	8.40	8.40
Fine powder (less than 1.6 micrometers)[5]	15.40	16.85	17.75	17.75	22.11
Powder (300-mesh, 400-mesh, 100-mesh)	14.47	13.84	14.74	14.71	18.63
S-grade powder (minus 48-mesh)	7.50	7.75	8.65	[6]8.65	[6]8.65
Cobalt oxide:					
Ceramic-grade (70% to 71% cobalt)	6.08	8.80	9.70	9.42	11.14
Ceramic-grade (72% to 73% cobalt)	6.24	9.04	9.94	9.67	11.44
Metallurgical-grade (76% cobalt)	6.51	9.41	10.31	10.06	11.67

[1]Prices for 1986-88 are from Metals Week; 1989 and 1990 prices are list prices from African Metals Corp., unless noted.
[2]Represents prices as of Jan. 21, 1988.
[3]See table 3 for cathode market price.
[4]250-kilogram drums.
[5]50-kilogram drums.
[6]Sherritt Gordon Ltd. list price.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY FORM

(Metric tons unless otherwise specified)

Form		1988	1989	1990
Metal:[1]				
Gross weight		6,675	5,444	[2]6,027
Cobalt content[e]		6,675	5,444	[2]6,027
Value	thousands	$105,544	$91,960	[2]$106,902
Oxides and hydroxides:[3]				
Gross weight		337	380	488
Cobalt content[e]		249	273	351
Value	thousands	$5,692	$6,598	$8,539
Other forms:[4]				
Gross weight		424	281	547
Cobalt content[e]		127	75	150
Value	thousands	$2,689	$1,426	$3,227
Total:[5]				
Gross weight		7,436	6,105	[2]7,062
Cobalt content[e]		7,051	5,793	[2]6,529
Value	thousands	$113,925	$99,984	[2]$118,668

[e]Estimated.
[1]Unwrought cobalt, excluding alloys; data before 1989 include waste and scrap.
[2]Includes 108 metric tons valued at $1,747,104, destined for the National Defense Stockpile.
[3]Data before 1989 are oxides only.
[4]1989 and 1990 data are cobalt sulfates, cobalt chlorides, cobalt carbonates, and cobalt acetates. Data before 1989 are cobalt sulfate, other inorganic cobalt compounds, and other cobalt salts of organic acids.
[5]Data may not add to totals shown because of independent rounding.
Source: Bureau of the Census; minor adjustments by the U.S. Bureau of Mines.

Cobalt originating from Brazilian ores was formerly refined at Falconbridge Nikkelverk in Norway. The U.S.S.R. has been a major cobalt producer, but was considered a net importer of cobalt until recently. Decreased domestic consumption and the need for hard currency are assumed to be the reasons for sales of Soviet cobalt to Western World markets.

U.S. net import reliance as a percentage of apparent consumption was estimated to be 84% in 1990. The net import reliance would be 100% if no cobalt were recovered from secondary sources (scrap).

In 1990, the United States exported an estimated 1,340 metric tons of unwrought cobalt and cobalt contained in chemicals, valued at $18.1 million. This represented a 51% increase as compared with exports in 1989. Major recipients were Canada (27%), Mexico (10%), Taiwan (9%), and Japan (8%). The remaining 46% was shipped to 44 other countries.

Exports also included 481 metric tons, gross weight, of wrought metal and cobalt articles, valued at $12.3 million. The majority of these materials was sent to four countries: the United Kingdom (54%), Canada (12%), France (8%), and the Netherlands (8%). The remainder was shipped to 22 other countries. In addition, the United States exported 49 metric tons, gross weight, of material under the category entitled, "Cobalt ores and concentrates." Canada was the major recipient of this material.

World Review

Estimated world refinery production was relatively unchanged from production in 1989. Increases in production by major producers Zaire and Zambia and minor producers Brazil, Japan, and France were balanced by decreases in estimated Soviet production and production reported for Canada and Norway. Refinery production reported by the seven Cobalt Development Institute (CDI) member producers[11]—Falconbridge, Gécamines, Inco Ltd., Outokumpu Oy, Sherritt Gordon, Sumitomo Metal Mining Co. Ltd., and ZCCM—was 5% greater than production in 1989. Sales by CDI producers were estimated at 23,500 metric tons, a 10% increase over sales in 1989. However, only 22,500 metric tons of these sales was believed to represent actual Western World consumption. For the third year in a row cobalt production was less than demand, resulting in a significant decrease in producers' stocks.

Capacity.—The data in table 13 are rated capacity for refineries as of December 31, 1990. 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

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY COUNTRY

Country of origin	Metal[1]				Oxides and hydroxides				Other forms[2]				Total content[3 4]	
	1989		1990		1989		1990		1989		1990			
	Gross weight (metric tons)	Value (thousands)	Gross weight (metric tons)	Value (thousands)	Gross weight (metric tons)	Value (thousands)	Gross weight (metric tons)	Value (thousands)	Cobalt content[3] (metric tons)	Value (thousands)	Cobalt content[3] (metric tons)	Value (thousands)	1989 (metric tons)	1990 (metric tons)
Belgium	718	$14,197	175	$4,042	236	$4,147	242	$4,078	21	$380	39	$926	909	388
Brazil	—	—	39	660	—	—	—	—	—	—	—	—	—	39
Canada	1,211	19,905	1,284	21,551	25	415	17	304	—	—	3	21	1,229	1,299
Finland	40	1,506	54	2,050	57	865	143	2,559	18	316	24	511	98	181
France	11	475	14	756	6	248	8	364	—	—	—	—	15	19
Germany, Federal Republic of	97	1,987	90	2,500	—	—	(5)	15	—	—	—	—	97	90
Japan	22	560	22	584	(5)	4	(5)	1	—	—	—	—	22	22
Norway	593	9,170	[6]844	[6]14,096	—	—	—	—	—	—	—	—	593	[6]844
South Africa, Republic of	223	3,687	2	51	—	—	24	366	16	230	55	939	239	74
United Kingdom	10	160	—	—	55	919	48	770	20	493	29	829	70	64
U.S.S.R.	—	—	42	832	—	—	—	—	—	—	—	—	—	42
Zaire	1,076	19,065	1,834	33,754	—	—	—	—	—	—	—	—	1,076	1,834
Zambia	1,418	20,852	1,611	25,523	—	—	—	—	—	—	—	—	1,418	1,611
Other	26	396	18	502	—	—	5	80	(5)	8	—	—	26	21
Total[4]	5,444	91,960	[6]6,027	[6]106,902	380	6,598	488	8,539	75	1,426	150	3,227	5,793	[6]6,529

[1]Unwrought cobalt, excluding alloys and waste and scrap.
[2]Cobalt sulfates, cobalt chlorides, cobalt carbonates, and cobalt acetates.
[3]Estimated from gross weights.
[4]Data may not add to total shown because of independent rounding.
[5]Less than 1/2 unit.
[6]Includes 108 metric tons valued at $1,747,104, destined for the National Defense Stockpile.
Source: Bureau of the Census; minor adjustments by the U.S. Bureau of Mines.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF ADDITIONAL COBALT MATERIALS, BY COUNTRY, 1990

Country of origin	Unwrought cobalt alloys		Other cobalt: Matte, waste and scrap[2]		Wrought cobalt and cobalt articles	
	Gross weight (metric tons)	Value[1] (thousands)	Gross weight (metric tons)	Value[1] (thousands)	Gross weight (metric tons)	Value[1] (thousands)
Belgium	—	—	—	—	(3)	$3
Canada	6	$158	7	$158	11	279
France	21	945	15	140	2	62
Germany, Federal Republic of	3	273	47	513	5	214
Japan	17	693	43	233	24	2,827
Mexico	—	—	19	56	—	—
Sweden	10	237	36	280	(3)	1
Switzerland	—	—	31	85	—	—
United Kingdom	9	84	46	320	6	316
Other	(3)	9	5	21	(3)	27
Total[4]	65	2,398	250	1,806	48	3,729

[1]Customs value.
[2]Includes other intermediate products of cobalt metallurgy; may include other cobalt-bearing materials from which cobalt is extracted or from which cobalt-containing chemical compounds are manufactured.
[3]Less than 1/2 unit.
[4]Data may not add to total shown because of independent rounding.
Source: Bureau of the Census; minor adjustment by the U.S. Bureau of Mines.

TABLE 11

U.S. IMPORT DUTIES FOR COBALT-CONTAINING MATERIALS, EFFECTIVE JANUARY 1, 1990

Item	HTS No.	Most favored nation (MFN)	Non-MFN	Special	
				CA[1]	A, E, IL[2]
Chemical compounds:					
Cobalt acetates	2915.23.00	4.2%	30%	2.5%	Free (A, E, IL).
Cobalt carbonates	2836.99.10	4.2%	30%	Free	Do.
Cobalt chlorides	2827.34.00	4.2%	30%	2.5%	Do.
Cobalt oxides and hydroxides	2822.00.00	2.6 cents per kilogram	44 cents per kilogram	1.5 cents per kilogram	Do.
Cobalt sulfates	2833.29.10	1.4%	6.5%	0.8%	Do.
Cobalt matte, waste and scrap	8105.10.90	Free	Free	XX	XX.
Cobalt ores and concentrates	2605.00.00	Free	Free	XX	XX.
Unwrought cobalt alloys	8105.10.30	5.5%	45%	[3]3.3%	Free (E, IL).
Unwrought cobalt, other	8105.10.60	Free	Free	XX	XX.
Wrought cobalt and cobalt articles	8105.90.00	5.5%	45%	3.3%	Free (A, E, IL).

XX Not applicable.
[1]United States-Canada Free-Trade Agreement.
[2]A, Generalized System of Preferences; E, Caribbean Basin Economic Recovery Act; IL, United States-Israel Free-Trade Area.
[3]Duty on unwrought alloys of cobalt, containing by weight, 76% or more but less than 99% cobalt, originating in Canada temporarily suspended (on or before Dec. 31, 1993).
Source: International Trade Commission.

TABLE 12

U.S. EXPORTS OF COBALT IN 1990, 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)		
Argentina	8	$207	12	$140	—	—	—	—	17	$347
Australia	5	117	23	339	13	$27	—	—	25	483
Brazil	12	400	23	276	13	67	6	$34	33	776
Canada	295	3,953	4	76	11	58	239	843	360	4,931
China	—	—	—	—	—	—	3	59	1	59
Costa Rica	—	—	61	79	—	—	—	—	44	79
El Salvador	[5]	4	44	67	—	—	—	—	32	71
France	17	389	2	45	—	—	—	—	19	433
Germany, Federal Republic of	35	1,032	7	50	—	—	—	—	40	1,083
India	—	—	[5]	4	4	23	—	—	1	27
Italy	12	291	61	408	—	—	—	—	56	699
Japan	30	382	101	1,448	13	70	—	—	106	1,900
Korea, Republic of	2	37	54	510	11	136	[5]	4	43	687
Malaysia	—	—	—	—	2	12	—	—	[5]	12
Mexico	8	179	136	1,451	128	666	3	38	137	2,334
Netherlands	11	192	[5]	9	6	33	—	—	13	233
Spain	1	31	38	208	—	—	—	—	28	239
Sweden	37	248	—	—	—	—	—	—	37	248
Taiwan	[5]	3	146	658	70	358	18	37	127	1,057
Thailand	3	134	7	49	—	—	2	12	9	194
Turkey	[5]	5	44	109	—	—	—	—	32	114
United Kingdom	46	806	[5]	9	—	—	—	—	46	815
Venezuela	—	—	104	342	—	—	—	—	75	342
Other	20	471	54	500	—	—	—	—	59	971
Total[6]	543	8,880	922	6,776	272	1,450	270	1,027	1,340	18,133

[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 13

WORLD ANNUAL COBALT PRODUCTION CAPACITY, DECEMBER 31, 1990

(Metric tons cobalt content)

Country	Refinery capacity
Brazil	300
Canada	3,000
Finland[1]	1,800
France[2]	600
Japan[1 3]	2,800
Norway	2,000
South Africa, Republic of[1]	1,000
U.S.S.R.[e 4]	6,600
United States[5]	900
Zaire	18,000
Zambia	5,000
Total[6]	42,000

[e]Estimated.
[1]Includes salts.
[2]Cobalt chloride.
[3]Includes standby capacity of 1,200 metric tons.
[4]Based on estimated production.
[5]Standby capacity.
[6]Does not include Albania or China.

judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Australia.—Nickel-cobalt sulfide and cobalt sulfide were produced as byproducts of nickel mining and refining by Western Mining Corp. (WMC) in Western Australia and Queensland Nickel Pty. Ltd. in Queensland, respectively. Minor amounts of cobalt oxide were produced as a byproduct of zinc production by Pacific Smelting and Mining Co. Ltd. in Risdon, Tasmania.

WMC reached an agreement to acquire a 70% share in the Bulong nickel-cobalt project from Resolute Resources Ltd. of Perth, Western Australia, and Energy Oil and Gas NL, also from Australia. The Bulong deposit is a nickeliferous laterite 35 kilometers east of Kalgoorlie, Western Australia. The deposit reportedly contains a resource of 108 million metric tons, with measured reserves of 9.8 million metric tons ore grading 1.05% nickel and 0.07% cobalt.[12] As part of the agreement, WMC planned to build a pilot plant and to conduct a feasibility study on technical and economic aspects of the project. The study was to include nickel and cobalt extraction by pressure acid leaching. The use of sulfuric acid manufactured from sulfur dioxide generated at WMC's Kalgoorlie smelter was to be investigated. Previous studies projected annual production rates of 12,000 metric tons nickel and 800 metric tons cobalt.

In January, the Queensland government increased its stake in Queensland Nickel to 28%. Dallhold Investments Pty. Ltd. held the remaining 72% interest in the joint venture. Queensland Nickel's plans to increase the capacity of its Yabulu nickel-cobalt processing plant at Townsville, Queensland, were delayed when approval to build an ore-handling facility at Halifax Bay was denied by the Great Barrier Reef Marine Park Authority. The Marine Park Authority rejected the proposal because of concerns over the impact of potential ore spills on the marine environment. The ore-handling facility was part of a plan to replace diminishing supplies of feed from the company's Greenvale Mine with increased imports of higher grade ore from New Caledonia, Indonesia, and the Philippines. At yearend, Queensland Nickel had lodged an appeal with the Administrative Appeals Tribunal and was discussing alternatives to importing through Halifax Bay with the Queensland government. Cobalt sulfide produced at the Yabulu refinery was refined by Outokumpu Oy in Finland.

Botswana.—BCL Ltd. continued development of a new copper-nickel mine in the Selebi North deposit, with the intention of maintaining current production levels into the future. Copper-nickel-cobalt matte produced by BCL was sent to refineries in Norway and Zimbabwe to be refined.

Brazil.—Cia. Niquel Tocantins was reported to have produced roughly 5 tons per month of cobalt cathode during 1990. Much of the cobalt produced was exported to the United States and Europe. The company planned to increase production to 15 to 20 tons per month in 1991.[13]

Canada.—In 1990, Falconbridge produced approximately 800 metric tons of cobalt from nickel ores at its Sudbury, Ontario, operations. An additional 500 metric tons of cobalt was produced in 1990 from custom feed smelting.[14] Cobalt-containing nickel-copper matte from Sudbury was refined at the Falconbridge Nikkelverk refinery in Norway.

Inco produced cobalt oxide at its Thompson, Manitoba, refinery and cobalt cathode at its Port Colborne refinery. Feed materials for the two refineries originated from mines in Thompson, Manitoba, and Sudbury, Ontario, respectively. Inco's production of refined cobalt decreased 9% in 1990. The company produced 1,380 metric tons of cobalt, as compared with 1,510 metric tons in 1989.[15] Inco's 1990 cobalt deliveries, including cobalt contained in alloys and engineered products, were relatively unchanged from deliveries in 1989 at 1,447 metric tons.[16]

Sherritt Gordon refined cobalt-containing materials from Canada and elsewhere at its nickel-cobalt refinery at Fort Saskatchewan, Alberta. Sherritt produced 688 metric tons of cobalt powder in 1990.[17] This represented a 12% increase over 1989 production, but remained below the high production levels achieved prior to 1989. During the third quarter, Sherritt closed its nickel-cobalt refinery in Edmonton, Alberta, for 2 months owing to a lack of nickel-cobalt feed. In September, a shareholders meeting was called by Canada SherGor Enterprises Inc., a private company formed by Sherritt shareholders dissatisfied with the way the company was being run. At the meeting, shareholders voted by a narrow margin to replace Sherritt's board of directors and executive managers with representatives from SherGor. At yearend, the company continued in its efforts to obtain new feed supplies.

Finland.—Outokumpu produced 1,220 metric tons of cobalt metal powder and salts, a 5% decrease from the 1,290 metric tons produced in 1989.[18] In 1990, Outokumpu purchased Vasset S.A. in France. Vasset converts cobalt chemicals to organometallic soaps for use by the tire and chemical industries.

India.—Hindustan Zinc Ltd. continued construction on a cobalt recovery unit at the Debari zinc smelter in Udaipur, Rajasthan State. The unit was to recover cobalt from zinc smelting residues.

Japan.—Sumitomo produced cobalt metal and salts as a byproduct of nickel production at its Niihama Nickel Refinery in Ehime Prefecture. The large increase in cobalt metal production in 1990 resulted from processing cobalt precipitates stockpiled during the previous year.

The precipitates were stocked during construction to expand nickel capacity at the Niihama refinery.

According to Japan's Ministry of International Trade and Industry, Japanese reported cobalt consumption increased 16% in 1990 to 2,994 metric tons. Cobalt use increased in all industry sectors: catalyst use increased 12% to 416 metric tons; cobalt in hard metal tools increased 14% to 345 metric tons; cobalt in special steels increased 13% to 890 metric tons; cobalt in magnetic materials increased 17% to 647 metric tons; and cobalt in other uses increased 23% to 696 metric tons. Demand was met primarily from imports, which increased 36% in 1990 to 4,537 metric tons.

Norway.—The Falconbridge Nikkelverk refinery produced 1,830 metric tons cobalt cathode in 1990, a 6% decrease from the 1,946 metric tons produced in 1989.[19] Feedstock for the refinery was in the form of matte, from company operations in Sudbury, Canada; BCL Ltd. in Botswana; and Noril'sk in the U.S.S.R. During 1990, cobalt from Falconbridge Nikkelverk was supplied to the NDS under the cobalt upgrading program (see Legislation and Government Programs section of this report).

Philippines.—In October, the Philippine Government signed a final agreement with the Philippine Nickel Co. (Philnico) for the sale of the Nonoc Mining and Industrial Corp. nickel production facility. During the year, Philnico continued rehabilitation of the idled plant. This work was begun under a memorandum of understanding signed in August 1989. Cobalt production at the plant would be in the form of mixed nickel-cobalt sulfide. Previous peak production at the facility was 1,374 metric tons of cobalt in mixed sulfide in 1979.

South Africa, Republic of.—Cobalt was produced as a byproduct of the Republic of South Africa's platinum mining and refining industry. Refined cobalt was produced by two companies: Rustenburg Base Metal Refiners Pty. Ltd. produced cobalt sulfate, and Impala Platinum produced cobalt metal powder. A third company, Western Platinum Ltd., produced nickel sulfate containing minor amounts of cobalt. Most of the cobalt produced in the Republic of South Africa was exported. Exports were expected to increase in the future as a result of increases in mine production.

In terms of South African consumption, a significant shift in cobalt use was reported in 1990. In 1989, the largest use of cobalt was in paint and ink driers (55% of total use), followed by enamels and glazes (25%), then cemented carbides (15%). In previous years, the primary use of cobalt in the Republic of South Africa was in cemented carbides, followed by paint and ink driers, then enamels and glazes.[20]

Sweden.—In March, the Swedish Government sold 33 metric tons of extra-fine cobalt powder from its stockpile. The cobalt was purchased by MHO, the Belgian processor that had originally supplied it to the stockpile 10 years ago. MHO reportedly bought the cobalt to prevent it from reentering the market because it was not equivalent in quality to powders currently available.

Tanzania.—Sutton Resources Ltd., a Canadian exploration company, acquired Romanex International Ltd., owner of the Kabanga Nickel project in Tanzania. Exploration of the property was underway to confirm previous reserve estimates and provide samples for mineralogical and metallurgical studies. A United Nations Development Program study in the mid-1970's resulted in indicated and inferred reserve estimates of 40.5 million tons of sulfide ore grading 1.05% nickel, 0.21% copper, and 0.11% cobalt.[21]

Zaire.—Gécamines remained the world's largest cobalt producer, providing about 40% of estimated world refinery production. The company's cobalt production increased 8% in 1990, reversing a downward trend in production that began in 1987. An overview of Gécamines cobalt production was presented.[22] Materials flow from mines to refineries, refining practices, enhancement or suppression of cobalt production, and medium- and long-term plans were discussed.

In January, Gécamines Commerciale and Sogem-Afrimet Inc. announced the formation of a joint-venture company. The company, named African Metals Corp., was created to act as the exclusive agent for the importation and sale of all cobalt metal produced in Zaire and sold in the United States and Canada.

In September, Gécamines' Kamoto underground mine suffered a major cave-in. The Kamoto Mine, in Gécamines Western Group near the town of Kolwezi, is the company's largest underground copper-cobalt mine. It provides concentrates to the Shituru and Luilu refineries and the Lubumbashi smelter. Before the cave-in, the mine had been a significant source of cobalt because of its high output levels and the high cobalt content of its ores. At the time of the cave-in, estimates of projected cobalt losses varied widely, but were likely to be on the order of 100 to 150 metric tons per month. Gécamines announced that it would meet its sales commitments and that the loss of cobalt concentrates from Kamoto could be "made up from other sources." Increased output from the Siège de Kolwezi Mines open pit operations was anticipated. No injuries were reported from the accident. However, news of the cave-in caused U.S. cobalt market prices to increase temporarily to more than $14.00 per pound.

While cobalt production at Gécamines is ultimately tied to copper production, there are various stages during mining, concentrating, and hydrometallurgical processing where cobalt recovery can be either enhanced or suppressed in favor of copper recovery. Emphasis on cobalt production at a given time depends on a balance between market demand, production, and stock levels. For many years Gécamines had been precipitating excess cobalt from its hydrometallurgical plants' cobalt leach circuits and stockpiling cobalt hydrates for later use. In late 1990, Gécamines decided to augment its cobalt production by reprocessing the stockpiled hydrates. Cobalt recovered from the hydrates offset production losses from the Kamoto Mine cave-in.

In a related project, in late 1990, Gécamines signed a contract with Techpro Mining and Metallurgy of the United Kingdom for a turnkey project for the recovery of cobalt and copper from current leach residues. Techpro was to construct a horizontal belt filter and two flotation columns at the Shituru plant and a horizontal belt filter at the Luilu plant, then train operations and maintenance staff in their use. The filters were intended to increase cobalt recovery by providing improved washing of the leach residues.

Zambia.—Production of refined cobalt metal from January to December 1990 increased 8% over that of the same period in 1989 to 4,844 metric tons.[23]

Zimbabwe.—Minor amounts of impure cobalt oxide were produced in Zimbabwe as a byproduct of nickel mining and refining. In 1990, the Bindura Nickel Corp. Ltd. produced 123 metric tons of contained cobalt from company nickel ores and toll-refined material.[24] The cobalt oxide was exported to be refined.

In October, BHP-Utah Minerals International, a subsidiary of Broken Hill Pty. Co. Ltd., formed a joint venture with Delta Gold NL to study the Hartley platinum deposit. The deposit is part of the Great Dyke, a 500-kilometer-long precious metals and chromite deposit that crosscuts Zimbabwe north to south. As part of the joint-venture agreement, BHP-Utah was to complete a 2-year feasibility study, then decide on the development of an underground mine. A 1989 feasibility study for Delta Gold showed 37 million metric tons proven and probable reserves. Based on a 2-million-ton-per-year underground mine, annual production was estimated to be in excess of 200,000 ounces of platinum-group metals and 15,000 ounces of gold. In addition, 2,450 metric tons of nickel, 1,570 metric tons of copper, and about 47 metric tons of cobalt could be produced from nickel-copper matte that was to be toll refined in Zimbabwe.

TABLE 14

COBALT: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons, cobalt content)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Albania[e 3]	600	600	600	600	600
Australia[e 4]	1,237	1,261	1,200	1,000	1,000
Botswana[5]	163	181	291	215	[6]205
Brazil[e]	150	150	150	200	200
Canada[7]	2,297	2,490	2,398	2,344	[6]2,291
Cuba[8]	1,553	1,566	1,783	1,825	1,600
Finland[9]	627	190	—	—	—
Morocco[9]	—	224	253	121	120
New Caledonia[e 10]	700	750	800	800	800
Philippines	92	—	—	—	—
South Africa, Republic of[e]	690	720	720	730	730
U.S.S.R.[e]	2,800	2,800	2,850	2,850	2,400
Zaire[9]	33,373	22,517	25,400	[e]25,000	20,000
Zambia[9 11]	5,869	7,365	7,090	7,255	7,100
Zimbabwe[e 12]	48	88	104	90	90
Total	50,199	40,902	43,639	43,030	37,136

[e]Estimated. [p]Preliminary.

[1]Table includes data available through May 31, 1991. 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, the Eastern states of the Federal Republic of Germany, Indonesia, and Poland are known to produce ores that contain cobalt, but information is inadequate for reliable estimates of output levels. Other copper-, nickel-, platinum-, or zinc-producing nations may also produce ores containing cobalt as a byproduct component, but recovery is small or nil.

[3]Calculated from reported and estimated weight of nickeliferous ore.

[4]Figures represent quantities of cobalt contained in intermediate metallurgical products (cobalt oxide and nickel-cobalt sulfide). Cobalt content of lateritic nickel ore, nickel concentrate, and zinc concentrate was as follows, in metric tons: 1986—2,914; 1987—2,715; 1988—2,574 (revised, estimated); 1989—2,375 (estimated); and 1990—2,375 (estimated).

[5]Reported cobalt content of pelletized nickel-copper matte.

[6]Reported figure.

[7]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.

[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 and Japan. The estimated cobalt content of total ores mined is as follows, in metric tons: 1986—5,000; 1987—5,800; 1988—6,000; 1989—6,000; and 1990—6,000.

[11]Fiscal years beginning Apr. 1 of that stated. Cobalt content of ore milled was as follows, in metric tons: 1986—8,656; 1987—11,198; 1988—10,687; 1989—10,590; 1990—10,700 (estimated).

[12]Estimated cobalt content of ore.

Current Research

The U.S. Bureau of Mines evaluated the availability of cobalt from 27 deposits or districts in 11 market economy countries. An economic evaluation of each deposit or district resulted in an estimation of quantities of cobalt that could be produced at various cobalt, copper, or nickel prices. The study concluded that an adequate supply of cobalt was available from market economy countries to meet their anticipated demand. The study also addressed issues that could affect cobalt availability, including the dependence of cobalt production on production of the operation's primary commodity and transportation routes used by major African producers.[25]

The U.S. Bureau of Mines published two studies on the processing of cobalt-rich manganese crusts from the United States' EEZ surrounding the Hawaiian Islands and Johnston Atoll. In one study,[26] froth flotation parameters were optimized to maximize separation of manganese crust from substrate waste rock. Flotation in seawater with diesel fuel-crude tall oil-sulfonate collectors resulted in recoveries of 89% to 95% and produced concentrates grading 15% manganese, 0.58% cobalt, and 0.32% nickel. Flotation tailings were subjected to the EPA Extraction Procedure Toxicity Test to evaluate the environmental impact of tailings disposal. Leachable metal ions were below maximum allowable concentrations established by EPA.

In the second study,[27] the Bureau researched the hydrometallurgical processing of cobalt-rich manganese crusts. Conditions were optimized for a hydrogen peroxide-sulfuric acid leach followed by a three-stage selective precipitation. Cobalt was recovered as a mixed cobalt-nickel sulfide precipitate. The EPA Extraction Procedure Toxicity Test was performed on flotation tailings, leach residue, and the iron precipitate to evaluate potential environmental impact. Metal ions leached from the process wastes were below EPA's maximum allowable concentrations.

Three examples of Bureau research on the recovery of cobalt from superalloy scrap were presented at a symposium on recycling held by the Minerals, Metals and Materials Society of the American Institute of Mining, Metallurgical and Petroleum Engineers (AIME). In two studies, superalloy scrap was melt-carburized

TABLE 15

COBALT: WORLD REFINERY PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Metric tons, cobalt content)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Albania: Oxide[e]	—	—	r10	r10	20
Brazil: Metal	—	—	—	r e30	60
Canada: Metal (including metal powder; may include oxide)	2,233	2,505	2,335	2,123	[3]2,068
China: Metal[e]	270	270	270	270	270
Finland:					
Metal (including metal powder)	NA	497	229	e292	300
Salts	NA	483	903	e1,003	1,000
Total	1,348	980	1,132	1,295	1,300
France: Chloride (solution)	158	136	176	r e160	170
Japan: Metal	1,338	124	109	99	[3]199
Norway: Metal	1,574	1,576	1,951	1,946	[3]1,830
South Africa, Republic of:[e]					
Metal (powder)	200	200	200	200	200
Sulfate	300	300	320	325	325
Total	500	500	520	525	525
U.S.S.R.: Unspecified[e]	5,300	5,300	5,300	5,300	4,500
Zaire: Metal	14,518	11,871	10,026	9,311	[3]10,033
Zambia: Metal[4]	4,160	4,694	4,871	4,447	4,800
Total	31,399	27,956	26,700	25,516	25,775
Of which: Metal[5]	24,293	21,737	19,991	18,718	19,760
Salts[5]	458	919	1,409	1,498	1,515
Unspecified	6,648	5,300	5,300	5,300	4,500

[e]Estimated. [p]Preliminary. [r]Revised. NA Not available.

[1]Table includes data available through May 31, 1991. 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 the Western states of the Federal Republic of Germany may recover cobalt from imported materials, but production is not reported, and information is inadequate to make reliable estimates of production.

[3]Reported figure.

[4]Fiscal years beginning Apr. 1 of that stated.

[5]Excludes Finland for 1986; included with "Unspecified."

and cast into anodes. Cobalt and nickel were then recovered hydrometallurgically from the anodes in one of two ways: as high-purity cobalt or nickel in separate double-membrane electrolytic cells,[28] or as a mixed nickel-cobalt alloy using controlled-potential electrolysis.[29] A third study detailed a chloride-based hydrometallurgical process to recover cobalt, chromium, manganese, nickel, and tungsten from hard-face alloy grinding waste. Ninety-seven percent of the cobalt in the grinding waste was recovered as a cobalt chloride solution using solvent extraction. An economic analysis of the process was also reported.[30]

A review of four methods for the identification of scrap metals was also published. The methods described were thermoelectric measurements, optical emission spectroscopy, X-ray fluorescence spectroscopy, and spark testing. Results of a large-scale field study using these and other techniques at a Department of Defense scrapyard were presented.[31]

The Bureau published a material flow model for the U.S. cobalt industry. The model addressed cobalt consumption, losses, and recycling for eight industry sectors: superalloy; magnetic alloy; cemented carbide; tool steel; stainless steel, heat-resistant steel, and other alloys; miscellaneous alloys; catalyst; and other chemical uses. A combined material flow for the eight sectors gave the following results, based on an estimated consumption of 8,085 metric tons in 1987: 1,139 metric tons of cobalt in recycled obsolete scrap, 1,017 metric tons of cobalt in recycled prompt scrap, 1,385 metric tons of cobalt lost to downgraded scrap, 582 metric tons of cobalt lost as waste, and 6,118 metric tons of cobalt reporting to final products.[32]

The Cobalt Development Institute of Wickford, Essex, United Kingdom, published abstracts on cobalt research, articles on selected cobalt uses, and annual and semiannual data on cobalt production by Institute members in quarterly issues of Cobalt News.

OUTLOOK

The outlook for cobalt consumption is dependent on the performance of a variety of industries. The largest single use of cobalt is in superalloys, which are used primarily in turbine engines for both commercial and military aircraft. Decreases in military spending are expected to result in a decline in demand for superalloys in military aircraft. In contrast, demand in the commercial aviation sector is expected to remain strong because of a record backlog of aircraft orders. Areas of potential growth for cobalt-containing superalloys include industrial applications requiring the alloys' ability to withstand corrosive conditions at high temperatures. While these nonaerospace applications represent a small fraction of total superalloy use, certain applications, such as waste incineration, have been cited for their growth potential.

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COLUMBIUM (NIOBIUM) AND TANTALUM

By Larry D. Cunningham

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Columbium 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 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 remaining the major source for columbium imports and the Federal Republic of Germany the major source for tantalum imports. Columbium price quotations were unchanged for the year, and tantalum prices remained stable.

The National Defense Stockpile (NDS) requirement (goal) for the columbium group nearly tripled in accordance with the National Defense Authorization Act for Fiscal Years 1990 and 1991. Also, to ensure future availability to the United States, the Defense Logistics Agency (DLA) awarded contracts for purchase of tantalum minerals for the NDS.

Overall reported consumption of columbium in the form of ferrocolumbium and nickel columbium rose slightly, with demand for columbium in superalloys at the highest level since 1986. Tantalum consumption was up for the year, aided by increased demand from the electronics industry.

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, three responded. Thus, ferrocolumbium production data for 1990 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 being nickel. Aluminum, iron, silicon, and tantalum are the principal impurities.

Columbium carbide is available as a powder containing about 87% columbium and the balance as carbon.

Columbium metal is available in many forms and shapes. Purity of unalloyed metal is usually more than 99%, with attention mainly given to iron, tantalum, and zirconium as metallic impurities and carbon, hydrogen, nitrogen, and oxygen as interstitial impurities. Alloys with hafnium, tantalum, titanium, tungsten, and zirconium are of most commercial importance. Chemical and physical standards for columbium and columbium alloy mill shapes are given in ASTM

Specifications B391-B394, B652, and B654-B655.

Products for Trade and Industry

Columbium, in the form of ferrocolumbium, is used worldwide, principally as an additive to improve the strength and corrosion resistance of steel. Columbium-containing high-strength and corrosion resistant steel is used in applications such as high-strength linepipe, structural members, lightweight components in cars and trucks, and exhaust manifolds. Because of its refractory nature, appreciable amounts of columbium in the form of high-purity ferrocolumbium and nickel columbium are used in nickel-, cobalt-, and iron-base superalloys for applications such as jet engine components, rocket subassemblies, and heat-resisting and combustion equipment. Columbium-base alloys are also used in aerospace applications such as rocket nozzles. Columbium carbide is used in cemented carbides to modify the properties of the cobalt-bonded tungsten carbide-base material. It is usually used with carbides of metals such as tantalum and titanium. Columbium oxide is the intermediate product used in the manufacture of high-purity ferrocolumbium, nickel columbium, columbium metal, and columbium carbide.

Geology-Resources

Columbium is almost always found in nature as an oxide in association with other minerals, but not in elemental form nor as a sulfide. Columbium has an overall crustal abundance estimated as 20 parts per million and a strong geochemical coherence with tantalum. Pyrochlore and bariopyrochlore (also known as pandaite), its barium analog, have become the main sources of columbium. The minerals contain little tantalum, having a columbium oxide-to-tantalum oxide ratio of 200:1 or greater. Pyrochlore and bariopyrochlore are commonly found in the interior parts of alkalic rock complexes, frequently in association with minerals of such other elements as thorium, titanium, uranium, and those of the rare earths. Columbite, the columbium-rich member of the columbite-tantalite isomorphous series, is normally found in intrusive pegmatites and in biotite and alkalic granites. However, because most such deposits relatively high in columbium content are small and erratically distributed, most columbite has been obtained as a byproduct of mining for other commodities, mainly tin.

Reserve and reserve base data for columbium are shown in table 1 and are based on a judgmental appraisal of current information. Reserve base is defined as the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. The reserve base may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. Reserves are defined as that part of the reserve base that could be economically extracted or produced at the time of determination.

Technology

Exploration.—Columbium deposits of economic interest are most likely to be found in alkalic rock complexes and associated carbonatites. Aerial photography and geological mapping can be used to reveal alkalic complexes, which frequently occur with circular geometry and concentric rock arrangement. Test pitting and panning can be used to explore placer deposits for columbium by virtue of the high specific gravity of columbium minerals. The columbium content of samples can be determined rapidly by means of truck-mounted spectrographic equipment and X-ray fluorescence spectroscopy.

Mining.—Pyrochlore has been mined mainly by mechanized open pit, under ground stoping methods, or a combination of both. Currently, all mining for pyrochlore in Brazil is open pit, whereas in Canada, underground mining is being done via a large-diameter blasthole method. Ore, with host rock, is usually dislodged from a working face with explosives. Beneficiation of the ore, after it has been finely ground, is achieved primarily by various flotation procedures combined with magnetic separation to remove iron minerals. A chloridizing and leaching process can also be employed to lower barium, lead, phosphorus, and sulfur contents. Methods used to mine columbite have ranged from simple hand operations in small pegmatite mines to hydraulic monitors and dredges at placer deposits.

Beneficiation.—Pyrochlore concentrates are used solely in the manufacture of ferrocolumbium for steelmaking. Aluminothermy, the process being used for making steelmaking-grade ferrocolumbium from pyrochlore concentrates, is carried out in batches. As practiced by Cia. Brasileira de Metalurgia e Mineração (CBMM) in Brazil, a mixed charge of concentrate, iron oxide (as hematite), fine aluminum powder, and slagging agents is reacted to produce ferrocolumbium in a refractory-lined, cylindrical steel shell open at the top and resting upon a lined silica sand bed. Also, processes have been developed for production of columbium oxide through treatment of ferrocolumbium produced from pyrochlore concentrates. This technology is being used to produce commercial quantities of columbium oxide suitable for the manufacture of high-purity ferrocolumbium, nickel columbium, and columbium metal.

TABLE 1

WORLD COLUMBIUM RESERVES AND RESERVE BASE, 1990

(Thousand pounds columbium content)

Country	Reserves	Reserve base[1]
Brazil	7,300,000	8,000,000
Canada	300,000	900,000
Nigeria	140,000	200,000
United States	—	(2)
Zaire	70,000	200,000
Other market economy countries	14,000	19,000
World total (rounded)	7,800,000	9,300,000

[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.

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 can also be recovered economically from some tin slags, which constitute an important raw material source for high-purity columbium and tantalum. Other elements frequently associated with columbium deposits include rare earths, thorium, titanium, and uranium; some of these have been recovered along with columbium in the past and may be coextracted in the future.

Substitutes

For established applications of both columbium-bearing steels and superalloys, substitution of some alternative steel or alloy requiring less columbium ordinarily lowers performance and/or cost effectiveness. In some high-strength low-alloy (HSLA) steels, use of columbium as a microalloying element competes with use of such elements as molybdenum, titanium, and vanadium. In other HSLA steels, it may be desirable to use one or more of these elements along with columbium in complementary fashion. Tantalum is a costly potential substitute for columbium in superalloys. Titanium can be used instead of columbium in stainless steel to improve corrosion resistance.

Economic Factors

Prices.—The price of columbium contained in concentrates, in terms of actual prices and in constant 1982 dollars, has been relatively stable for the period shown in table 2. Actual prices reported are based on historical price quotations or best available information from producers. Additionally, prices for products based on columbium concentrates have been stable over the past decade. At yearend 1990, the published price for columbium oxide was $7.64 per pound of oxide, the published price for regular-grade ferrocolumbium was $6.58 per pound of contained columbium, the published price for high-purity ferrocolumbium was $17.50 per pound of contained columbium, the published price for nickel columbium was $19.50 per pound of contained columbium, and the published price for columbium metal was at a range of $30 to $50.

Depletion Provisions.—U.S. columbium-producing companies are granted a depletion allowance of 22% for domestic production of columbium minerals and 14% on foreign production.

BACKGROUND—TANTALUM

Tantalum is a refractory metal that is ductile, easily fabricated, has a high melting point (2,996° C), is highly resistant to corrosion by acids, and is a good conductor of heat and electricity. It combines readily with other refractory metals such as hafnium and tungsten to form alloys having high-temperature strength and stability. Tantalum forms highly stable anodic films and exhibits a rectifying, or electronic valve, action in an electrolyte. Tantalum is twice as dense as steel with a specific gravity of 16.6.

TABLE 2

TIME-PRICE RELATIONSHIPS FOR COLUMBIUM

Year	Average annual price, dollars per pound of contained columbium in concentrates	
	Actual price	Based on constant 1982 dollars
1954	4.86	18.48
1955	1.93	7.10
1956	1.79	6.37
1957	1.68	5.77
1958	1.54	5.19
1959	1.54	5.07
1960	1.73	5.60
1961	1.43	4.58
1962	1.36	4.26
1963	1.36	4.20
1964	1.36	4.13
1965	1.34	3.96
1966	1.43	4.09
1967	1.42	3.96
1968	1.42	3.77
1969	1.42	3.57
1970	1.65	3.93
1971	1.65	3.72
1972	1.87	4.02
1973	1.97	3.98
1974	2.23	4.13
1975	2.23	3.76
1976	2.73	4.33
1977	5.53	8.22
1978	3.69	5.11
1979	3.79	4.82
1980	4.55	5.31
1981	4.87	5.18
1982	4.83	4.83
1983	4.73	4.55
1984	4.71	4.37
1985	4.63	4.17
1986	3.78	3.32
1987	3.71	3.16
1988	3.71	3.06
1989[e]	[r]3.93	[r]3.11
1990[e]	3.93	2.99

[e]Estimated. [r]Revised.

Definitions, Grades, and Specifications

Metallic forms of tantalum are produced chiefly in unalloyed form or alloyed with up to about 10% tungsten.

Unalloyed metal and alloys with tungsten are available as ingot, plate, sheet, strip, bar, rod, wire, and tubing in accordance with ASTM Specifications B364, B365, and B521. Allowable impurity levels do not exceed 0.3% in most cases; the main impurities are columbium and oxygen, plus tungsten in the case of unalloyed tantalum. Purity of tantalum metal powder is usually about 99.9%. Depending on powder usage, impurities that must be controlled consist mainly of calcium, carbon, columbium, iron, nickel, nitrogen, oxygen, silicon, and sodium. Commercial tantalum carbide usually contains about 93% tantalum and about 6.3% carbon.

Products for Trade and Industry

The major end use for tantalum, as tantalum metal powder, is in the production of electronic components, mainly tantalum capacitors. Applications for tantalum capacitors include computers, communication systems, and instruments and controls for aircraft, missiles, ships, and weapon systems. The tantalum capacitor exhibits reliable performance and combines compactness and high efficiency with good shelflife. Because of its high melting point, good strength at elevated temperatures, and good corrosion resistance, tantalum is combined with cobalt, iron, and nickel to produce superalloys that are employed in aerospace structures and jet engine components. Tantalum carbide, used mostly in mixtures with carbides of such metals as columbium, titanium, and tungsten, is used in cemented-carbide cutting tools, wear-resistant parts, farm tools, and turning and boring tools. Because of its excellent corrosion resistant properties, tantalum mill and fabricated products are used in the chemical industry in applications such as heat exchangers, evaporators, condensers, pumps, and liners for reactors and tanks.

Geology-Resources

The principal source of tantalum is an isomorphous series of minerals containing columbium, iron, manganese, and tantalum oxides. Tantalum and columbium have strong geochemical affinity and are found together in most rocks and minerals in which they occur. Tantalite-columbite occurs mainly as accessory minerals disseminated in granitic rocks or in pegmatites associated with granites. The microlite-pyrochlore mineral series is also a source of tantalum. These minerals consist essentially of complex oxides of calcium, columbium, sodium, and tantalum in combination with hydroxyl ions and fluorides. Microlite occurs mainly in the albitized zones of granite pegmatites, often associated with tantalite or columbite. Struverite is a low-grade source of tantalum recoverable from tin mining wastes in Southeast Asia. Struverite is a variation of the titanium mineral rutile. Tantalum is also obtained through byproduct recovery from tantalum-bearing tin slags, principally from smelters in Brazil and Southeast Asia.

Reserve and reserve base data for tantalum are shown in table 3 and are based on a judgmental appraisal of current information. Reserve base is defined as the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. The reserve base may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. Reserves are defined as that part of the reserve base that could be economically extracted or produced at the time of determination.

Technology

Exploration.—Exploration for tantalum is generally pursued on the basis of its known frequent association with tin and certain other elements in pegmatite environments, some features of which can be distinguished by aerial photography. Application of X-ray fluorescence analysis techniques has been helpful in measuring tantalum at the low concentrations at which it occurs. The high specific gravity of tantalum minerals makes it possible to reveal their presence in placer deposits by test pitting and panning.

Mining.—Most tantalum-related mining developments in the past generally were small, relatively high-cost intermittent operations that depended on the recovery of byproduct or coproduct minerals for economic viability. Future mine development will shift more to primary tantalum sources, notably operations in Australia.

Both alluvial and residual tantalum and tantalum-containing tin deposits are normally mined by hand, by hydraulic monitors, by dredges, or by mechanized open pit mining. The mining of pegmatite deposits, which may be either open pit or underground, is carried out by blasting, transporting, and crushing the rock to free the tantalum and associated coproduct minerals. The materials are then concentrated by wet gravity methods (sluices, jigs, spirals, and tables) and finally separated from associated minerals by gravity and electrostatic and electromagnetic processes.

TABLE 3

WORLD TANTALUM RESERVES AND RESERVE BASE, 1990

(Thousand pounds tantalum content)

Country	Reserves	Reserve base[1]
Australia	10,000	20,000
Brazil	2,000	3,000
Canada	4,000	5,000
Malaysia	2,000	4,000
Nigeria	7,000	10,000
Thailand	16,000	20,000
United States	—	(2)
Zaire	4,000	10,000
Other market economy countries	3,000	4,000
World total	48,000	76,000

[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.

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 can also be made by reacting metallic tantalum directly with carbon.

Recycling.—Recycling of tantalum largely takes place within the processing and product-producing industry and is mostly runaround or home scrap that is consumed internally. In addition, quantities of tantalum are recycled indirectly in the form of used tantalum-bearing cutting tools and high-temperature alloy melting scrap.

Byproducts and Coproducts

Economic exploitation of tantalum minerals often is dependent on the price of associated recoverable byproduct or coproduct minerals, principally tin and columbium. Tantalite-columbite minerals occur in deposits associated with beryllium, lithium, rare-earth, tin, titanium, tungsten, uranium, and zirconium minerals. Minerals associated with tantalum in pegmatite deposits include beryl, feldspar, lepidolite, mica, pollucite, and spodumene. Tantalum and columbium can also be recovered economically from some tin slags, which constitute an important raw material source for tantalum and high-purity columbium. Tantalum is usually extracted in conjunction with columbium in much the same type of equipment.

Substitutes

Substitution for tantalum is usually made at a performance or economic penalty for most uses. Also, substitution requires both investment and experimentation and does not necessarily occur quickly. Aluminum and ceramics compete strongly with tantalum for use in electronic capacitors. In cemented carbides, columbium carbide and columbium-hafnium carbide can take the place of tantalum carbide in some cutting tools. Replacements for tantalum in corrosion-resistant equipment are columbium, glass, platinum, titanium, and zirconium. Columbium, hafnium, molybdenum, tungsten, and some platinum-group metals can be substituted for tantalum in high-temperature applications.

Economic Factors

Prices.—Time-price relationships for tantalum contained in concentrates in terms of actual prices and in constant 1982 dollars are shown in table 4. 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, with recent year pronounced maximums occurring in 1980 and 1988. 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

TABLE 4

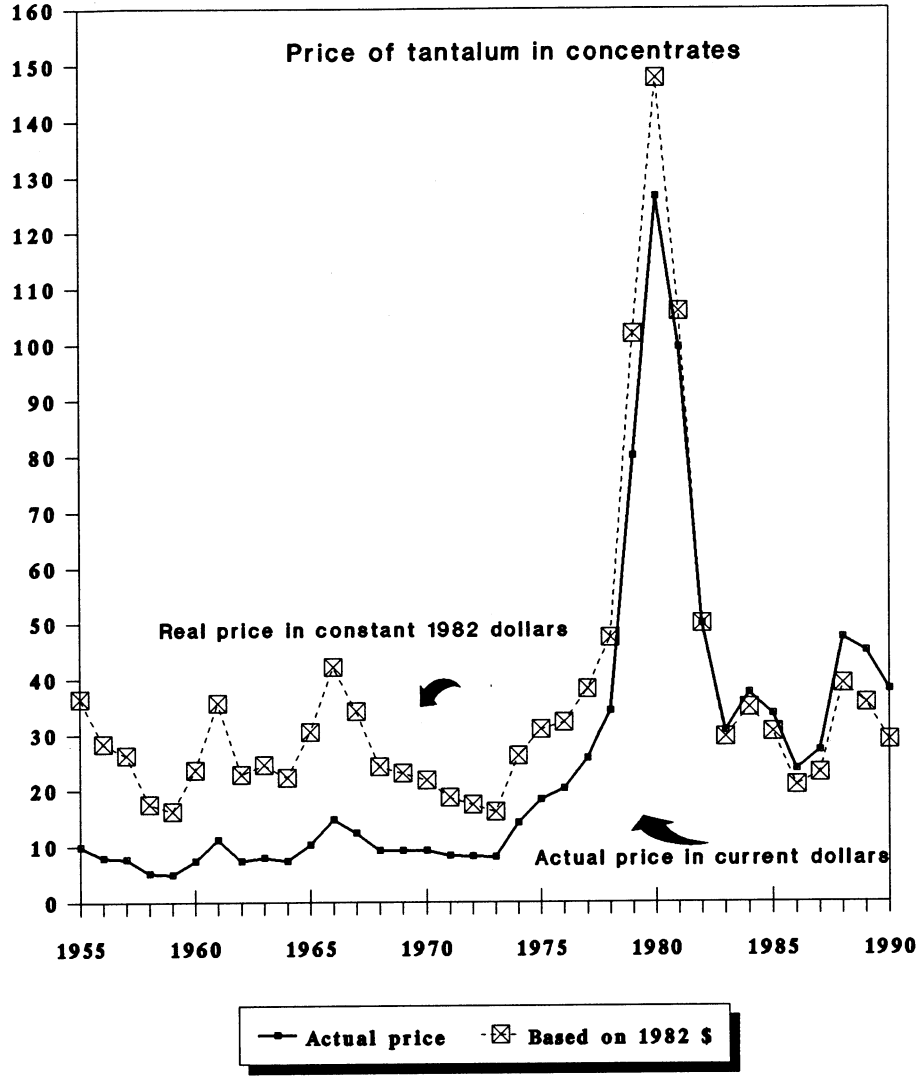
TIME-PRICE RELATIONSHIPS FOR TANTALUM

Year	Average annual price, dollars per pound of contained tantalum in concentrates[1]	
	Actual price	Based on constant 1982 dollars
1954	9.77	37.15
1955	9.91	36.43
1956	7.96	28.33
1957	7.63	26.22
1958	5.18	17.44
1959	4.92	16.18
1960	7.28	23.56
1961	11.11	35.61
1962	7.29	22.85
1963	7.93	24.48
1964	7.31	22.22
1965	10.26	30.36
1966	14.72	42.06
1967	12.24	34.09
1968	9.13	24.22
1969	9.15	22.99
1970	9.15	21.79
1971	8.26	18.60
1972	8.09	17.40
1973	8.00	16.16
1974	14.13	r26.17
1975	18.32	30.89
1976	20.31	32.19
1977	25.64	38.10
1978	34.19	47.35
1979	80.00	101.78
1980	126.37	147.46
1981	99.51	105.86
1982	49.95	49.95
1983	30.60	29.45
1984	37.44	34.76
1985	33.68	30.37
1986	23.74	20.86
1987	27.08	23.07
1988	47.37	39.05
1989	44.93	35.57
1990	38.06	28.94

rRevised.
[1]60% basis, combined tantalum and columbium pentoxides.

FIGURE 1

TIME-PRICE RELATIONSHIPS FOR TANTALUM



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.

Depletion Provisions.—U.S. tantalum-producing companies are granted a depletion allowance of 22% for domestic production of tantalum minerals and 14% on foreign production.

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Legislation and Government Programs

Under the offset concept for the NDS, less than 25% of the goal for columbium concentrates and 37% of the goal for tantalum minerals were met (table 7).

In June, the goal for the columbium group in the NDS was raised to 12,520,000 pounds of contained columbium from 4,850,000 pounds of contained columbium. The action to nearly triple the columbium stockpile goal was taken under the authority vested in the Assistant Secretary of Defense and in accordance with the National Defense Authorization Act for Fiscal Years 1990 and 1991. This followed the U.S. Department of Defense findings concerning military requirements for strategic and critical materials.

TABLE 5

SALIENT COLUMBIUM STATISTICS

(Thousand pounds of columbium content unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Mine production of columbium-tantalum concentrates	—	—	—	(1)	(1)
Releases from Government excesses	—	—	—	—	—
Consumption of raw materials[e]	W	W	NA	NA	NA
Production of ferrocolumbium	W	W	NA	NA	NA
Consumption of primary products: Ferrocolumbium and nickel columbium[e]	4,995	5,179	5,876	r5,377	5,699
Exports: Columbium metal, compounds, alloys (gross weight)[e]	120	130	120	NA	NA
Imports for consumption:					
Mineral concentrates[e]	1,320	2,010	1,750	2,680	2,480
Columbium metal and columbium-bearing alloys[e]	5	42	32	26	5
Ferrocolumbium[e]	3,432	4,016	4,238	5,316	4,183
Tin slags[e 2]	W	W	NA	NA	NA
World: Production of columbium-tantalum concentrates[e]	32,149	r20,633	r36,917	r30,286	27,054

[e]Estimated. [r]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.
[1]A small unreported quantity was produced.
[2]Receipts reported by consumers; includes synthetic concentrates and other miscellaneous materials, after deduction of reshipments.

TABLE 6

SALIENT TANTALUM STATISTICS

(Thousand pounds of tantalum content unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Mine production of columbium-tantalum concentrates	—	—	—	(1)	(1)
Releases from Government excesses	—	—	—	—	—
Consumption of raw materials[e]	W	W	NA	NA	NA
Exports:					
Tantalum ores and concentrates (gross weight)[2]	71	103	214	8	2
Tantalum metal, compounds, alloys (gross weight)	392	413	487	r358	374
Tantalum and tantalum alloy powder (gross weight)	160	193	278	211	182
Imports for consumption:					
Mineral concentrates[e]	280	220	400	1,100	660
Tantalum metal and tantalum-bearing alloys[3]	46	60	128	82	47
Tin slags[e 4]	W	W	NA	NA	NA
World: Production of columbium-tantalum concentrates[e]	473	605	r641	r835	758

[e]Estimated. [r]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.
[1]A small unreported quantity was produced.
[2]Includes reexports.
[3]Exclusive of waste and scrap.
[4]Receipts reported by consumers; includes synthetic concentrates and other miscellaneous materials, after deduction of reshipments.

Also in June, the DLA awarded contracts to purchase 200,000 pounds of tantalum pentoxide (Ta_2O_5) contained in tantalum natural minerals and concentrates for the NDS. The minerals and concentrates were to be grade 1 as defined in National Stockpile Purchase Specification P-113a, effective August 3, 1981, requiring a minimum Ta_2O_5 content of 25% and a minimum combined Ta_2O_5 plus columbium pentoxide (Cb_2O_5) content of 55%.

The awards were made to O'Dell Construction Co., Prattville, AL, a domestic producer, and Sogem-Afrimet, New York, NY, for two allotments of 100,000 pounds each for placement in the NDS storage depot at New Haven, IN, and Somerville, NJ, respectively. The tantalum materials are to be delivered to the NDS within 2 years of contract award. The material to be provided by O'Dell Construction reportedly will be produced at a mine in Rockford, AL.

Offers for the first allotment ranged from $37.00 to $45.00 per pound of contained tantalum pentoxide. O'Dell Construction Co. was the low bidder. Offers for the second allotment ranged from $36.62 to $47.00 per pound of contained tantalum pentoxide. Sogem-Afrimet was the low bidder.

At about the time the bids were opened, the Metals Week and Metal Bulletin published price for tantalite ore ranged from $27.00 to $28.50 and $27 to $33 per pound of tantalum pentoxide, respectively.

The U.S. Department of Defense's planned targets of opportunity for fiscal year 1991 included the purchase of an additional 200,000 pounds of tantalum pentoxide contained in tantalum natural minerals and concentrates for the NDS.

Strategic Considerations

The high degree of import reliance for columbium and tantalum continues to be the principal strategic problem faced by the United States. 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

TABLE 7

COLUMBIUM AND TANTALUM MATERIALS IN GOVERNMENT INVENTORIES AS OF DECEMBER 31, 1990

(Thousand pounds of columbium or tantalum content)

Material	Stockpile goals	National Defense Stockpile inventory		
		Stockpile-grade	Nonstockpile-grade	Total
Columbium:				
Concentrates	13,270	1,150	869	[1]2,019
Carbide powder	100	21	—	21
Ferrocolumbium	—	598	333	[1]931
Metal	—	45	—	[1]45
Total	([2])	1,814	1,202	3,016
Tantalum:				
Minerals	8,400	1,686	1,152	[3]2,838
Carbide powder	—	29	—	[3]29
Metal	—	201	([4])	[3]201
Total	([2])	1,916	1,152	3,068

[1]All surplus ferrocolumbium and columbium metal were used to offset columbium concentrates shortfall. Total offset was 1,148,000 pounds.
[2]Overall goals, on a recoverable basis, total 12,520,000 pounds for the columbium metal group and 7,160,000 pounds for the tantalum metal group.
[3]All surplus tantalum carbide powder and tantalum metal were used to offset the tantalum minerals shortfall. Total offset was 271,000 pounds.
[4]100 pounds.

Source: Defense Logistics Agency, Defense National Stockpile Center.

goals. Consequently, a degree of vulnerability still remains.

Issues

At the start of the 1980's, there were four major processors of columbium- and tantalum-bearing source materials (feedstocks). One of the operations was shut down in 1985, and another shut down its processing operation at yearend 1989. Of the remaining two companies, one is dedicated solely to the processing of columbium materials, whereas the other company processes both columbium and tantalum materials. The NDS goals and inventory for both columbium and tantalum are mostly for source materials. Thus, it is assumed that the United States would have on hand in an emergency adequate processing capacity for conversion of the material to an upgraded form and quality required by the critical end uses. However, the United States has become more reliant on the processing capability of foreign sources and the availability of intermediate products from those sources.

Production

In 1990, there were only 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. was a major producer of tantalum products, and 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.

Additionally, Thai Tantalum Co. Ltd. (TTA), formally Thailand Tantalum Industry Corp. Ltd. (TTIC) of Bangkok, reportedly began production of a range of precursor powders at its tantalum facility in Muskogee, OK, in late 1990. The powders produced at Muskogee were to be shipped to TTA's other tantalum facility in Gurnee, IL, where the powders will be upgraded to capacitor-grade quality. Commercial-scale production of the capacitor powders at Gurnee was to commence in early 1991.

Buttes Gas & Oil Co. reportedly entered into an agreement with Teck Corp., Vancouver, British Columbia, to develop Buttes' Powderhorn titanium property in Gunnison, CO. Teck would earn a 60% interest in Powderhorn by taking the property to commercial production. The property reportedly contains significant quantities of columbium in the form of the mineral perovskite.

Consumption and Uses

Overall reported consumption of columbium as ferrocolumbium and nickel columbium rose by 6% compared with that of 1989. Consumption of columbium by the steelmaking industry was up slightly in line with a small increase in raw steel production, with virtually no change in the percentage of columbium usage per ton of steel produced. Consumption in all reported steel end-use categories was down with the exception of carbon steels, which increased by 15%. Demand for columbium in superalloys was up by 27% to the highest level since 1986. That portion used in the form of nickel columbium increased to more than 470,000 pounds to the highest level since 1985. U.S. columbium consumption, by end use, is shown in figure 2.

Overall consumption of tantalum was up from that of 1989, aided by increased demand from the electronics sector in the form of tantalum capacitor-grade powder. Tantalum shipments data were no longer available from the Tantalum Producers Association (TPA). The TPA was dissolved in December 1990. Factory sales of tantalum capacitors rose by 10%, as reported by the Electronic Industries Association. Additionally, the trend in recent years toward miniaturization of tantalum capacitors in the electronics industry continued. U.S. tantalum consumption, by end use, is shown in figure 3.

Markets and Prices

A published price for pyrochlore concentrates was not available. The published price for pyrochlore produced in Canada was suspended in early 1989, and a price for Brazilian pyrochlore has not been available since 1981 when exports were stopped. Unchanged since midyear 1989, the Metals Week published price for regular-grade ferrocolumbium was $6.00 to $6.58 per pound of contained columbium, f.o.b. shipping port.

The Metals Week published price for high-purity ferrocolumbium containing 62% to 68% columbium remained at $17.50 per pound of contained columbium, f.o.b. shipping point, and the

TABLE 8

MAJOR DOMESTIC COLUMBIUM AND TANTALUM PROCESSING AND PRODUCING COMPANIES IN 1990

Company	Plant location	Products[1]						
		Metal[2]		Carbide		Oxide and/or salts		FeCb and/or NiCb
		Cb	Ta	Cb	Ta	Cb	Ta	
Cabot Corp.	Boyertown, PA	X	X	—	—	X	X	—
Do.	Revere, PA	—	—	—	—	—	—	X
Kennametal Inc.	Latrobe, PA	—	—	X	X	—	—	—
NRC Inc.[3]	Newton, MA	X	X	—	—	—	—	—
Reading Alloys Inc.	Robesonia, PA	—	—	—	—	—	—	X
Shieldalloy Metallurgical Corp.	Newfield, NJ	—	—	—	—	—	—	X
Teledyne Inc.: Teledyne Wah Chang Albany Div.	Albany, OR	X	—	—	—	X	—	X

X Indicates processor and/or producer.
[1]Cb, columbium; Ta, tantalum; FeCb, ferrocolumbium; NiCb, nickel columbium.
[2]Includes miscellaneous alloys.
[3]Jointly owned by Bayer U.S.A. and Hermann C. Starck Berlin KG.

published spot price for columbite ore continued at a range of $3.00 to $3.50 per pound of contained Cb_2O_5 and Ta_2O_5, c.i.f. U.S. ports. Also unchanged for the year, the published price for nickel columbium was $19.50 per pound of contained columbium, the published price for columbium oxide was $7.64 per pound of oxide, and the 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 60% combined Cb_2O_5 and Ta_2O_5, c.i.f. U.S. ports, began the year at $26 to $28 per pound, rose to $34 to $36 by midyear, and then widened in the fourth quarter to finish the year at $31 to $35. The Metal Bulletin published price for tantalite rose from $29 to $35 per pound of contained Ta_2O_5 to $34 to $37 by year-end. 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 $50 per pound. A published price for tantalite from the Canadian producer, Tantalum Mining Corp. of Canada Ltd. (TANCO), was not available. Tantalum capacitor-grade powder reportedly sold for about $120 per pound, and tantalum mill products reportedly sold for about $160 per pound.

Foreign Trade

Net trade for columbium and tantalum remained at a deficit, but closed to about one-half the 1989 deficit. Overall trade value for exports was relatively unchanged, with total volume up by 25%, owing to a significant increase in the volume of ferrocolumbium exports to Canada. Exports of columbium and tantalum ores and concentrates decreased substantially to 108,000 pounds valued at $365,000. Germany was the principal recipient, with more than 50% of total shipments. For imports, trade volume and value were down appreciably for most items, the major exception being a significant increase in columbium oxide imports from Brazil.

Imports for consumption of columbium mineral concentrates were virtually unchanged from those of 1989. Canada remained the leading supplier, providing almost all of both total quantity and total value. Imports at an average grade of approximately 61% Cb_2O_5 and less than 1% Ta_2O_5 were estimated to contain 2.12 million pounds of columbium and a small quantity of tantalum.

Imports for consumption of tantalum mineral concentrates declined substantially, with the average unit value for overall imports decreasing by more than 15%. Imports from Belgium-Luxembourg and the Federal Republic of Germany, both nonproducing countries, together accounted for about 50% of total quantity and value. Imports at an average grade of approximately 35% Ta_2O_5 and 23% Cb_2O_5 were estimated to contain 640,000 pounds of tantalum and 360,000 pounds of columbium.

Imports for consumption of synthetic tantalum-columbium concentrates declined significantly: 113,000 pounds valued at $1.5 million compared with 170,000 pounds valued at $2.2 million in 1989. These figures are not included in the salient statistics data.

Brazil continued as the major source for U.S. columbium imports, and the Federal Republic of Germany remained the major source for U.S. tantalum imports (see figures 4 and 5).

World Review

Industry Structure.—Brazil and Canada remained as the major producers of columbium raw materials feedstock, while tantalum raw materials continued to be produced mainly in Australia, Brazil, Canada, and in Thailand in the form of high-grade tantalum-bearing tin slags. Synthetic concentrates, produced from low-grade tin slags, from the Federal Republic of Germany were an additional source of columbium and tantalum raw material supply. Principal world raw material and product producers are shown in tables 15 and 16, respectively.

Capacity.—The data in table 17 are rated capacity for mines and mills as of December 31, 1990. 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

TABLE 9

REPORTED SHIPMENTS OF COLUMBIUM AND TANTALUM MATERIALS

(Pounds of metal content)

Material	1989	1990
Columbium products:		
Compounds, including alloys	993,575	NA
Metal, including worked products	465,800	NA
Other	—	NA
Total	1,459,375	NA
Tantalum products:		
Oxides and salts	7,260	NA
Alloy additive	77,890	NA
Carbide	NA	NA
Powder and anodes	448,400	NA
Ingot (unworked consolidated metal)	1,000	NA
Mill products	275,200	NA
Scrap	10,200	NA
Other	—	NA
Total	819,950	NA

NA Not available.

Source: Tantalum Producers Association.

TABLE 10

CONSUMPTION, BY END USE, AND INDUSTRY STOCKS OF FERROCOLUMBIUM AND NICKEL COLUMBIUM IN THE UNITED STATES

(Pounds of contained columbium[1])

	1989	1990
END USE		
Steel:		
Carbon	r1,789,523	2,050,705
Stainless and heat-resisting	r867,689	796,351
Full alloy	(2)	(2)
High-strength low-alloy	1,823,685	1,787,363
Electric	—	—
Tool	(3)	(3)
Unspecified	64,959	27,220
Total	r4,545,856	4,661,639
Superalloys	r788,143	999,725
Alloys (excluding alloy steels and superalloys)	(4)	(4)
Miscellaneous and unspecified	42,967	37,200
Total consumption	r5,376,966	5,698,564
STOCKS		
Dec. 31:		
Consumer	NA	NA
Producer[5]	NA	NA
Total stocks[e]	NA	NA

[e]Estimated. [r]Revised. 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.

within a short period of time with minimum capital expenditure. Mine capacity for columbium and tantalum is based on published reports, maximum production statistics, and estimates where capacity information is either incomplete or unavailable.

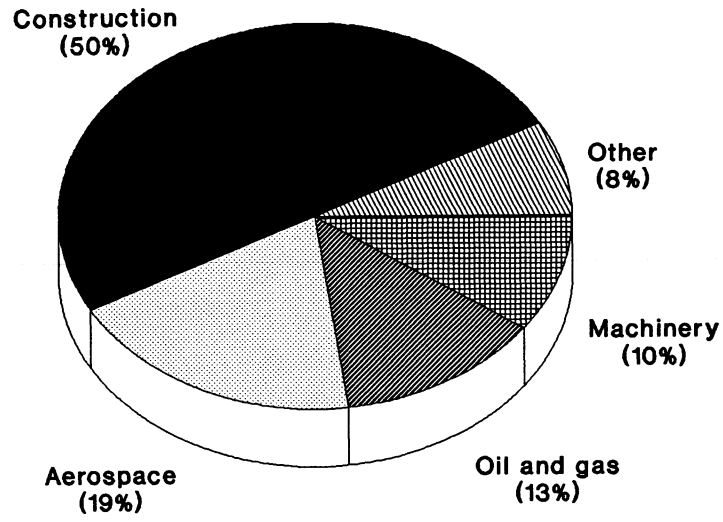
Australia.—For its fiscal year ending June 30, 1990, Gwalia Consolidated Ltd. reported that, as a result of mergers, all company operations at Greenbushes have been consolidated and will be conducted as a single business unit known as the "Greenbushes Mine." Ore treated at Greenbushes was down by about 30% to 1.7 million tons, with tantalum oxide production in tantalum concentrates decreasing to about 203,000 pounds. The tailings retreatment plant produced 99,400 pounds of Ta_2O_5 contained in tantalum concentrates, and tantalum oxide contained in tantalum glass (slag) production rose to 87,000 pounds. The mine's chemical plant produced 12,300 pounds of Ta_2O_5 and 4,700 pounds of Cb_2O_5, both down from the production levels of 1989. Feasibility and marketing studies were being conducted to make a decision, prior to March 1991, with respect to future mine operation and the marketing of products produced.[1]

Brazil.—Production of ferrocolumbium was 17,747 tons, 14,440 tons produced by Cia. Brasileira de Metalurgia e Mineração (CBMM) and 3,307 tons produced by Mineração Catalão de Goiás S.A. (CATALAO). CBMM also produced 1,709 tons of columbium oxide, up considerably from the 418 tons produced in 1989. CBMM reportedly started construction of a new ferrocolumbium plant in Araxa. With a planned annual ferrocolumbium capacity of about 25,000 tons, the plant will cost about $8 million to construct. The new facility is said to be more cost effective, will allow for production of ferrocolumbium to a tighter specification, and will eliminate atmospheric pollution.

Canada.—As reported by Teck Corp. (operator) and Cambior Inc. (product marketing and sales), production of Cb_2O_5 at the Niobec Mine at St. Honoré, Quebec, a 50-50 joint venture, was down from the record level in 1989 to 7.5 million pounds. Ore milled was virtually unchanged at 876,000 tons, as the mill operated on the average of 2,399 tons of ore per day. Average recovery was

FIGURE 2

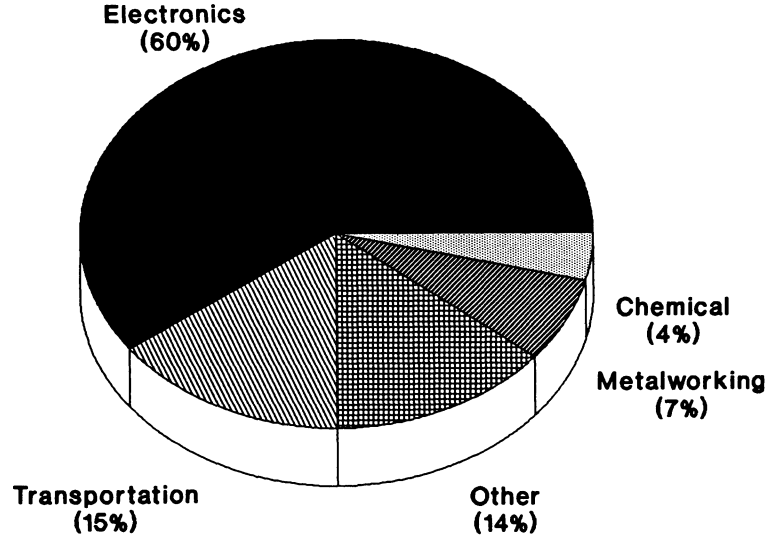
U.S. COLUMBIUM END USE IN 1990



7.4 MILLION POUNDS

FIGURE 3

U.S. TANTALUM END USE IN 1990



860,000 POUNDS

TABLE 11

U.S. FOREIGN TRADE IN COLUMBIUM AND TANTALUM METAL AND ALLOYS, BY CLASS

(Thousand pounds, gross weight, and thousand dollars)

Class	1989		1990		Principal destinations and sources, 1990
	Quantity	Value	Quantity	Value	
EXPORTS[1]					
Tantalum:					
Unwrought and waste and scrap	167	3,412	196	3,862	Federal Republic of Germany 176, $2,993; Canada 12, $481; Belgium-Luxembourg 2, $126; Austria 2, $89; Netherlands 2, $82.
Unwrought powders	211	21,451	182	21,638	Federal Republic of Germany 55, $6,177; France 38, $4,303; United Kingdom 35, $4,202; Japan 35, $3,957; Spain 10, $1,202.
Unwrought alloys and metal	11	1,099	28	3,700	Canada 25, $3,324; Japan 1, $88; Spain 1, $69; Netherlands (2), $49.
Wrought	180	21,715	132	20,068	Japan 58, $8,650; Federal Republic of Germany 18, $3,204; United Kingdom 23, $3,049; France 12, $2,458; Canada 11, $1,088.
Total	XX	47,677	XX	49,268	Japan $12,700; Federal Republic of Germany $12,500; France $6,800; Canada $4,900.[3]
IMPORTS FOR CONSUMPTION					
Columbium:					
Oxide	1,454	9,470	2,145	15,348	Brazil 1,958, $13,006; Federal Republic of Germany 187, $2,339; United Kingdom (2), $2.
Ferrocolumbium	8,178	28,657	6,435	24,685	Brazil 6,412, $24,587; Canada 23, $98.
Unwrought alloys, metal, and powders	26	514	5	150	Federal Republic of Germany 2, $78; Brazil 3, $72.
Tantalum:					
Unwrought waste and scrap	159	7,142	169	6,990	Federal Republic of Germany 74, $4,355; France 27, $821; United Kingdom 13, $550; Taiwan 13, $476.
Unwrought powders	45	2,880	28	2,038	Federal Republic of Germany 13, $1,056; Hong Kong 10, $692; Australia 1, $63.
Unwrought alloys and metal	35	1,573	12	733	Federal Republic of Germany 5, $379; France 3, $148; Austria 2, $100; Australia 2, $92.
Wrought	2	431	7	1,028	Federal Republic of Germany 2, $593; Canada 4, $416; Austria (2), $10; United Kingdom (2), $4.
Total	XX	50,667	XX	50,972	Brazil $37,700; Federal Republic of Germany $8,800; France $1,000.[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.

down to 60.4% with Cb_2O_5 grade of concentrate at 71%. Lower recovery was attributed to treatment of more refractory ore. Yearend ore reserves decreased to 11 million tons assaying 0.65% Cb_2O_5, reportedly sufficient for 14 years of production. Expansion of the mine's tailings storage capacity is scheduled for late 1991. When construction is completed on the tailings pond, the mine will have an additional 12 years of storage capacity.

Germany, Federal Republic of.—Hermann C. Starck Berlin KG announced that it had increased its holding in V Tech of Japan, a tantalum capacitor powder producer, to 92%, with the balance being held by V Tech management. Starck had acquired a 54% interest in V Tech from Fansteel Inc. (USA) in December 1989, when Fansteel sold most of its domestic and foreign tantalum business.

Japan.—Production of ferrocolumbium was 1,085 tons, up considerably from the 812 tons produced in 1989. Columbium ore imported for ferrocolumbium production increased by 70% to 1,291 tons, with Canada providing more than 80% of the total. Ferrocolumbium imports fell to 3,876 tons from the 3,957 tons reported in 1989. The bulk of ferrocolumbium imports continued to come from Brazil.

Thailand.—Thai Tantalum Co. Ltd. (TTA), formerly Thailand Tantalum Industry Corp. Ltd. (TTIC) of Bangkok, reportedly commenced civil work for construction of a tantalum-processing plant at the Map Ta Phut Industrial Estate in Rayong Province east of Bangkok. The new facility will replace TTA's tantalum plant that was destroyed by fire in June 1986. The fire followed demonstrations by protestors against the opening of the chemical plant because of environmental concerns over the plant's waste treatment facilities and acid storage areas.

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF COLUMBIUM MINERAL CONCENTRATES, BY COUNTRY

(Thousand pounds and thousand dollars)

Country	1989		1990	
	Gross weight	Value	Gross weight	Value
Brazil	12	281	53	91
Canada	4,879	7,368	4,899	7,787
Zaire	—	—	11	20
Total[1]	4,891	7,649	4,964	7,898

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

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

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF TANTALUM MINERAL CONCENTRATES, BY COUNTRY

(Thousand pounds and thousand dollars)

Country	1989		1990	
	Gross weight	Value	Gross weight	Value
Australia	118	2,322	163	2,835
Austria[1]	1	62	—	—
Belgium-Luxembourg[1]	244	3,036	92	886
Bolivia	3	75	3	38
Brazil	244	2,873	338	3,563
Burundi[1]	—	—	21	250
Canada	154	2,429	253	2,795
Germany, Federal Repubic of[1]	2,085	26,918	1,081	11,985
Hong Kong[1]	77	1,279	—	—
Japan[1]	120	1,796	—	—
Malaysia	—	—	12	143
Netherlands[1]	491	7,417	14	203
Singapore[1]	52	747	—	—
Spain	—	—	13	116
Thailand	118	2,073	39	490
United Kingdom[1]	29	566	1	19
Zaire	112	1,124	167	1,895
Zimbabwe	2	43	44	371
Total[2]	3,850	52,762	2,240	25,589

[1]Presumably country of transshipment rather than original source.
[2]Data may not add to totals shown because of independent rounding.

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

Completion of major civil work is planned by third quarter 1991, with production of columbium oxide and potassium fluotantalate to commence first quarter 1992. Availability of high-quality tantalum capacitor-grade powders is anticipated by first quarter 1992. The cost of the facility has been estimated at $30 million and will have a combined columbium and tantalum product annual capacity of about 600 tons. The plant will use domestically produced columbium and tantalum feedstock materials, and product production will be exclusively for export.

Laporte Ltd. of Thailand reportedly began construction of a hydrofluoric acid plant at Map Ta Phut. TTA indicates that the plant will supply the tantalum plant with all of its hydrofluoric acid requirements.

OUTLOOK

Columbium

Columbium is used principally as an additive in steelmaking, which has accounted for about 80% of the reported consumption in the United States in recent years. No significant change to this trend is expected in the near term for there are few other growth markets and/or uses for columbium. Thus, future columbium demand growth will continue to be directly related to the worldwide performance of the steel industry. The outlook for steel is discussed in the annual report for Iron and Steel. A boost for columbium consumption in steelmaking has been the price volatility in recent years for competing ferroalloys of titanium and vanadium. Some steel companies reportedly have initiated projects for the substitution of columbium for titanium and vanadium in steelmaking. Domestic columbium consumption in the production of superalloys is currently about 15%. Future growth for this end use will be affected mainly by the demand for columbium-containing superalloys from the aircraft industry, which continues to have an up and down cyclical history. The major components of U.S. supply-demand relationships for columbium in 1980-90 are given in table 19.

Tantalum

During the 1980's, more than 60% of the tantalum consumed in the United

TABLE 14

U.S. IMPORT DUTIES ON COLUMBIUM AND TANTALUM MATERIALS

Item	HTSUS No.	Rate of duty effective January 1, 1990	
		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 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]2.2% ad valorem for products of Canada.
[4]Nonspecific tariff classification.
[5]1.8% ad valorem for products of Canada.
[6]Free from beneficiary countries under the CBERA and for products of Israel.
[7]3% ad valorem for products of Canada.
[8]3.3% ad valorem for products of Canada.
[9]2.9% ad valorem for products of Canada.

FIGURE 4

MAJOR SOURCES OF U.S. COLUMBIUM IMPORTS

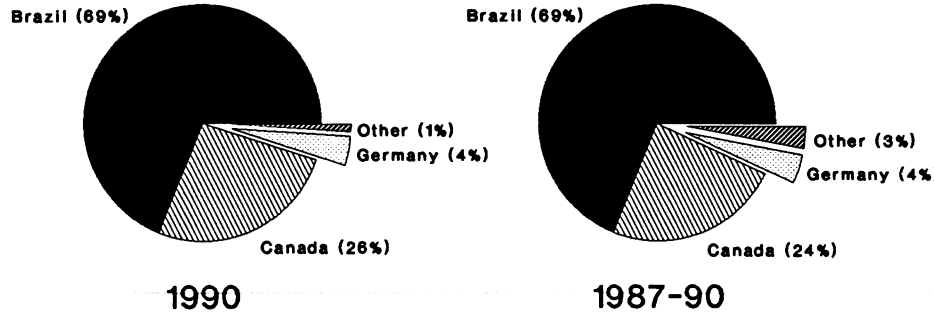


FIGURE 5

MAJOR SOURCES OF U.S. TANTALUM IMPORTS

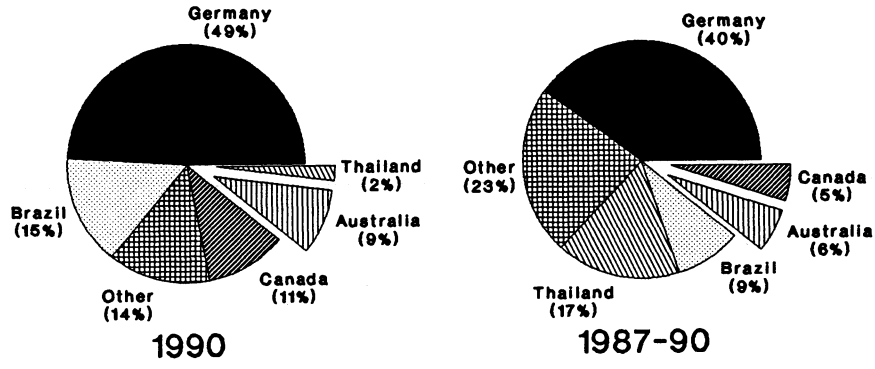


TABLE 15

PRINCIPAL WORLD COLUMBIUM AND TANTALUM RAW MATERIAL PRODUCERS

Country	Company and/or Mine	Material type
	MINING OF COLUMBIUM- AND TANTALUM-BEARING ORES	
Australia	Gwalia Consolidated Ltd. (Greenbushes)	Columbium/tantalum.
	Pan West Tantalum Pty. Ltd. (Wodgina)	Tantalum.
Brazil	Cia. Brasileira de Metalurgia e Mineração (CBMM) (Araxa)	Columbium.
	Cia. de Estanho Minas Brasil (MIBRA)[1]	Columbium/tantalum.
	Paranapanema S.A. Mineração Indústria e Construção (Pitinga)	Columbium/tantalum.
	Mineração Catalão de Goiás S.A. (Catalão)	Columbium.
Canada	Cambior/Teck Corp. (Niobec)	Columbium.
	Tantalum Mining Corp. of Canada Ltd. (Tanco)	Tantalum.
China	Government-owned	Columbium/tantalum.
U.S.S.R.	Government-owned	Columbium/tantalum.
Zaire	Société Minière du Kivu (SOMIKIVU)[1]	Columbium.
	PRODUCTION OF COLUMBIUM- AND TANTALUM-BEARING TIN SLAGS	
Australia	Gwalia Consolidated Ltd. (Greenbushes)	
Brazil	Cia. Industrial Fluminense.[1]	
	Mamoré Mineração e Metalurgia.[2]	
Malaysia	Malaysia Smelting Corp. Sdn. Bhd.	
Thailand	Thailand Smelting and Refining Co. Ltd. (Thaisarco).	
	PRODUCTION OF COLUMBIUM- AND TANTALUM-BEARING SYNTHETIC CONCENTRATES	
Germany, Federal Republic of		
Western states	Gesellschaft Für Elektrometallurgie mbH (GFE).[1]	
	Hermann C. Starck Berlin KG.	

[1]A wholly owned subsidiary of Metallurg Inc., New York.
[2]A subsidiary of Paranapanema S.A. Mineração Indústria e Construção.

TABLE 16

PRINCIPAL WORLD PRODUCERS OF COLUMBIUM AND TANTALUM PRODUCTS

Country	Company	Products[1]
Australia	Gwalia Consolidated Ltd. (Greenbushes)	Cb and Ta oxide.
Austria	Treibacher Chemische Werke AG	Cb and Ta oxide/carbide, FeCb, NiCb.
Brazil	Cia. Brasileira de Metalurgia e Mineração (CBMM)	Cb oxide/metal, FeCb, NiCb.
	Cia. Industrial Fluminense[2]	Cb and Ta oxide.
	Mineração Catalão de Goiás S.A. (Catalão)	FeCb.
Germany, Federal Republic of:		
Western states	Gesellschaft Für Elektrometallurgie mbH (GFE)[2]	Cb and Ta oxide/metal, K-salt, FeCb, NiCb, Ta capacitor powder.
	Hermann C. Starck Berlin KG	Cb and Ta oxide/metal/carbide, K-salt, FeCb, NiCb, Ta capacitor powder.
Japan	Awamura Metal Industry Co. Ltd.	FeCb.
	Japan Metals & Chemicals Co. Ltd.	FeCb.
	Mitsui Mining and Smelting Co.	Cb and Ta oxide/metal/carbide.
	Showa Cabot Supermetals[3]	Ta capacitor powder.
	Taiyo Mining & Industrial Co. Ltd.	FeCb.
	V Tech[4]	Ta capacitor powder.
United Kingdom	London & Scandinavian Metallurgical Co. Ltd.[2]	Cb and Ta carbide.
United States	Cabot Corp.	Cb and Ta oxide/metal, K-salt, FeCb, NiCb, Ta capacitor powder.
	Kennametal, Inc.	Cb and Ta carbide.
	NRC, Inc.[5]	Cb and Ta metal, Ta capacitor powder.
	Reading Alloys, Inc.	FeCb, NiCb.
	Shieldalloy Metallurgical Corp.[2]	FeCb, NiCb.
	Teledyne Wah Chang Albany	Cb oxide/metal, FeCb, NiCb.

[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 17

WORLD COLUMBIUM AND TANTALUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990

(Thousand pounds of columbium or tantalum content)

Country	Rated capacity[1 2]	
	Columbium	Tantalum
North America:		
Canada	5,000	200
United States	—	—
Total	5,000	200
South America: Brazil	40,000	400
Africa:		
Nigeria	400	100
Zaire	100	100
Other	200	200
Total	700	400
Asia:		
Malaysia	200	200
Thailand	600	800
Total	800	1,000
Oceania: Australia	200	400
World total (may be rounded)	47,000	2,400

[1]Includes capacity at operating facilities as well as facilities on standby basis.
[2]Includes estimated byproduct recovery as tin slag.

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 because of the industry's continued emphasis on higher capacitance powders and the miniaturization of electronic components resulting in less tantalum used per unit. A similar situation exists for tantalum in cemented carbide use. Tantalum demand in this market has been affected by the growing use of mixed carbides, coated cutting tools, improved tool life, and the down-sizing of components. Additionally, the demand and price for tantalum has had a cyclical and somewhat volatile history. Thus, the future growth for tantalum will continue to depend not only on the fortunes of the electronic and carbide industries but also on tantalum's price stability. The major components of U.S. supply-demand relationships for tantalum in 1980–90 are given in table 20.

[1]Gwalia Consolidated Ltd. 1990 Annual Report. 59 pp.

TABLE 18

COLUMBIUM AND TANTALUM: WORLD PRODUCTION OF MINERAL CONCENTRATES, BY COUNTRY[1]

(Thousand pounds)

Country[2]	Gross weight[3]					Columbium content[e 4]					Tantalum content[e 4]				
	1986	1987	1988	1989	1990[e]	1986	1987	1988	1989	1990	1986	1987	1988	1989	1990
Australia: Columbite-tantalite	309	351	498	1,224	1,224	64	60	70	141	141	109	115	164	263	263
Brazil:															
Columbite-tantalite	604	r985	r888	r961	822	139	226	r204	r222	190	175	285	r257	r279	239
Pyrochlore	63,354	r37,734	r74,547	r58,045	50,706	26,610	r15,849	r31,310	r24,379	21,385	—	—	—	—	—
Canada:[e]															
Pyrochlore	11,500	9,490	11,530	12,000	11,622	5,160	4,270	5,190	5,400	5,230	—	—	—	—	—
Tantalite	—	—	200	650	730	—	—	8	20	21	—	—	60	160	180
Malaysia: Columbite-tantalite	474	503	—	—	[5]9	71	75	—	—	1	33	35	—	—	1
Mozambique:															
Microlite	e13	—	—	—	—	NA	—	—	—	—	7	—	—	—	—
Tantalite	e9	—	—	—	—	NA	—	—	—	—	3	—	—	—	—
Namibia: Tantalite	18	30	r15	r13	11	3	3	r2	r1	2	3	5	r2	r1	2
Nigeria: Columbite	29	106	110	r101	[5]97	12	45	46	r43	41	2	6	6	6	5
Portugal: Tantalite	13	—	—	—	—	3	—	—	—	—	4	—	—	—	—
Rwanda: Columbite-tantalite	—	—	(6)	(6)	(6)	—	—	(6)	(6)	(6)	—	—	(6)	(6)	(6)
South Africa, Republic of:															
Columbite-tantalite	—	(6)	(6)	(6)	(6)	—	(6)	(6)	(6)	(6)	—	(6)	(6)	(6)	(6)
Spain: Tantalite	e26	e22	24	e24	24	NA	NA	NA	NA	NA	7	6	6	6	6
Thailand: Columbite-tantalite	267	403	273	240	[5]20	46	69	46	41	3	73	109	74	65	5
Zaire: Columbite-tantalite	e110	e110	r74	r106	110	30	30	r19	r28	29	31	31	r21	r30	31
Zimbabwe: Columbite-tantalite	73	82	146	71	73	11	6	22	11	11	26	13	51	25	26
Total	76,799	r49,816	r88,305	r73,435	65,448	32,149	r20,633	r36,917	r30,286	27,054	473	605	r641	r835	758

[e]Estimated. [r]Revised. NA Not available.

[1]Excludes columbium- and tantalum-bearing tin slags. Production of tantalum contained in tin slags was, in thousand pounds, 1986—623; 1987—543; 1988—1,145; 1989—799; and 1990—756 according to data from the Tantalum-Niobium International Study Center. Table includes data available through June 21, 1991.

[2]In addition to the countries listed, China, the U.S.S.R., and Zambia also produce, or are believed to produce, columbium and tantalum mineral concentrates, but available information is inadequate to make reliable estimates of output levels.

[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. Metal content estimates are revised as necessary to reflect changes in gross weight and/or pentoxide data.

[5]Reported in and/or by official country sources.

[6]Less than 1/2 unit.

FIGURE 6

WORLD TANTALUM SUPPLY

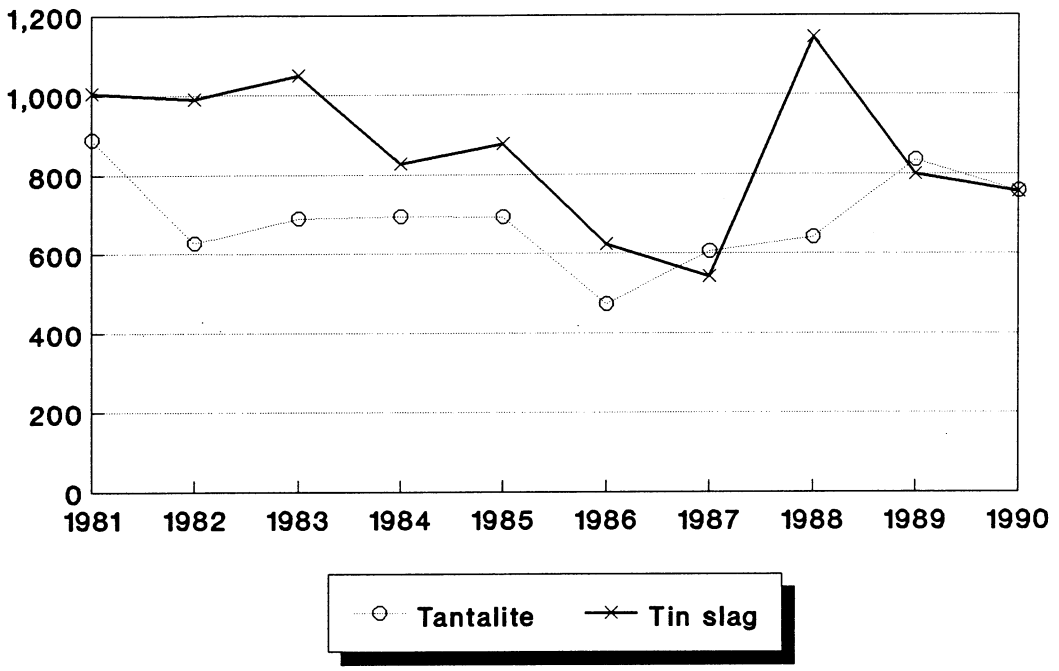


TABLE 19

COLUMBIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand pounds columbium content)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990[p]
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mine production	([1])	([1])	([1])	—	—	—	—	—	—	([1])	([1])
Shipments of Government stockpile excesses	—	—	—	—	—	—	—	—	—	—	—
Imports[2]	9,728	7,960	[e]4,353	W	W	W	W	W	NA	NA	NA
Industry stocks, Jan. 1	6,631	8,581	8,332	W	W	W	W	W	NA	NA	NA
Total U.S. supply	16,359	16,541	12,685	W	W	W	W	W	NA	NA	NA
Distribution of U.S. supply:											
Industry stocks, Dec. 31	8,581	8,332	[e]5,971	W	W	W	W	W	NA	NA	NA
Exports[e]	171	91	88	78	80	77	72	85	100	[r]230	200
Government accessions	—	—	26	—	—	213	—	—	—	—	—
Industrial demand	7,607	8,118	6,600	5,750	7,670	7,550	7,060	7,300	7,900	[r]7,500	7,400
U.S. DEMAND PATTERN											
Construction	2,360	3,166	2,706	2,300	2,920	3,320	3,110	3,140	3,710	[r]3,750	3,700
Machinery:											
Metalworking machinery	210	284	214	173	230	227	211	200	200	[r]180	180
Special industry machinery	627	853	644	517	614	604	564	610	590	[r]560	560
Total	837	1,137	858	690	844	831	775	810	790	[r]740	740
Oil and gas industries	1,215	1,624	1,122	748	1,070	1,130	920	950	790	[r]980	960
Transportation	2,435	1,623	1,518	1,495	1,990	1,890	1,690	1,530	1,740	[r]1,430	1,400
Other	760	568	396	517	846	379	565	870	870	[r]600	600
Total U.S. primary demand	7,607	8,118	6,600	5,750	7,670	7,550	7,060	7,300	7,900	[r]7,500	7,400

[e]Estimated. [p]Preliminary. [r]Revised. 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 20

TANTALUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand pounds tantalum content)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990[p]
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mine production	(1)	(1)	(1)	—	—	—	—	—	—	(1)	(1)
Secondary[e]	121	95	89	40	130	90	75	125	130	120	120
Shipments of Government stockpile excesses	—	—	—	—	—	—	—	—	—	—	—
Imports[2]	2,280	1,580	[e]1,087	W	W	W	W	W	NA	NA	NA
Industry stocks, Jan. 1	2,753	3,261	3,452	W	W	W	W	W	NA	NA	NA
Total U.S. supply	5,154	4,936	4,628	W	W	W	W	W	NA	NA	NA
Distribution of U.S. supply:											
Industry stocks, Dec. 31	3,261	3,452	[e]3,195	W	W	W	W	W	NA	NA	NA
Exports[e]	706	222	340	262	383	320	312	376	564	[r]430	380
Government accessions	—	—	33	—	—	254	—	—	—	—	—
Industrial demand	1,187	1,262	1,060	1,181	1,680	800	820	840	930	[r]830	860
U.S. DEMAND PATTERN											
Electronic components	862	882	703	733	1,052	444	484	504	610	[r]500	520
Transportation	70	102	121	165	218	131	123	126	70	[r]120	130
Machinery:											
Chemical equipment	72	83	69	47	60	48	44	34	30	[r]30	30
Metalworking machinery	152	192	138	189	264	102	112	59	60	[r]60	60
Total	224	275	207	236	324	150	156	93	90	[r]90	90
Other	31	3	29	47	86	75	57	117	160	[r]120	120
Total demand	1,187	1,262	1,060	1,181	1,680	800	820	840	930	[r]830	860
Total U.S. primary demand (industrial demand less secondary)	1,066	1,167	971	1,141	1,550	710	745	715	800	[r]710	740

[e]Estimated. [p]Preliminary. [r]Revised. 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.

OTHER SOURCES OF INFORMATION

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World Mining.

COPPER

By Janice L. W. Jolly and Daniel L. Edelstein

Mrs. Jolly is a physical scientist (geologist) with more than 30 years in the mining industry, including 17 years with the U.S. Bureau of Mines. She worked as a research geologist on mineral deposits with the U.S. Geological Survey and Roan Selection Trust, Ltd., of Zambia and as a consultant on mineral affairs with the U.S. House of Representatives Armed Services Committee and the World Bank. Mrs. Jolly is currently the copper specialist for the U.S. Bureau of Mines, a position she has held since 1983.

Mr. Edelstein is a physical scientist (geologist) with more than 16 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 8 years as well as the specialist for the copper byproduct metals, selenium and tellurium.

Domestic survey data were prepared by Lisa Conley, Lisa Christian, and Wannette Davis, mineral data assistants, and Jean Moore, data controller. The world production tables were prepared by Audrey D. Wilkes, Harold Willis, and Virginia Woodson, international data coordinators, from data provided by the foreign mineral specialists.

World copper mine production of almost 9 million tons and refined consumption of 11 million tons were at record levels. World supply and demand was more or less in balance throughout the year. Copper demand by U.S. semifabricators was higher during the first half of the year, but declined in the last 3 months of the year as a result of the recession in domestic markets. Increased world demand continued to be driven by increased consumption in the Asian countries. Increased supplies from new capacity in Chile, Indonesia, Portugal, and the United States were offset by disruptions at other sources and the continued closure of the Bougainville Mine, Papua New Guinea. Serious mine accidents in both Chile and Zaire and sporadic labor disputes also restrained the flow of copper. At yearend, visible refined inventories increased slightly to an estimated 684,000 tons, slightly more than 4 weeks of market economy countries (MEC) consumption.[1] The U.S. producers' average annual price, at $1.21 per pound, was lower than that of 1989, reflecting more pessimism about the economy and the future copper market than actual surplus supply of the time. U.S. exports of scrap, concentrates, and refined copper continued to be high; most were destined for Far Eastern markets in Japan, Taiwan, and the Republic of Korea.

In the United States, ownership changes and modernization continued, but were more prevalent on the copper consuming and secondary processing side of the industry. Permits were received to begin building a new mine in Wisconsin, and the first underground mine to open in Oregon since World War II started production during the year. Several older mines in Arizona and New Mexico were being prepared for reopening; the Superior Mine, AZ, reopened late in the year.

DOMESTIC DATA COVERAGE

Domestic production data for copper were developed by the U.S. Bureau of Mines from seven separate surveys of U.S. operations. Typical of these surveys is the mine production survey. Of 119 operations to which a survey request was sent in 1990, 91% responded and 71 reported copper production, representing an estimated 99.7% of the mine production shown in tables 1, 12, 15, and 16. Production for the remainder was estimated using other surveys.

BACKGROUND

Definitions, Grades, and Specifications

Copper is traded in its many forms that relate to differing stages of processing. For example, at the mine, copper may be sold as ore, concentrates, or precipitates. *Copper ore* may contain as little as 0.40% copper or more than 10% copper, depending upon its source. *Copper concentrates* are produced by milling and concentrating copper ore and may contain between 18% and 40% copper. *Copper precipitates, or cement copper,* are recovered from leach solutions by chemical precipitation with scrap iron and may contain as much as 90% copper.

Smelter products include copper matte, blister, slag, and anode. Slag is the waste formed in smelting through the combination of a *flux*, such as limestone and silica, with the gangue or waste portion of the ore and, though it may contain small amounts of copper, is high in silicon and iron. *Copper matte* contains between 15% and 65% copper, together with much of the sulfur and other nonferrous and precious metals. The newer flash smelting technologies result in a much lower sulfur content in the matte than was possible in the reverberatory furnaces. Copper matte is transferred to a converting furnace, where the sulfur and iron are oxidized and removed as sulfur dioxide gas and slag, respectively; the enriched copper melt (97% to 98.5% copper) is poured as *blister copper.* The blister is then *fire-refined* by oxidizing the impurities in a reverberatory furnace, followed by removal of the excess oxygen by a process called poling. Poling may be done by insertion of green logs or a reducing gas into the melt. The blister is then cast into *anode* shape and further treated in an electrolyte bath to form *refined copper cathode* through electrolysis, a process in which the copper ions of the anode are transferred by electrical current to the negatively charged cathode. Impurities in the copper anode, such as gold, selenium, and silver, are collected at the bottom of the electrolytic tank as a residue and are recovered in a later process. Cathode copper may also be obtained from an *electrowinning* process. In this process, cathode copper is plated directly from copper-bearing solutions obtained from leaching copper-bearing ore, matte, scrap, or other material and enriched by solvent extraction methods. Alternatively, the fire-refined blister, or scrap, may be cast into *ingots, bars, billets,* or *cakes,* and

TABLE 1

SALIENT COPPER STATISTICS

(Metric tons unless otherwise specified)

		1986	1987	1988	1989	1990
United States:						
Ore produced	thousand metric tons	172,476	202,632	223,576	r237,301	249,499
Average yield of copper	percent	0.60	0.57	0.60	r0.61	0.62
Primary (new) copper produced:						
From domestic ores, as reported by:						
Mines		1,144,213	1,243,596	1,416,928	r1,497,818	1,587,191
Value	millions	$1,666	$2,262	$3,764	r$4,324	$4,310
Percent of world total		14	15	17	17	18
Smelters[1]		908,087	972,141	r1,042,961	1,120,445	1,158,461
Refineries		r1,032,968	[2]1,126,908	r1,282,370	1,351,748	1,502,014
From foreign ores, matte, etc., as reported by refineries		41,013	W	123,650	125,085	74,620
Total new refined, domestic and foreign		1,073,981	1,126,908	1,406,020	1,476,833	[3]1,576,633
Refined copper from scrap (new and old)		405,944	414,738	446,427	r480,018	440,757
Secondary copper recovered from old scrap only		r479,213	497,937	518,179	r547,561	535,372
Exports:						
Refined		12,452	9,197	58,325	130,189	211,164
Unmanufactured[4]		442,000	387,000	557,000	r725,000	780,000
Imports for consumption:						
Refined		501,984	469,159	331,671	300,110	261,672
Unmanufactured[4]		r597,536	r568,441	r513,038	515,000	512,000
Stocks, December 31: Total industry and COMEX:						
Refined		r225,000	r113,000	r97,000	r107,000	101,000
Blister and materials in solution		136,000	150,000	121,000	132,000	119,000
Consumption:						
Refined copper (reported)		r2,097,351	r2,127,178	2,210,424	r2,203,116	2,150,426
Apparent consumption, primary and old copper (old scrap only)		r2,138,223	r2,196,540	r2,213,768	r2,180,840	2,167,892
Price: Weighted average, cathode, cents per pound, producers		66.05	82.50	120.51	130.95	123.16
World:						
Production:						
Mine	thousand metric tons	r7,939	r8,256	r8,455	p8,731	e8,815
Smelter	do.	r8,777	r8,897	r9,251	p9,510	e9,378
Refineries	do.	r9,505	r9,711	r10,199	p10,612	e10,642
Price: London, Grade A, average cents per pound[5]		62.28	80.88	117.92	r128.91	121.02

eEstimated. pPreliminary. rRevised. W Withheld to avoid disclosing company proprietary data.

[1]Includes copper content of blister and anodes produced from foreign ores and concentrates.

[2]Includes primary copper produced from foreign ores, matte, etc., to avoid disclosing company proprietary data.

[3]Data do not add to total shown because of independent rounding.

[4]Includes copper content of alloy scrap. Copper content of alloy scrap imported and exported in 1989 and 1990 was estimated from gross weight.

[5]High-grade prior to 1988.

not processed electrolytically in a refining tank before direct use.

Refined copper cathode, which contains greater than 99.3% copper, is the predominant form traded. *Tough-pitch copper* is refined copper cast into shapes. *Oxygen-free copper,* which is preferred for special electrical uses, is refined copper melted and recast in a deoxidizing atmosphere. *Deoxidized copper* is refined copper treated with deoxidizers to reduce cuprous oxide and remove oxygen. Normal refinery shapes cast from cathodes and fire-refined copper are wire bars, billets, slabs, ingots, and *bars.* Since the late 1970's, the *continuous cast wire rod* nearly has eliminated the wire bar as an intermediate shape used for making wire rod from refined copper. Wire rod is used to make wire of all types. *Wire bar* currently comprises less than 1% of the copper market. *Billets* typically are large cylindrical shapes often used for extruding tubing, or sometimes wire rod. *Slabs* are the precursors to flat products such as sheet. *Ingots* are small shapes that are usually remelted and used for making alloys.

There are more than 370 copper and copper alloys divided into broad categories of wrought and cast metals. A Unified Numbering System (UNS) for Metals and Materials was developed by the American Society for Testing and Materials (ASTM) and the Society of Automotive Engineers. This system designates each alloy by five digits preceded by the letter C. The UNS system is administered by the Copper Development Association (CDA) and is widely used by ingotmakers, brass mills, and foundries in the United States. The major classes are: *coppers*, which contain greater than 99.3% copper; *high-copper alloys*, which contain at least 94% copper; *brasses*, which contain zinc as the dominant alloying agent; *bronzes*, which normally contain tin as the dominant alloying agent, but which also may contain such other metals as aluminum, lead, phosphorous, and silicon, but only small amounts of zinc; *copper-nickels*, which contain nickel as the principal alloy metal; *nickel silver*, which contains copper, nickel, and zinc as the principal metals; *leaded coppers*, which are cast alloys containing 20% or more of lead, but no zinc or tin; and *special alloys*, which are copper alloys with compositions not covered in the above groups. *Master alloys* and *hardeners* are copper-base alloys cast with a high alloying element content and are used in producing copper alloys. Hardeners and master alloys not only permit closer composition control than possible by addition of pure metals, but also permit easier introduction of a deoxidizer, such as phosphorus. Beryllium copper master alloy, containing 7% to 10% beryllium, and phosphor copper, containing 10% to 14% phosphorus, are examples. The ASTM specifications for refined copper are designated in part 6, section B5-77 of the ASTM specifications and are under the jurisdiction of ASTM Committee B-5 on copper and copper alloys.

Geology

According to their mode of origin, copper deposits may be grouped in the following broad genetic classes: (1) porphyry copper deposits and their associated skarn, hydrothermal veins, and replacement breccia deposits; (2) deposits associated with ultramafic, mafic, and alkaline ultrabasic and carbonatite rocks; (3) volcanogenic and metavolcanogenic deposits; (4) sedimentary and metasedimentary deposits; and, (5) veins and replacement bodies associated with metamorphic sequences, not otherwise classified. As a percent of total world capacity, the predominant types mined were the porphyry copper and associated deposits (59%), stratiform sedimentary replacement and metasedimentary deposits (24%), volcanogenic massive sulfide deposits (7%), veins and replacement bodies (7%), and ultrabasic massive sulfide and carbonatite deposits (4%). Though the massive sulfide and vein and replacement deposits were much more numerous than the porphyry and stratiform sedimentary deposits, they tended to be smaller in both capacity and reserves, but generally contain a wider variety of other mineral coproducts. In the United States, porphyry copper deposits comprised about 93% and stratiform sedimentary and metasedimentary deposits about 6% of established mine capacity.

In recent years, plate tectonic theory has been emphasized in defining copper deposits as they relate to the Earth's lithospheric plates, their edges, subduction zones, and spreading axes in space and time. For example, deposits of the porphyry copper type occur mainly in magmatic, volcanic arc, and back-arc regions of plates overlying subduction zones; hence, their predominant location along areas such as the continental edges of North and South America. Copper deposits found in ultramafic sequences are characteristic of oceanic plate settings and ophiolite rock groups. Alkaline ultrabasic rocks and carbonatites intrude stable continental cratons and are presumed to have come from mantle-derived magmas contaminated with crustal rocks. At Palabora, the Republic of South Africa, a carbonatite is host to a copper deposit; as a significant producer of copper, this is a unique occurrence. Sedimentary copper deposits generally occur in rocks typical of passive continental margin and interior environments and intracontinental rift systems. In addition, these deposits may have been redistributed by later diagenetic or metamorphic hydrothermal systems, but retain their stratiform identity. *Stratiform* applies to a layered mineral deposit of any origin. *Stratibound* refers to a deposit confined by a single stratigraphic horizon.

Copper occurs in about 250 minerals; however, only a few are commercially important. The most common are chalcopyrite ($CuFeS_2$), covellite (CuS), chalcocite (Cu_2S), bornite (Cu_5FeS_4), enargite (Cu_3AsS), and tetrahedrite ($3Cu_2S \cdot Sb_2S_3$). Metals may be leached out of the rock above the water table by circulating ground water, oxidized, and enriched in the underlying supergene zone. The supergene capping of an ore body often contains the highest concentration of copper as chalcocite or as various copper oxide and silicate minerals. Native copper also occurs in the oxidized or supergene zones.

Technology

Exploration.—Exploration for copper deposits may take place in potential areas within which the anticipated copper deposit is masked by post-ore cover in the form of alluvium and volcanic or sedimentary rock. Following discovery of a potential deposit by geophysical and geochemical means, successively and increasingly intensive drilling campaigns to characterize and quantify the deposit are undertaken before a decision is made to bring a deposit into production. Continued drilling programs to extend identified reserves may continue throughout the production life of the deposit. As a result of ongoing exploration and acquisition programs, a mining company develops an inventory of exploration properties. As properties are explored and evaluated, they move up the development chart. As a potential property is better defined, it may become a candidate for development. Economic conditions determine whether there is a hiatus at this stage or whether the property can move on to development. Taking a prospect through all stages to a producing mine is full of risks and requires complex analyses in geology, metallurgy, engineering, and finance. Environmental considerations are also important in today's decision process.

Good geological concepts will lead an exploration team into a regional environment with the highest probability of economic discovery. In addition, before exploration or development occurs, political and economic factors also will be considered. These factors include the potential for expropriation, availability of land, ease of land acquisition, and local attitude of people toward mining, including environmental concerns. Economic factors include tax policy, transportation facilities, infrastructure power costs, availability of labor force, development incentives, and environmental and reclamation requirements. One analyst reported[2] that non-U.S. companies were exploring in the United States for two reasons: (1) the political environment was thought to be more attractive than the rest of the world, and (2) the geologic opportunity was

perceived as high. Other inducements were availability of markets, infrastructure, good work force, and the fact that North Americans were good explorationists. In the United States, recent exploration and development has focused on oxide ores suitable for processing by low-cost, leaching solvent extraction-electrowinning (SX-EW) technology and on the stratiform ores of Montana.

Copper exploration was seriously lacking through most of the 1970's and 1980's, not only owing to a lack of available funds, but also to an increasingly hostile public point of view about the need for mining. For at least two decades, the socioeconomic and political trends of the United States have been effective in preventing rapid exploration and development of new ore deposits. Creeping urbanism, a desire to preserve pristine wilderness areas, and prevention of environmental pollution have all had effect on the success of companies in getting exploration and mining permits in the United States.

No old mining district is positively dead in a geologic sense; the next minor geologic revelation may bring it to life. Further elucidation of ore genesis theory could revolutionize exploration. As a result, collective data pools, core storage facilities, and increased availability of all types of geological and geochemical information through improved data base reliability and accessibility could dramatically increase the numbers of deposits discovered. Improved exploration techniques on the horizon include: improved spatial and spectral imagery resolution for penetration of foliage and surface cover; increased digital geophysical coverage of the United States (magnetically, gravitationally, radiometrically, and spectrally), and improved drilling, sampling, and analytical methods. With geosensing, the ability to predict ore body variations, geological disturbances, and in situ ore-grade variations, can be improved. Estimates have varied as to the frequency of success as the result of exploration programs. Prompted by the rapid economic growth era accompanying the Korean and Vietnam wars, the exploration tempo began to pick up in the 1950's with the maximum exploration rate occurring in 1962. Thereafter, the deposit discovery rate gradually declined to the present. The data indicate that, despite worldwide exploration expenditures for all mineral deposits that exceeded several hundred million dollars each year, there was a significant decrease in the exploration success ratio. For example, $70 million was spent for each deposit discovery in the early 1960's, compared with $225 million in the late 1970's.[3]

World class deposits have been defined as those that consistently returned a profit even in periods of low metal prices, that are of a magnitude to significantly affect a medium-sized company's profit, and that are in the lower one-third of cost per unit of metal sold. Using this definition, it was estimated that in more than 30 years (720 combined corporate years) of effort, only 69 world class deposits were found. A rough ratio might be 1:100; i.e., that for every 1 ore body of any type, 100 raw prospects will have to be tested. Substantial ore bodies that are large enough to return exploration expenditures and provide a profit are much more scarce. The ratio for world class deposits to all deposits has been estimated to be more like 1:1,000.[4] Using a revised criteria relating to size and profitability, i.e., a deposit yielding more than $500 million in revenue, the number of successful, large discoveries could be increased from 70 to 166 between 1950 and 1986.[5]

Base metal exploration in Canada during the 1951-74 period involved an expenditure of about $2 billion and resulted in the discovery of 87 economic deposits. About 2,100 base metal deposit occurrences were discovered at an average cost of $450,000 each. An economic mineral deposit in the Canadian study was defined as one that realizes a total revenue of at least $20 million and a rate of return of at least 8%. In this context, about 1 economic mineral deposit was found for every 40 mineral occurrences discovered. The average exploration cost required to find and delineate an average economic deposit was $16 million, compared with an average return of $77 million for each deposit. The potential value of an economic deposit was therefore estimated to be $61 million.[6]

Mining.—Since the turn of the century, the evolution of technology for large-scale mining, milling, and concentrating low-grade ores has resulted in a continued shift away from mining small, high-grade, massive sulfide deposits by labor-intensive underground methods. Today, open pit mining accounts for almost 60% of MEC production and more than 80% of domestic production. Open pit mining requires a relatively shallow deposit with typical stripping, waste-to-ore, ratios between 1:1 and 2:1. A typical surface copper mine uses rotary blasthole drills and a shovel-truck combination for the loading and hauling operation. Underground mining methods vary with the physical nature of the ore and host rock, but typically have lower waste-to-ore ratios and higher grades and employ some form of large-scale block caving, such as that employed at San Manuel in the United States and El Teniente in Chile. Following extraction, run-of-mine ore is crushed and ground to liberate the copper sulfide minerals and beneficiated or concentrated via froth flotation to produce a concentrate containing about 30% copper suitable for smelting.

Faced with higher energy costs, deeper mines with longer haul distances, high labor rates, and lower ore grades, the domestic industry has strived to maintain and/or lower production costs over the past few decades. Major improvements in energy use and labor management in mining and milling technology have been made in recent years through improved methods of materials transport, grinding, and concentration. Technological improvements include: in-pit crushing and conveying systems to replace truck haulage to the mill; semiautogenous and autogenous grinding circuits; column and cyclone flotation cells; larger scale equipment, including trucks and flotation cells; computer-controlled truck dispatch systems; and improved on-line sampling and automated regent control in the mill. A microwave system for communications was being used by Phelps Dodge at the Morenci Mine. Microwave was chosen over cable because of the changing mining contour, the distances to be covered, and potential for equipment damage by lightning to the older systems. In mining, further improvements were anticipated in automated mining, nonexplosive rock fragmentation, and process and extraction technologies that result in minimal hazardous conditions. The clean plant concept (hazardous free) should be built into design criteria.

An important factor in domestic mine cost savings has been the development and rapid expansion of SX-EW technology for the treatment of acid soluble oxide or chalcocite ores. In this process, dilute sulfuric acid is percolated through the ore, either in dumps, pads, or in situ. The copper-bearing solution (leachate) is collected and processed by solvent extraction methods to concentrate the copper, which then is recovered by electrowinning, plating copper directly from solution onto a starter cathode. The resultant pure copper cathode

thus bypasses the traditional smelting and refining steps. Recent advances in the organic extractants and in electrowinning have improved the economics of this process. In addition to being able to process oxidized ores, mines have realized tremendous cost savings by being able to leach existing waste and ore dumps as well as lower grade mined ore and by adjusting cutoff grades to the concentrator upward. Growth in SX-EW capacity has been rapid since the mid-1970's. In the United States, SX-EW capacity increased from only 37,000 tons in 1974 to 405,000 tons of copper in 1990. Similarly, SX-EW capacity for the world, which was estimated to be 950,000 tons of copper per year in 1990, was expected to exceed 1.7 million tons by the year 2000.

Only one U.S. company, Cyprus Minerals, was using a roast-leach process to extract copper. In this process, copper sulfide concentrates are roasted, with the sulfur recovered as sulfuric acid, and then placed in a large vat for leaching, followed by SX-EW recovery.

Smelting-Refining.—Most copper concentrates are processed through three-stage smelting to produce anode suitable for electrolytic refining. Concentrate first is processed in the primary smelting reactor to produce a copper sulfide-iron sulfide matte containing up to 60% copper. The matte is passed to a converter where it is oxidized. Sulfur is removed from the matte as sulfur dioxide in the gas streams, and iron is removed in the converter slag. Blister copper from the converter is fire refined in an anode furnace to remove oxygen and other impurities. The anode shapes are interspersed with either copper, stainless steel, or titanium starter sheets in an electrolytic cell or tank, and copper is plated from the anode to the cathode. Valuable impurities, including the precious-metal values, collect as sludge in the bottom of the electrolytic cell.

In the 1970's, environmental constraints and energy costs became a prime concern of the domestic smelting industry. Through the late 1970's and mid-1980's, smelters were able to use interim methods, such as tall stacks and intermittent operation to meet sulfur dioxide emissions standards. However, by 1987, most remaining smelters had abandoned traditional batch reverberatory smelting and had adopted one of the various continuous, flash, and oxygen-enriched methods (Outokumpu flash, Noranda, Inco flash, and Mitsubishi continuous). These furnaces require lower energy input and provide a more concentrated sulfur dioxide gas stream, which allows for sulfuric acid production as a means of sulfur dioxide capture. In some instances, the byproduct sulfuric acid not only became an inexpensive source of acid, but also contributed to the expansion of the SX-EW capacity. However, its overall economic value to a smelter has varied.

Flash smelting involves the blowing of concentrate, flux, and oxygen into a hot furnace. The concentrate reacts rapidly with oxygen, releasing a tremendous amount of heat. As a result, flash processes are generally autogenous, requiring no external fuel input after firing-up. In 1988, Magma Copper Co. commissioned the world's largest single-furnace Outokumpu flash smelter with a 272,000-ton-per-year blister capacity. The majority of new smelters constructed worldwide since 1970 have been Outokumpu flash smelters. However, in the United States, two new Inco furnaces, Hayden and Hurley, have been commissioned since 1980. The Noranda process smelter, installed by Kennecott, was not autogenous, but had the advantage of being able to process larger size material, including scrap, and to produce a higher grade copper matte. Many copper smelters have found that the limit on environmental improvement at an acceptable cost rested with upgrading the converting process. Most plants have operated Pierce-Smith converters adapted for high-sulfur capture, but generally at high cost. A switch from the present batch mode of matte processing to one of continuous operation without converters is expected to be a major improvement for the future.

Canada pioneered the use of oxygen in smelting during the 1960's, and some forecast that this is the trend of the future. The use of oxygen in copper smelting was borrowed from steelmaking technology. If the smelter complex (smelting furnace, converters, and anode furnace) are considered one operation, the smelting process would use a typical ratio of total oxygen tonnage to concentrate of about 1:4. A 100,000-ton-per-year smelter, treating typical southwestern U.S. concentrates, would require about 300 tons of oxygen per day. The trend is toward higher levels of oxygen enrichment in smelting; this ratio is expected to increase through the next decade to more than 0.35 ton of oxygen per ton of concentrate. In the future, most smelters are likely to process all of their primary copper sulfides by oxygen enrichment processes, whether by flash or bath smelting, by the end of the decade.[7]

The Contop (Continuous Top-Blowing process) smelter is an autogenous process in which concentrate is continuously melted in a cyclone furnace on top of a large settling chamber. The high temperature of the flash smelting, combined with top blowing of the slag in the settling chamber, volatilizes most of the impurities, such as lead, arsenic, etc., and is well suited to ores having high impurity levels. It also provides for a low-copper slag that can be dumped without further treatment. Because of its relatively low capital requirement and compact size, it was reportedly well-suited for retrofit installation at reverberatory furnaces.

Cyprus Minerals Co. was building the first Isasmelt-process smelter in the United States. Developed by Mount Isa Mines (MIM) Co. and the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia, this process used a single cylindrical reactor and a submerged Sirosmelt smelting lance in an easily controlled oxygen-enriched, high-intensity smelting process. The Isasmelt process has considerably lower energy needs than Cyprus' existing Miami, AZ, electric plant. The system offered capital and operating cost advantages, in addition to resolving some environmental problems. Associated with a 500-ton-per-day oxygen plant, the process also will allow a significant increase in concentrate capacity at the Cyprus plant. Slag from the new smelter will be cleaned in the existing electric furnace, and the existing acid plant will handle all of the sulfur dioxide process streams. The Cyprus smelter is the only remaining electric primary copper smelter in the United States.

The foam smelting process developed in the U.S.S.R. was being used on an industrial scale at three Soviet plants; enriched air was injected into the slag melt, and smelting occurs in the resulting slag foam. At present, this process is only used in the U.S.S.R.[8]

Technical improvements at the refinery level have included the use of permanent stainless steel or titanium starter sheets, improved solution chemistry, and automated system control leading to greater current efficiency and reduced impurity levels. As a result of reagent and production refinements, almost all domestic SX-EW production is high-quality cathode that does not require further refining. Continuous cast rod technology, in particular, requires

high-quality refined copper. The rapid increase in continuous cast technology for rod, since the middle 1970's, has rendered the wire bar, an intermediate cast shape for wire rod, almost obsolete and has effectively shifted intermediary casting from the refinery to the wire mill. Though it has not replaced deep well casting of intermediate cake, slab, and billet at brass mills, continuous casting technology also has been developed for some aspects of the sheet and tube sectors.

***Recycling.*—Scrap Consumption and Type.**—The Institute of Scrap Recycling Industries Inc. (ISRI) recognized about 53 classes of copper and copper alloy scrap and published a booklet describing them. Although there were several grades of scrap within each, the major unalloyed scrap categories were known generally as No. 1 copper, which contained greater than 99% copper and often is simply remelted, and No. 2 copper, which, while clean and containing 94.5% to 99% copper, usually must be re-refined. In 1990, about 1.6 million tons of copper-base scrap, containing an estimated 1.3 million tons of copper, was consumed in the United States. The largest scrap categories were: No. 1 copper, 26%; No. 2 copper, 21%; leaded yellow brass, 15%; yellow and low brass, 7.5%; cartridge cases, 6%; automobile radiators, 6%; red brass, 5%; and low-grade ashes and residues, 8.5%. A wide variety of alloys made up the remaining 5%. Brass and copper tube mills processed 60% of No. 1 copper and most of the cartridge cases and yellow brass, while the secondary smelters and ingotmakers processed 79% of the No. 2 scrap and most of the auto radiators and red brass scrap. With a few exceptions, U.S. wire rod mills did not consume purchased scrap directly. One U.S. wire rod-producing company constructed a continuous-process scrap refining and wire rod casting plant, in which No. 1 return scrap from its own plants was processed. Scrap is classified into two general categories called old and new scrap. *New scrap,* or manufacturing scrap, is generated during the fabrication of copper products and returned to the mill for reprocessing, or sold, and is not considered a new source of copper supply. New scrap is termed "run-a-round" or *home scrap* when it was generated internally at the plant reusing it, or it may be called *purchased return scrap,* when returned by a customer from a plant external to that purchasing and reusing it.

Old scrap is generated from worn out, discarded, or obsolete copper products and, thus, is considered to be a new source of supply. Since World War II, the ever-increasing reservoir of copper products in use, much of which was eventually recycled as "old" copper, provided annually between 19% to 33% of U.S. apparent demand and, on average, provided about 18% of world copper demand. It is estimated that the world copper reservoir of old scrap items, in use or abandoned in place, exceeded 173 million tons. The U.S. scrap reservoir is estimated to exceed 66 million tons or 38% of the world's total.

The rate of old scrap recovery is limited by copper's long life and its essential uses. On average, the rate of old scrap recovered in the United States, as a percentage of total scrap consumption, declined from 50% to 60% in the 1940's to about 40% in the 1980's. The decline in the old scrap component was the result of an increasing manufacturing base from which to generate new scrap and also of a changing demand pattern to one dominated by electrical uses. Electrical items, which now account for greater than 70% of copper consumed, were less likely to be substituted, replaced, and scrapped than items in other end-use sectors. The long service life for utility and building cable, among other reasons, results in a practical limit to the amount and rate at which old scrap from this source can be recovered. The average life for old copper items has been estimated at about 20 years. Historically, old scrap recovery not only improved during periods of high refined copper prices, but also increased at any time that primary supplies became scarce, including the deep recessionary years of the 1930's.

According to one source, using a definition for "recycling rate" as the ratio of copper scrap consumed to copper produced annually, copper has a recycling rate of 50% in Europe, 60% in the United States, and 47% in Japan. By comparison, aluminum has a recycling rate of 30% in Western Europe, 28% in the United States, and 36% in Japan. Zinc recovery is similar to aluminum, while lead is similar to copper. The average life for copper recovery in Germany, according to this same source, was cars, 8 years; small electric motors, 12 years; cables, about 42 years; and buildings, exceeding 80 years.[9] In the United States, about 44% of total annual copper consumption was from copper in old and purchased new scrap. Copper scrap accounted for a similar percentage, 36%, in the countries of the European Community (EC), which collectively comprises one of the largest sources of copper scrap in the world.

Parts of the copper industry are very scrap intensive. For example, nearly all of the copper raw material used to make specialty alloy ingot for use in foundries was scrap. Scrap also was the dominant feed for yellow and leaded yellow brass rod mills and for many copper tube mills. In both Europe and the United States, many smelters and refiners used scrap as feed, a trend that has been increasing along with the need for purer forms of copper. In recent years, about 40% of refined copper produced in Western Europe and about 22% of refined copper in the United States was derived from copper scrap. Copper scrap accounts for about 19% of the world's refined copper production. Direct melt copper and copper alloy scrap, used mostly by brass mills and foundries, was more than double that used to make refined copper.

Scrap Processing.—Impure old copper scrap from sources such as radiators, electronics, cable, or tubing generally is processed by smelters and refiners. Alloy scrap, such as brass and bronze, is refined in a special scrap converter that enables alloying metals such as zinc, tin, and nickel to be removed by reduction and evaporation, or by oxidation and elimination, in the slag phase. The flue dust of the converter process contains mainly zinc, tin, and lead, most of which is recovered when the dusts are processed. A Pierce Smith converter or a Top Blow Rotary Converter (TBRC) can be used for the converting process of alloy scrap. The TBRC consists of a cylindrical vessel that rotates on its midaxis. Processing of complex copper-containing materials, such as drosses, flue dust, catalysts and collector dust, slimes from electroplating wastewater, and metal-rich slags from converter processes also require versatile production processes. 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 with holding furnaces in conjunction with continuous casting systems.

Problems.—Problems on the horizon for recyclers include stricter regulations for emissions, higher costs for waste disposal, legislation limiting the lead content of alloys and in drinking water, and the Basel

Convention. The cost for dumping hazardous materials, such as lead-containing plastic wire coverings and fluff, is high. While acceptable in some other nations, such as in Japan, incineration to destroy some of the unwanted plastics in the United States does not appear to be an acceptable solution. Cable scrap is an important source of metal, and whereas the plastic parts of the cable were removed previously by burning, stringent legislation on emissions has restricted this procedure. Thus, mechanical dismantling of cables has become common. An estimated 340,000 tons of cable is chopped every year in the United States, resulting in about 158,000 tons of plastic waste that must be disposed in some way. Thermoplastic resins are recyclable, but some high lead-containing plastics are not. Lead is used as a stabilizer in plastic cable coverings. Legislation limiting the content of lead in copper alloys was also being considered in the United States and may create many problems for both producers of these alloys and their consumers. Improperly applying waste-handling laws to scrap could have a stifling effect on recycling.

The Basel Convention, negotiated in 1989 under the auspices of the United Nations Environment Program (UNEP), eliminates uncontrolled transboundary movement of hazardous and other wastes between nations, provides for accountability for waste movement, and encourages self-sufficiency in waste treatment. As currently written, the convention separates recyclables from other waste and recognizes the international community's need to trade in recyclables; however, "hazardous waste" is defined much broader than that in current U.S. law and regulations. The convention becomes effective 90 days after 20 countries ratify the document. EC ratification and implementation was not expected until early 1992. Eleven countries had ratified the treaty by yearend 1990. Another 53 countries, including the United States, have signed a UN document indicating an interest in ratifying the agreement. While the United States was a signatory to the convention, the ratification process will take 3 years or more. Because the convention would prohibit trade in wastes between nonparticipants, trade, which includes metal scrap, could be limited between the United States and other countries if the convention is activated prior to U.S. ratification. In addition, the regulatory scheme under Basel could be cumbersome, and documents may duplicate existing procedures. The Organization for Economic Development (OECD) was developing a protocol for issues relating to the convention.

Economic Factors

Each copper product, including scrap, from mine through refinery has a distinct pricing procedure linked, for the most part, to its copper content and the market price for copper. For example, copper concentrates, which contain between 20% and 40% copper, are purchased on the basis of recoverable copper content and anticipated smelter and refinery charges for processing.

Copper concentrates were sold predominantly under long-term contracts and included provisions for the delivery of specified quantities and the formula by which the price paid was to be calculated. Contracts tended to be for periods as long as 10 years, though various terms were renegotiated at shorter intervals, and thus provided smelters with secure sources of feed material. Without such contracts, new mines would find development financing difficult. Contracts provided for two types of charges. A treatment charge was made for every ton of concentrate by the smelter, and a refining charge was made for every pound of recoverable copper. There was generally a provision for the participants to benefit from copper price rises. There also may be penalties for undesirable impurities, such as antimony, arsenic, and bismuth. The basis for additional payment for precious metals in the concentrates was generally slightly less than the amount actually contained.

Refined copper prices vary according to form and purity. Historically, the price for refined wirebar was the "bellwether" price for refined copper, because this was the dominant form traded. With the advent of continuous casting for wire rod, however, high-grade cathode became the dominant form traded. Copper wire rod prices are based on the refined copper cathode price plus a processing premium. The price spread between copper scrap and refined copper must be sufficient to allow for processing costs. Refined prices not only relate to the refined shape and its quality, but also to the manner in which it was priced; i.e., through producer's annually negotiated contracts, or through the commodity exchanges of the London Metal Exchange (LME), Commodity Exchange of New York (COMEX), and Mid-America Commodity Exchange (MACE). Trading in copper began on the LME, January 1, 1877, and on the COMEX, May 15, 1929. A futures exchange, such as COMEX, is a centralized market where contracts for the future delivery of the commodity are bought and sold by competitive auction. Each contract for a particular commodity is identical, representing a specific amount and grade of a commodity designated for delivery at a specified date, which may be as far as 2 years in the future. Because all futures contracts are standardized, the only negotiable aspect of a contract is price. Futures contracts changed gradually over the years to correspond to the most active markets. The LME dropped its wire/bar and standard cathode contracts and, beginning January 1989, traded only the Grade A (high-grade) cathode contract. Similarly, COMEX converted to the High-Grade cathode contract on January 1, 1990. The spot, or first position, price is most often quoted for the exchanges. To this price, however, various premiums and other charges were added to determine the actual price paid by the buyer. Historically, the U.S. copper producers' price series was related to annually negotiated contract sales with price changes occurring at frequent intervals. When quoted, this price normally included a charge for delivery and insurance. Most U.S. producers abandoned classic producer pricing during the 1970's and 1980's, as inventories accumulated on the exchanges and the COMEX price became more influential. Producers adopted the custom of using the first position COMEX price as a basis for contract pricing. During tight markets, however, such as that which has existed since late 1987, the speculative influence of a COMEX-based pricing system has proved to be less than satisfactory for the consumer, owing to price volatility. The conventional producer pricing system tended to provide more stability to the market. Periods of speculative interest have usually been brief, however. The long period of stock surpluses since 1982 dampened speculative interest until the end of 1987. Since that time, both producers and consumers have increasingly used futures contracts and the newly introduced copper options to hedge their sales and purchases.

Based on constant dollars, one must look to the depression era of the 1930's to find prices as low as those occurring between 1981 and 1988. Since that time, current prices have been within the range of the constant dollar average for all prices,

1901-90. Copper prices not only responded to changes in the world economy, but also to the effects of large copper inventory accumulation; to copper cartel actions to restrict production, which were most effective prior to World War II; and from time to time, to speculative influences on the commodity exchanges.

Refined copper inventories are kept on hand by consumers and producers as a means to meet demand. A just-in-time inventory philosophy in recent years has been assisted by the advent of the computer, allowing a more accurate analysis and timing of production and shipments. Normally, about 4 weeks of supply is considered adequate to meet market needs and prevent excessive speculation. Whenever inventories exceed this mark, prices tend to be lackluster, and conversely, whenever inventories are below this mark, speculation can drive market prices up. Surplus inventories may find their way to the commodity exchanges where their high visibility tends to depress prices. The exchanges also provide a mechanism for hedging production and consumption, providing liquidity to the market. The primary economic purpose of futures trading is to provide a marketplace for hedging against the financial risk associated with volatile fluctuations in prices by transferring that risk to speculators.

Surplus refined copper inventories not only have accumulated periodically in response to periods of economic recession, but also as a result of U.S. Government purchases for the National Defense Stockpile (NDS). There is an inverse relationship between the amount of commercial stocks on hand and the market price for copper. High inventory levels have had a depressing effect on prices when these surplus supplies were released onto the market to compete with newly mined copper. Trends in U.S. copper inventories since 1955 are shown in table 2.

The U.S. Government has been historically a large holder of refined copper inventories, but since the final large elease of 1974 has not attempted to refill the NDS, which was released for the most part in response to the shortages of the Vietnam war years. From time to time, other nations, such as Japan, also have held refined copper stocks for strategic reasons. Materials shortages created during World War II prompted the creation of the NDS late in the 1940's. Beginning in the 1950's, the NDS became a vehicle for controlling the flow of mineral supplies during an emergency, buying copper in times of surplus (524,000 tons was purchased between 1953 and 1958; very little has been purchased since), and selling copper in times of shortage (808,000 tons was sold between 1965 and 1969 and 229,000 tons in 1974). The stockpile currently holds 26,352 tons of copper materials, including 20,000 tons of refined copper, 6,124 tons of copper in brass scrap, and 548 tons of nonstockpile copper.

TABLE 2

U.S. REFINED COPPER INVENTORIES, END OF YEAR[1]

(Thousand metric tons)

Year	Consumers			Producers[3]	COMEX[4]	Total industry	U.S. Government[5]	Total United States
	Brass mills	Wire mills	Other[2]					
1955	39	20	4	31	0.32	93	802	895
1956	46	36	9	71	.80	163	845	1,009
1957	46	48	3	99	.70	196	918	1,113
1958	47	34	8	44	10	142	1,031	1,172
1959	30	16	11	16	12	85	1,035	1,120
1960	29	32	4	89	2	157	1,040	1,197
1961	34	26	8	44	8	120	1,036	1,156
1962	31	34	6	64	4	139	1,029	1,168
1963	30	15	4	47	1	97	1,018	1,115
1964	31	19	2	31	3	86	994	1,079
1965	35	20	5	32	9	101	814	915
1966	61	41	4	39	4	148	410	559
1967	35	20	4	24	12	96	250	346
1968	36	24	4	44	11	118	242	361
1969	36	34	4	35	4	112	230	342
1970	38	95	4	118	16	271	230	501
1971	37	84	5	68	18	213	228	441
1972	25	45	5	52	52	179	228	407
1973	27	39	5	34	5	110	226	335
1974	33	98	6	92	39	268	32	300
1975	28	108	6	188	91	420	24	444
1976	33	103	6	172	182	497	44	541
1977	31	105	6	212	167	522	21	543
1978	28	63	7	153	163	414	21	435
1979	25	44	9	64	90	232	20	252
1980	22	50	10	49	163	294	20	314
1981	26	109	9	151	170	465	20	485
1982	25	125	9	268	248	675	20	695
1983	26	116	5	154	371	672	20	692
1984	27	134	11	125	251	548	20	r568
1985	20	100	5	66	109	300	20	320
1986	14	66	r4	35	84	205	20	r225
1987	15	28	3	29	17	93	20	r113
1988	17	29	r3	16	12	r77	20	r97
1989	12	32	r4	r24	15	r87	20	r107
1990	10	24	r4	r24	18	r87	20	r107

rRevised.

[1]Semifabricated forms such as rod, sheet, etc., at consumers are not included. Data may add not to totals shown because of independent rounding.

[2]Stocks held by miscellaneous manufacturers, foundries, and chemical plants. Data for the years 1955-64 estimated based on partial data.

[3]Inventories held by primary and secondary refineries.

[4]Data from Commodity Exchange Inc., New York.

[5]General Services Administration Inventory of the National Defense Stockpile.

ANNUAL REVIEW

Legislation and Government Programs

Copper Study Group.—The United States notified the United Nations, on March 15, of its provisional acceptance of the terms of reference of the International Copper Study Group (ICSG). Because the United States had led the movement to establish the study group, other countries were waiting for this signal to indicate their own interest. There was a June 30, 1990, deadline for acceptance of the terms of reference by countries representing 60% of the world copper trade. However, by the end of June, only Chile, Greece, Peru, and Poland had notified the United Nations that they had accepted the terms of reference. Even so, by yearend, several other nations and the EC were viewing the study group positively. A followup meeting by interested nations was to be held, in late 1991, to discuss objections by Japan and consider bringing the organization into force.

Environmental Legislation.—In late 1990, the U.S. Environmental Protection Agency (EPA) issued a strategy for reducing lead exposure based on a goal of reducing lead exposures to the fullest extent through market-based incentives to limit or eliminate lead use. The strategy included application of regulatory mechanisms, such as the Toxic Substances Control Act (TSCA), which would be used to reduce the use of lead in current and future products; combined with efforts to identify and encourage cleaner technologies for mining, smelting, and processing lead. Studies were to be made on potential hazardous exposures that might occur in the future, after disposal of any lead-bearing product, including copper alloys. The EPA planned to explore the desirability and feasibility of discouraging overall consumption of lead in any form.

The Lead Exposure Reduction Act (S. 2637 and H.R. 5372) and Lead Ban Act of 1990 (S. 2593) were introduced, but not passed. These bills were viewed by the scrap industry as having the potential to impede copper alloy recycling in the United States. Restrictions would have been placed on solder (greater than 0.1% lead), copper alloy plumbing fixtures (greater than 2% lead), and many other items, such as soldered copper pipe, many lead-containing plastics, wire coatings, and brass and copper plumbing fittings and construction materials, as well as the scrap materials derived from them. The Brass and Bronze Ingotmakers testified that these bills, which sought to restrict all lead-containing products, could actually result in more lead being released into the environment if such laws were passed. Currently, much of the lead-bearing copper alloy material is safely recycled, but the legislation could result in at least 6 to 10 million tons per year going to landfills, where lead could leach into the ground waters. The industry asked for rewording of the legislation to state clearly that it does not apply to the processing or distribution of copper alloy products of the recycling process. A new organization, Recyclers of Copper Alloy Products (RECAP), was formed to make the industry's views known. Among the members were the Brass and Bronze Ingot Manufacturers Inc., the Copper Development Association (CDA), the Copper and Brass Fabricators Council (CBFC), the ISRI, the American Foundrymen's Society, the American Cast Metals Association, the Non-Ferrous Founders' Society, the Plumbing Manufacturers Institute, the Air-Conditioning and Refrigeration Institute, and the American Pipefittings Association.

On October 19, 1990, the EPA solicited comments for the proposed final rule (published August 18, 1988) for the National Primary Drinking Water Regulations and Maximum Contaminant Level Goals for lead and copper in drinking water. Under the proposed rule, water delivery systems would be required to optimize corrosion control treatment if one of the following action levels were exceeded at consumers' taps: an average lead level greater than 0.010 milligrams per liter (mg/l); a copper level in 5% of the samples exceeding 1.3 mg/l; or a pH of less than 8.0 in 5% of the samples. In addition, water delivery systems would be required to implement public education, as specified, if the level of lead exceeded 0.02 mg/l in 5% of the tap samples. The final rule under consideration would apply the lead and copper action levels as a trigger for corrosion control treatment only to systems serving less than 50,000 persons. Larger water systems would have to install treatment to minimize lead and copper levels at consumer taps. Based on source water and tap water monitoring, a State may determine that source water treatment is necessary to minimize lead and/or copper levels.

Federal Actions.—The Small Business Administration (SBA) published a notice that established a waiver of the "non-manufacturer rule" for copper cathodes. The basis for the waiver is that no small business manufacturer is supplying these classes of products to the Federal Government. The effect of the waiver would allow an otherwise qualified regular dealer to supply the product of any domestic manufacturer on a Federal contract set aside for small business or awarded through the 9(a) program (SBA regulations 13 CFR 121.906 (b) and 121.1106 (b). Included were copper cathodes and five nonferrous base metal refining and intermediate forms, including ingots and slabs (PSC-9650), and nickel cathodes and brickettes.

The U.S. General Accounting Office issued a report in May 1990 (GAO/CD-90-88), commissioned by the House of Representatives Committee on Banking, Finance, and Urban Affairs, that analyzed the feasibility and effects of replacing the dollar bill with a dollar coin and the possibility of eliminating the penny and half dollar. The report concluded that a dollar coin could save the Government $318 million annually in printing costs by replacing the $1 note. The proposed coin would contain 80% to 90% copper. The report also concluded that there is no compelling reason to eliminate the penny or half dollar.

State Legislation.—Fearing that State approval of the open pit copper and gold mine near Ladysmith, WI, would result in a rush of mines being developed in northern Wisconsin, a State mining moratorium bill was proposed that would be a "yellow light" to mining in the State. The moratorium would have enforced stricter State regulations, requiring regional environmental and economic impact statements, and the so-called "local agreement" provision of the current mining law would be repealed. This provision essentially granted mining companies a short cut through the permit process. According to mining opponents, about 25 multinational mining corporations have bought or leased more than 500,000 acres of land in northern Wisconsin since the mid-1970's. The bill was not expected to pass the Wisconsin legislature, but was symptomatic of the current antimining movement in the United States.

A higher severance tax on minerals in Utah was passed (Senate bill 1991) in March 1990. The severance tax on copper was increased by 60%.

A large number of bills were introduced during the 1990 session of the Arizona

legislature that addressed environmental issues, particularly in the areas of hazardous waste and air and water pollution. One of the most significant laws passed was Arizona House bill 2007, which established penalties of up to $10,000 per day for each air pollution violation committed by anyone in metal mining. The Arizona Desert Wilderness Act of 1990 incorporated about 1.1 million acres of Bureau of Land Management land and 1.3 million acres of Fish and Wildlife Service land into the National Wilderness Preservation System.

Trade Legislation and Actions.—By October 1990, Mexico had exceeded its General Selected Preference (GSP) competitive-need limit for unrefined copper and copper anodes exports to the United States. U.S. imports from Mexico through October totaled $43 million or 38.2% of the total product imports. GSP competitive-need limits are based on a dollar figure tied to the Gross National Product (GNP) or to the percentage of total U.S. imports of the item. For 1990, the dollar limit was expected to be about $93 million. Also, GSP imports normally could not exceed 50% of the total imports for the item. The limits were lowered for countries found to be sufficiently competitive in a product. Mexico exceeded its limit of 25% of total U.S. imports for unrefined copper and copper anodes. The import data are reviewed annually, and decisions about removing or renewing GSP status are announced on or about April 1. Other metal items likely to exceed the percentage limit are some types of copper wire cables from Mexico, as well as copper wirebars and stranded copper cables from Peru. GSP duty-free status was to be granted for U.S. imports of stranded copper wire from Peru, removing the 4% ad valorem duty. Legal procedures delayed any action until January 1, 1991.

A bill was passed, attached to the Commerce Department Appropriations bill, to establish a foreign trade zone in Cedar Rapids, IA. Designation as a foreign trade zone would enable Poongsan Inc. to build a copper and brass rolling mill in Cedar Rapids for the purpose of shipping finished copper products around the world, especially to Canada, using coils of copper and brass made in the Republic of Korea. The International Trade Administration (ITA) had determined that brass sheet and strip from Poonsgan Metal of Korea was dumped in the United States at a margin of 25.58% during the period August 22 through December 31, 1986. As a result, Poongsan was required to pay a duty of 7.2% on any brass or copper it shipped to this country, which would have made Poongsan noncompetitive. Establishing the free trade zone would allow Poongsan to avoid this obligation at its mill in Iowa. The mill was to employ 800 workers and, thus, the bill received full support of Iowa legislators in the U.S. Congress.

The Non-Ferrous Metals Producers Committee (NFMPC), an industry group formed in 1988 to represent the domestic copper, lead, and zinc industries, petitioned the U.S. Trade Representative (USTR) to provide information under section 409/(b) of the United States-Canada Free-Trade Agreement (FTA) and section 308 of the Omnibus Trade and Competitiveness Act (OTCA). The NFMPC, and individually, ASARCO Incorporated, The Doe Run Co., Magma Copper Co., Phelps Dodge Inc., and Zinc Corp. of America, sought identification of the domestic copper, lead, and zinc industries as industries that could face increased competition from subsidized Canadian imports. The NFMPC believed these industries could be adversely affected by elimination of import tariffs on goods traded between the two countries. In particular, the NFMPC requested information about Canadian Federal and Provincial government assistance to the Canadian copper, lead, and zinc industries. In July 1990, based on the committee's recommendations, the USTR, in consultation with the Department of Commerce, found that the copper and lead industries should be "identified" as industries that could face increased competition from subsidized Canadian imports with which they compete as a result of the FTA.

The ITA determined that five West German companies were dumping brass sheet and strip in the United States at margins from 7.30% to 16.18% between 1986 and 1988. The companies, with new preliminary findings and current applied duties, in parenthesis, were Wieland Werke Ag (7.94%, 3.81%), Langenberg Kupfer und Messingwerke (7.94%, 16.18%), Metallwerke Schwarzwald (7.94%, 7.3%), William Prym (16.18%, 7.3%), and Schwermetall Halbzeugwerke (7.3%, 7.3%).

Issues

Industry Investments, Earnings, and Ownership Changes.—Arizona's copper industry, growing and expanding since the mid-1980's, contributed $6.3 billion to the State's economy in 1990, according to the Arizona Mining Association.[10] Direct contributions amounted to $1.54 billion, up from $1.25 billion in 1989 and $1.08 billion in 1988, but as that money recirculated throughout the State economy, it made an indirect impact of $4.8 billion, according to an analysis by the Western Economic Analysis Center in Arizona. The industry showed increases in several categories, including property tax payments, numbers of Arizonians employed, earnings of employees and, specifically, a 38% increase in purchases from Arizona suppliers.

According to the U.S. Bureau of Mines, Arizona led the Nation in the value of nonfuel minerals produced in 1990, equaling about 10% of the Nation's total. Of the State's $3.1 billion in nonfuel minerals, $2.8 billion was generated by the copper industry, about $100 million more than the previous year, despite lower copper prices. The Arizona copper industry paid almost $106 million in 1990 in direct support of State, county, municipal, and local governments in the State. This was about 5% more than in 1989. The largest payments were as property taxes levied on the industry's land, ore reserves, production facilities, and equipment. Property taxes were $34 million. Second was severance taxes, a tax paid only by mining firms and timber producers. The severance tax on net value of copper production made up 29% of the industry's total State and local government tribute. Sales taxes paid on Arizona purchases of products and services were about 16% of the copper industry's direct payments, most of which went to the State's school districts, with the remainder going to State, counties, and incorporated cities and towns. Corporate State income taxes were almost as much as sales taxes, amounting to almost $13 million. Payroll taxes, including both unemployment and worker's compensation premiums, comprised 7%. Rents and royalties paid for land use owned by the State accounted for less than 3% of industries tax payments.

Asarco reported net earnings of $122 million on sales of $2.2 billion in 1990.[11] Markets for the company's metals held up well in 1990, despite the slowing of economic activity in the United States late in the year. Asarco's strategy since the mid-1980's has been to transform the company from principally a custom smelter and refiner of ores and concentrates produced

by others into an integrated producer and processor on its own account. The company planned to invest about $250 million in acquisitions and expansion programs to accomplish this goal by 1992. In 1990, Asarco committed $75 million to expand and modernize its copper production facilities at the Ray and Mission Mines in Arizona. Other investments included $213.3 million for Southern Peru Copper Corp. (SPCC), of which $176.9 million is equity in restricted net assets. Peru had placed currency control restrictions on SPCC net assets of about $331.2 million.

Copper Range Co., of White Pine, Michigan, owned 96.1% by Metall Mining Corp., reported operating earnings of $2.0 million in 1990 compared with $18.7 million for 9 months of 1989. Lower realized copper prices of $1.09 per pound in 1990 were a key factor in the reduction of operating profits, from $18.7 million in 1989 to $2 million in 1990. The costs of mining reorganization were higher than anticipated, and the benefits only began to materialize late in the year. In 1990, the first phase toward modernizing the mill was started. In May, Copper Range purchased a mill section from Echo Bay Inc. for $4 million at its mine in White Pine, MI. Copper Range owned five sections of the existing mill equipment at White Pine, while Echo Bay, the previous owner, still owned one idle section in the mill.

Cox Creek Refining Co. became 80% owned by Mitsubishi Metal Corp. during the year; Southwire Corp. retained a 20% share. Mitsubishi's move to increase its original 60% share in the Baltimore, MD, facilities was seen as a move to enable a direct link with planned output from the company's Texas City, TX, smelter, which was scheduled to start construction in 1992, providing environmental permits were obtained in a timely manner. Cox Creek was principally a tolling firm for imported copper anode.

Cyprus Minerals Co. had a net income from its copper-molybdenum-gold mining segment of $111 million in 1990 compared with $165.9 million in 1989. Profits for the year were reduced by asset write-downs of about $63 million, including the Tonopah, NV, molybdenum-copper mine. In addition, lower metal prices and higher costs reduced earnings, although revenues of $1.9 billion were higher than those in 1989. The earning levels of recent years reflect both strong metals prices and Cyprus Minerals' growth resulting from acquisitions of 22 properties from 1985 through 1989, at a cost of about $500 million. The emphasis during these years was growth through acquisitions, but the focus in 1990 shifted to increasing operating efficiencies. Cyprus Minerals Co. completed the purchase of MCR Products' wire-rod mill in Chicago, IL, from Magma Copper Co. The mill, shuttered since late 1989, began production in March. Full capacity of about 125,000 tons of wire rod per year would probably not be reached until next year.

Gold Express Corp. of Denver, CO, estimated that $53 million would be needed for startup costs at the Copper Flat Mine, including repayment of capital already spent by previous operators. Costs reportedly were to be partially financed by Paribas Corp. of New York. Quintana Corp. operated the mine and mill at Copper Flat only a few months in 1982, before giving up the project because of depressed prices.

In 1990, Magma Copper Co. began to benefit from the prior 2 years of restructuring, consolidation, and employee team building. Magma Copper was made up by the San Manuel Mining Div., Pinto Valley Mining Div., Smelting & Refining Div., and three new divisions formed during 1990: Superior Mining Div., McCabe Mining Div., and the Robinson Mining Ltd. Partnership. Record financial and production levels were achieved despite lower copper prices. Net income increased by 44% to a record $84 million. International sales increased to 34% of total copper sold. Earnings increased primarily owing to the attainment of full-capacity smelter performance and increases in productivity and copper production. Magma's refined copper cathode sold (excluding rod conversion premiums) at $1.17 per pound in 1990 compared with $1.19 in 1989. The company acquired 54% of the Robinson Mining District, NV, from Kennecott Corp. at a cost of $21 million; $18 million was spent on the development of the Kalamazoo and Superior mines; and $37.5 million went to repay bank debts. Gross profit from custom smelting and refining was $18 million in 1990. Magma started selling 25% to 30% of its cathode on a spot basis in 1990, permitting the company to take advantage of higher prices in Asian markets owing to the closure of Taiwan's sole copper smelter and falling concentrate stocks at Japanese smelters. The strategy also cut the company's need to hedge in the futures market. In order to free material for planned spot sales, Magma sold its rod mill near Chicago to Cyprus Minerals.

Magma and Alta Gold Co. completed the purchase of the Robinson Mining District near Ely, NV, at yearend. Magma acquired 51% interest in the property, consolidated through payments of $10.5 million each to Kennecott and to the Alta Gold and Echo Bay Inc. gold mining partnership. Alta Gold acquired 49% in the partnership through a $2 million payment to Kennecott. The 12,500-acre Robinson Mining District included a large high-grade ore body that greatly strengthened Magma's reserve position. Alta Gold had been paying royalties to Kennecott for its gold operations on the property. Echo Bay Mines Ltd., which had been in a gold venture with Alta Gold in the district, also sold its stake in the gold mining lease to Alta Gold and Magma for $2.0 million. Magma agreed to invest $1.5 million on a feasibility study to confirm estimated reserves of 248 million tons of ore grading 0.6% copper.

Phelps Dodge Corp. had a net income of $454.9 million, after $237 million in write-downs, compared with $267 million net income in 1989. The company invested $290 million in capital improvement and cost reduction programs and paid $98 million of debt. Record copper production and sales, favorable prices, low production costs, and a strong international investment contributed to the record net income. The $237 million after-tax charge to earnings was for certain nonproducing assets. Phelps Dodge Mining Co. had pretax earnings of $594.4 million compared with 1989 earnings of $290.6 million. The company's exploration efforts focused on increasing worldwide reserves. New resources were added at Morenci, Lone Star, and Bisbee in Arizona, and at Ojos del Salado in Chile. Discussions were entered into with potential partners in the La Candelaria Project of northern Chile for up to 30% of the project. Project structuring and financing options were expected to be completed by yearend 1991. The company expended $55 million in exploration, advance mine evaluations, and research and development in 1990.

In 1989, Phelps Dodge recorded a nonrecurring pretax charge of $374.6 million for the Morenci smelter ($145 million); the Ajo Mine, concentrator, and smelter ($50 million); the Dos Pobres underground mine development costs ($115 million); and certain other facilities rendered obsolete by environmental requirements or other economic considerations. Other provisions included in this charge related to the planned shutdown of the Tyrone, NM, mine and concentrator

in the early 1990's and reserve for estimated environmental costs associated with other previously closed facilities. In 1988, the corporation corrected a previous pretax charge of $50 million for anticipated obsolescence and closure costs of certain closed facilities.

RTZ Corp., although British based, was an international company with one-half of its assets in North America. Production from its principal U.S. investment, Kennecott's Bingham Canyon Mine, UT, was up by 3%, but earnings were less than in 1989, as a result of the lower copper price, timing of stock sales, and increased operating costs. A major part of the debt incurred for the acquisition of BP Minerals in 1989 was refinanced, resulting in lower interest costs. Exploration costs ($171 million) were higher, but were spent mainly in Queensland, Australia, and Papua New Guinea. Net profits from RTZ's U.S. companies were $459.3 million for 1990, comprising 43.7% of total corporation profits. Capital expenditures for 1990 were $540.6 million, with a significant amount ($227 million) being spent for the Bingham Canyon expansion. Copper and gold remained the largest contributors to RTZ's earnings in 1990, most of which came from its Bingham Canyon copper mine.

RTZ continued to use currency exposure management to reduce possible adverse effect of long-term currency changes by diversifying the risk among a wide range of currencies by decreasing exposure to key currencies to acceptable levels. The U.S. dollar's weakness against most major currencies in 1990 had an impact on RTZ's results. Metal and mineral prices were determined by the company from a basket of currencies, even when they were denominated in U.S. dollars. Whenever the dollar declined, there would be some partial offsetting increase in U.S. dollar prices. RTZ also managed its portfolio of cash and debt to take account of the currencies in which its costs and revenues were incurred. In this respect, the U.S. dollar was the most important net revenue exposure, and this was offset by dollar debt. If, for example, the dollar weakened, not only would the sterling value of revenues decrease, but the sterling value of dollar debt to be repaid would also decrease.

Sindor Resources negotiated a new sublease arrangement on the Lisbon Valley, UT, copper property that eliminated large preproduction payments and improved the likelihood for development of the 10 million tons of leachable ore reserves.

Court approval was granted in late 1990 for bankrupt Tennessee Chemical Co. to sell its Copperhill, TN, sulfuric acid and copper sulfate operations to Boliden Intertrade AG of Sweden. Approval was granted only after Boliden and the EPA reached a settlement on Boliden's obligation regarding past environmental damage at the site resulting from mining, roasting, and smelting operations. The agreement called for Boliden to spend about $8 million over the next 10 years on an environmental improvement plan. Boliden assumed management of the operation in March 1990. Mining of sulfide ore ended in 1987. There were no immediate plans to reopen the mines. A new firm, Gaston Copper Recycling Corp. (GCRC), owned by Southwire (87.5%) and the Bank of Montreal (12.5%), purchased AT&T's Nassau Metals Corp.'s Gaston, SC, rod mill and integrated scrap processing plant (processing, smelting, and refining). The change in ownership resulted in a curtailment of operations during the third quarter.

A plan was approved for Sharon Steel Corp., owner of the shuttered Continental Mine, NM, and Mueller Brass Co., Port Huron, MI, to split into two companies, as part of its reorganization under chapter 11 creditor protection. The company's nonsteel assets would be transferred to unsecured creditors led by Quantum Overseas N.V. Quantum expected to sell shares in the spinoff segment, to be named Mueller Industries Inc., after the group's largest company.

Restructuring of the U.S. brass mill industry continued, as the trend toward modernization and specialization continued. BP America withdrew entirely from the copper industry. Chase Brass & Copper Co.'s, Montpelier, OH, copper alloy rod mill was sold by BP America for an estimated $91 million to an investment group that included Martin V. Alonzo, Citicorp Venture Capital, and Westinghouse Credit Corp. The modern plant was North America's largest supplier of copper alloy rod. Talco Metals Co. of Philadelphia, PA, reportedly purchased Chase Brass and Copper Co.'s 50,000-ton-per-year copper and brass narrow strip plant at Shelby, NC. The plant was to be renamed Metals America, and the melting and casting facilities were to be used to produce special copper and copper alloy plating anodes. The strip rolling facilities will reportedly remain idle. Talco Metals created a new commodities and trading unit aimed at reducing the risk associated with the company's increased investments.

JPS Ltd., of Japan, through its newly formed subsidiary Great Lakes Metal Corp., signed a letter of intent to purchase the brass mill facilities of the closed North Coast Brass and Copper Co., near Euclid, OH. The new owners reportedly would operate the plant as a reroll mill, but would not operate the casting plant.

American Brass Co., Buffalo, NY, signed an agreement for the sale of all assets to Outokumpu Oy copper group of Finland, including its brass and tube mills in Buffalo, NY, Kenosha, WI, and Franklin, KY. Outokumpu already owned the rod mill facilities of Valleycast Inc., WI, and Nippert Co., OH.

Hussey Copper Ltd. launched a $10 million expansion and quality improvement program, including installation of three new casting furnaces at its Leetsdale, PA, plant. The improvements would enable the company to expand its variety of alloys and to rely less on outside sourcing. A continuous strip annealer was also installed, and two rolling mills were to be upgraded with new automatic controls.

Halstead Industries Inc., Greensboro, NC, closed its Zelienople, PA, copper tubing plant in September, mainly because of continued weak construction markets. All production previously handled by the plant was assumed by the company's newer facilities in Arkansas and North Carolina.

Cerro Copper Tube Co., IL, selected a northeast Missouri location for its $30 million integrated copper tube mill, scheduled for completion in mid-1991. The new mill would boost the producer's capacity by more than 50%. Cerro was to spend more than $12 million in cleaning up a contaminated creek, known as Dead Creek, that crossed its Sauget, IL, property. The creek had been polluted by years of industrial waste from manufacturing companies in the Sauget, IL, area. As part of a consent decree with the Illinois Environmental Protection Agency, the company agreed to stop all discharge into the 1,600-foot creek segment crossing its property, construct an alternate storm water collection and retention system, and remove contaminated sediment from the creek bed.

***Environmental Issues.*—Secondary Materials.**—Brass and bronze foundries and ingotmakers scored a minor victory when the U.S. District Court of Appeals ruled in early 1990 that OSHA Lead Standard would remain at 200 micrograms throughout the pending legal challenge of

OSHA's current recommendations. Labor unions had sought to remove the court's stay and to start the 5-year phase-in period for eventual compliance with the 50/75 microgram airborne lead standard as outlined in OSHA's January 22, 1990, ruling on Non-Ferrous Foundries and its June 28, 1989, recommendation for Brass & Bronze Ingot Manufacturers. The court's action was an acknowledgment that there were valid concerns over whether or not nonferrous foundries can meet OSHA's proposed regulations.

The secondary processing industry claimed that a major portion of the scrap export market could be curtailed if the Solid Waste Disposal Act (SWDA)(H.R. 3736) was implemented. If scrap metals are found to be hazardous waste under section 201 of the SWDA, then the export controls of SWDA would govern their entry into international trade. In addition to adverse scrap export effects, at proposed 0.1% heavy-metal concentration, the legislation defined many discarded consumer goods as hazardous, even though these same goods currently were being recycled safely with no harmful release of hazardous constituents. Metallic products that would come under the hazardous definition included such commonly used items as stainless steel flatware and foil wine wrappers. For many, if not most, metals recyclers, becoming classified as hazardous waste facilities would be disastrous. The legislation defined as hazardous many millions of tons of metals recycled each year, based upon the mere presence of certain heavy metals, with no reference to the toxicity of these metals. This legislation would deem as hazardous waste any discarded material that contained more than 0.1% of any heavy metal, such as beryllium, cadmium, chromium, lead, mercury, and nickel. This proposal grew out of concern that wastes bearing heavy metals could expose those metals to the environment. Thus, stainless steel, with far more than 0.1% nickel and chromium, would be deemed hazardous regardless of whether it could escape into the environment. Copper, brass, bronze, galvanized steel, and other metals that are commonly and safely recycled also would not pass this arbitrary test.

The ISRI warned against movements toward laws and regulations that do not recognize the unique role of recycling. Current law would treat scrap as solid waste, not as a raw material, and it failed to define what constituted recycling and what did not. Metals should be viewed as renewable resources in that they can be used again and again in new products, conserving scarce resources and preventing pollution. The industry viewed one of the biggest barriers to increased use of recycled materials had been the governmental failure to give recycling priority over disposal. ISRI recommended that any new rules should be studied to determine their effect on scrap supply and processing. A regulatory program should, ideally, encourage legitimate recycling. State and local governments, when passing rules, often had failed to look at the interplay of markets, commodities, and regulation before putting into effect their own recycling regulations. The recycling program often ended up being a very costly storage, and in some cases, disposal program.[12]

Claiming to protect the environment by preventing the production of waste and by "organizing" its disposal or recycling, administrations and legislators worldwide have decided to take charge of all aspects of waste management—whether hazardous or not—including those recyclable raw materials that the industry reclaims, processes, and sells. Legislators tend to confuse "recyclable raw materials" with "waste," and, in the process, create enormous obstacles to trade for the entire reclamation and recycling industry. In 1990, there were reports of cases in which entire shipments of nonhazardous recyclable raw materials were detained at borders, even though there was no doubt whatsoever regarding their end use or the ecological credibility of their consignees. The Bureau Internationale de la Recuperation (BIR) and national federation members, as well as large multinationals, were to provide as concise a definition as possible for the term "recyclable raw materials" as opposed to "waste."[13]

Mines.—At the Sierrita Mine, Cyprus Minerals continued to look for a practical way to eliminate dust blown by high winds from its active mill-tailings pond. Remedies used by other copper producers included covering inactive tailings areas with crushed rock or soil and vegetation to prevent dust pollutions. In Arizona, several exploration or developmental programs were reportedly canceled or postponed because of environmental constraints. Bond Gold Corp. had planned drilling in the Prescott National Forest, but after lengthy regulatory delays and issuance of an exploration permit that was too restrictive, the company terminated its plans. Strong local opposition to proposed exploration in the Coronado National Forest forced Newmont Mining Corp. to postpone drilling on its claims. Phelps Dodge withdrew its request to trade land with the Forest Service so that it might develop its Copper Basin deposit in Yavapai County. After spending $93,000, the company decided the projected cost of $2.5 million for an environmental impact study was unacceptable at this time.

Asarco and a subsidiary received notices from EPA that they and, in most cases, other parties, were potentially responsible to remediate alleged hazardous substance releases at certain sites under Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). The company anticipates to spend significant capital and other expenditures over the next several years to comply with environmental laws and regulations, including required remediation at various Superfund sites. Based on developments in 1990 at a number of Asarco's properties, the company added $75.5 million to its closed plant and environmental liability reserves. At the end of 1990, such reserves totaled $129 million. Cash expenditures charged to these reserves were $15 million in 1990, $13 million in 1989, and $14 million in 1988.[14]

The U.S. EPA and Boliden Intertrade A.G. of Sweden reached an agreement regarding cleanup and liability for past contamination at Tennessee Chemical Co. in Copperhill, TN. Under the agreement, Boliden, which purchased the bankrupt Tennessee Chemical facilities in 1990, will spend $8 million over the next 10 years on an environmental improvement program that will include reforestation, installation of sediment traps, continued operation of wastewater treatment plants for runoff, installation of a sulfur burner, and remediation of soil contamination. Boliden will not be held liable for any contamination that occurred prior to its assumption of management. Most of the environmental damage was caused by waste dumped along Davis Mill Creek by the plant and associated copper mine, which closed in 1987. Acid emissions from the plant destroyed much of the surrounding vegetation.

Smelters.—Kennecott's plans to comply with environmental requirements by 1994 included a possible investment of $200 million in pollution control equipment. However, even these measures would be insufficient to meet particulate emissions standards proposed by the Utah

Bureau of Air Quality under its draft State Implementation Plan (SIP). Other options included construction of a new, larger smelter.

Mine and Plant Labor.—Productivity at all mines that produced copper as a principal production was 16.8 worker-hours per ton of recoverable copper produced by open pit, underground, and leach methods. Average productivity, including mine, mill, and leach operations, was 54 worker-hours per ton for 4 underground operating mines and 14 worker-hours per ton of recoverable copper for 12 open pit mines. The number of workers at U.S. copper mines and mills averaged 12,924 in 1990. Arizona (8,759 workers) led in the average number of mine and mill workers, followed by New Mexico (1,585 workers), Utah (1,173 workers), and Michigan (928 workers).

Arizona's copper production exceeded the high level achieved in 1973, with slightly less than one-half of the 21,000 persons employed at that time. This reduction of labor force and equivalent increase in productivity was accomplished through large capital investments on larger and more efficient equipment and on new labor- and energy-saving techniques to increase production and lower costs. The SX-EW process can be applied to certain lower grade ores and produces market-ready copper while requiring far fewer workers. One SX-EW plant, for example, needs only 26 workers to produce 100 million pounds per year. Copper industry workers continued to be the highest paid industrial workers in the State of Arizona, with average earnings of $36,608 per year. In addition, copper industry workers enjoy generous fringe and retirement benefits.[15]

In the United States, talks were carried out between management and unions at Asarco's Ray, AZ, mine; Kennecott's Bingham Canyon, UT, mine, mill, and smelter complex; and Phelps Dodge's Chino, NM, mine, mill, and smelter complex. Four-year contracts negotiated by Kennecott in 1986 expired in June 30, 1990. Following the ratification of a 3-year contract at Kennecott's Bingham Canyon Mine, members of the United Steelworkers Union ratified a 3-year contract at Phelps Dodge Corp.'s Chino Mine on June 12. A short strike at Asarco's Ray Mine, AZ, was ended with the ratification of a new 3-year labor agreement on July 21 that provided increased wages and improved insurance and pension benefits. The new contract provided for a $2.00 per hour increase for the first year and an average of 25 cents per hour increase for each of the following 2 years. A $400 lump-sum payment in the third year was part of the Phelps Dodge contract.

In 1990, the White Pine Mine employed a total of 1,113 workers compared with 1,069 in 1989, according to the company annual report. Although under new ownership, employees of Copper Range still participated in an Employee Stock Ownership Plan and had representation on the board of directors. Copper Range has a collective agreement with the United Steelworkers of America, representing the unionized employees at Copper Range, which expires in November 1993. No further wage increases will be granted under the current contract.

Production Costs.—The weighted-average cash cost, including byproduct credits and taxes but excluding depreciation, of producing refined copper in the United States was estimated to have remained nearly the same, at 54 cents per pound

TABLE 3

PRODUCTIVITY[1] IN THE U.S. COPPER INDUSTRY, BY ACTIVITY

		1986	1987	1988	1989	1990
COPPER MINE PRODUCTION						
Ore concentrated and leached	metric tons	172,476,000	202,632,000	223,576,000	r237,301,000	249,499,000
Copper recovered	do.	1,041,520	1,154,181	1,341,279	r1,438,627	1,547,059
Average yield of copper	percent	0.60	0.57	0.60	r0.61	0.62
Copper from in situ leach	metric tons	79,031	70,136	49,299	34,485	19,817
Total production[2]	do.	1,120,551	1,224,317	1,390,578	r1,473,112	1,566,876
MINE AND SX-EW PLANT LABOR						
Average annual workers[3]		10,154	11,924	11,873	12,421	12,924
Employee-hours worked		20,326,091	23,197,110	25,707,013	29,371,885	26,314,237
PRODUCTIVITY AT MINES						
(hours per ton)		18.14	18.95	18.49	19.94	16.79
REFINED COPPER PRODUCTION						
Electrolytic copper	metric tons	1,241,309	1,276,933	1,525,470	1,541,543	1,511,366
PRODUCTIVITY AT PLANTS[4]						
(hours per ton)		10.27	9.48	8.19	8.17	8.58
INDUSTRY PRODUCTIVITY						
(hours per ton)		28.41	28.43	26.68	28.11	25.37

rRevised.

[1]Employee-hours per metric ton mined and processed.

[2]Production from byproduct mines not included.

[3]Includes mine, mill, SX-EW (solvent extraction and electrowinning) plant, and administrative workers at copper open pit and underground mines. Construction workers and workers at mines developing, on standby, or care and maintenance are included. Mines producing copper as a byproduct are not included.

[4]U.S. Bureau of Mines estimates based on unpublished Department of Labor data.

Sources: U.S. Department of Labor and Mine Safety and Health Administration and U.S. Bureau of Mines, production statistics.

in 1990, according to the U.S. Bureau of Mines Minerals Availability System (MAS) estimates. Including recovery of capital, the average production cost was 60 cents per pound. Even so, the massive restructuring program undertaken by the U.S. copper industry was now paying off; although it had taken immense amounts of capital, the producers were positioned favorably for international competition and lower prices.

Asarco's administrative costs rose by $15 million in 1990, as a result of higher marketing costs in the specialty chemicals business and other corporate expenses. Depreciation and depletion increased $11 million in 1990 on higher metal production rates and increased capital spending. Research and exploration costs rose $2.8 million in 1990 compared with those of 1989, reflecting the second year of increased exploration activity. Interest expense was $9 million higher in 1990 than that in 1989, because of increased borrowing. In 1990, lower prices for copper, silver, and zinc were largely offset by higher lead prices, higher copper sales volume, and specialty chemical sales.

Copper Range's cash costs were reported by the company to be 96 cents per pound in 1990 compared with 88 cents per pound in 1989. Total costs were $1.08 per pound in 1990 and $1.00 per pound in 1989. Metall Mining began significant investment in the White Pine Mine to reorganize and modernize the mine in order to increase production and lower operating costs. The underground mine was reorganized into two distinct operations, the Northeast and Southwest Mines. The priority in 1990 was to replace the aging equipment in the Northeast Mine and to develop additional headings to achieve higher production levels. These measures increased the mine output to its highest rates since the restart of operations in 1985. The production increases and productivity improvements had not yet translated into higher earnings because of the high costs associated with this program as well as a fall in copper prices in 1990. The priority for 1991 was to be the modernization of mining equipment in the Southwest Mine and consolidation of mining activities.

Copper Range developed the "super unit" concept by creating larger production areas with the intent of improving productivity and achieving economies of scale. All

TABLE 4

ESTIMATED PRODUCTION COSTS AT PRODUCING COPPER MINES[1]

(January 1990 U.S. dollars per pound of refined copper)

	Number of mines	Mine operating cost	Mill operating cost[2]	Smelter refinery cost[3]	(Less) byproduct credit	Net operating cost	Taxes[4]	Cash costs	Recovery of capital[5]	Total production cost[4]
Production costs:[6]										
Australia	3	$0.36	$0.15	$0.20	$0.19	$0.52	—	$0.52	$0.10	$0.62
Canada[7]	17	.35	.32	.38	.54	.51	—	.51	.12	.63
Chile	8	.17	.18	.11	.05	.40	$0.01	.41	.11	.52
Peru	5	.23	.23	.39	.07	.77	.02	.80	.14	.94
Philippines	8	.28	.36	.24	.39	.49	.04	.53	.10	.63
United States	17	.17	.27	.18	.10	.53	.01	.54	.06	.60
Zaire	4	.39	.21	.34	.29	.65	.01	.66	.04	.70
Zambia	9	.40	.30	.24	.09	.86	.09	.94	.08	1.02
Other[8]	34	.33	.33	.37	.31	.71	.02	.73	.21	.94
Total or average	105	.26	.26	.24	.19	.57	.02	.59	.11	.70
Life-of-the-mine production costs:[9]										
Australia	3	$0.59	$0.27	$0.27	$0.46	$0.67	—	$0.67	$0.09	$0.76
Canada[7]	17	.31	.30	.35	.43	.53	—	.53	.12	.65
Chile	8	.17	.21	.10	.05	.44	$0.01	.45	.06	.50
Peru	5	.17	.23	.53	.21	.73	.01	.74	.14	.89
Philippines	8	.25	.32	.23	.23	.57	.03	.60	.10	.71
United States	17	.17	.27	.18	.08	.54	.01	.55	.06	.61
Zaire	4	.39	.20	.30	.21	.67	.01	.68	.03	.72
Zambia	9	.40	.30	.25	.09	.86	.09	.95	.06	1.01
Other[8]	34	.31	.39	.36	.30	.76	.02	.78	.19	.97
Total or average	105	.24	.26	.22	.15	.57	.02	.59	.09	.67

[1]Data may not add to totals shown because of independent rounding.
[2]Includes copper recovery by leaching.
[3]Includes cost of transportation and cost of byproduct and coproduct smelting.
[4]Taxes and production costs are at a zero percent rate of return and do not include State or Federal revenue-based taxes.
[5]Average over life-of-the-mine capital cost.
[6]Based on annual production rates and ore grade estimates for 1990.
[7]Does not include INCO Ltd.'s and Falconbridge Ltd.'s Sudbury nickel-copper operations.
[8]Does not include Yugoslavia copper mines.
[9]Based on life-of-the-mine production rates and ore grades. Does not necessarily reflect 1990 operating grade and production.

Source: U.S. Bureau of Mines, Minerals Availability System (MAS) cost analysis. Prepared by Kenneth Porter.

new equipment was mobile, to allow for a more efficient and uninterrupted process of drilling, blasting, mucking, and removal of ore. New techniques at the White Pine Mine have increased drilling flexibility; primary crushing was moved closer to the production face, and haulage distances were shortened through the extension of conveyor systems to the working areas. The Northeast and Southwest Mines each will have its own management structure and equipment fleet.

The emphasis during Cyprus' previous 5 years was growth through acquisitions, but the focus in 1990 shifted to increasing operating efficiencies. To increase productivity, lower operating costs, and maintain capacity, Cyprus spent more than $200 million in 1990. A similar expenditure was planned for 1991. Over the past 5 years, Cyprus had invested almost $700 million to sustain and improve operations and develop new mines, with about $180 million being spent on copper.

Cyprus Minerals planned to modernize and expand its electric Miami, AZ, smelter to reduce the company's overall costs. Addition of an oxygen enrichment combustion process was expected to reduce electrical costs. The increased throughput also would result in additional sulfuric acid, decreasing the company's need to purchase sulfuric acid for its leaching projects. The additional mill capacity at Bagdad, which was completed during the year, was designed to reduce production costs through added processing capacity and improved productivity.

Kennecott reported operating costs were up at its Bingham Canyon Mine during the year, as a result of higher labor rates and reduced smelter production.[16] Construction of the fourth concentrator line was 25% completed by yearend and was scheduled for commissioning in early 1992. Although exact costs were not made public, Kennecott officials cited costs at Bingham of about 35 cents per pound after credit for byproducts. This would make the mine one with the lowest cost in the world.[17]

Production costs at Phelps Dodge operations were reduced to between 55 and 60 cents per pound of copper, from a high of more than 80 cents in 1981. Substantial capital programs underway or planned will cost another $365 million over the next 3 years, further supporting the company's cost-reduction goal. Incremental production costs at the Tyrone SX-EW plant have been below 30 cents per pound of copper cathode; similar costs have also been experienced at the Morenci plant. The Morenci plant was being doubled in size.

Phelps Dodge's planned capital expenditures for 1991 were budgeted at about $290 million, very near the 1990 level of investment. The more important projects in 1990 included the completion of the Northwest Extension at Morenci, additional in-pit crushing and conveying equipment to support reentry into the Metcalf area of the Morenci Mine, and expansion of Tyrone's SX-EW facility. Phelps Dodge Mining Co. had capital expenditures in 1990 of $182.5 million. With unit costs substantially below combined conventional methods, the SX-EW method of copper production was a major factor in cost reduction by Phelps Dodge. The in-pit crusher and conveying project allowed the company to phase out rail haulage and reduce haulage costs in the Morenci pit.

Magma Copper's strategy for the future was to continue to reduce costs and increase production. Within the next 5 years, Magma planned to develop electrowon cathode production of 72,575 tons per year from existing and new properties at a fully loaded cost of less than $0.65 per pound. Coupled with cost reductions and productivity increases from sulfide copper sources, Magma anticipated an overall average cost at its mines of $0.70 per pound could be achieved. San Manuel mine is deep, hot, and labor intensive, making it high cost. However, these costs were expected to decline significantly once primary development of the Kalamazoo is completed in 1991. Additional cost reductions were expected from productivity and other cost reduction programs. Other production outside of the underground mine have a break-even cost of $0.59 per pound, including general, administrative, and marketing costs. As the last of the technical problems were resolved and Magma's smelter was operating at full capacity, the company reported cash operating costs had been reduced substantially from about 80 cents per pound in the first quarter to 71 cents per pound in the fourth quarter.[18]

In a recent study, the U.S. Bureau of Mines estimated direct operating costs for smelting facilities with emission controls. Retrofit capital costs were estimated to be on the order of $150 million per facility or 5.6 cents per pound of copper produced. The overall cost penalty, including capital invested, to the producer for implementing the new smelting and sulfur dioxide capture facilities was estimated to be 7.5 cents per pound after deductions of a 1.3 cent per pound acid credit. The realized benefit derived from providing a cleaner air could not be evaluated in monetary terms. The operating costs for the individual smelters studied ranged from 10 to 15 cents per pound of copper, and the average operating cost in 1987 was 12.3 cents per pound. This operating cost included 3.2 cents, or 26% of the total, as the cost burden of compliance with environmental, health, and safety regulations. Installation of the new processes led to some savings in operating cost as well as increased production capacity, but the study concluded that the retrofits would not have been economically justified had not compliance with regulations been dictated.[19]

Production

Mine Production and Reserves.—Copper was mined in 13 States during 1990, with Arizona maintaining its lead with 60% of the total, followed by New Mexico and Utah. There were 62 copper-producing mines, down from 68 mines in 1989. Of these, 36 were copper mines and 26 were mines from which copper was produced as a byproduct or coproduct of gold, lead, silver, or zinc. Total U.S. operating mine capacity, in terms of recoverable copper per year, was estimated to be 1.86 million tons in 1990 compared with 1.79 million tons in 1989. The growth was largely the result of further increases from SX-EW recovery, but also was from the startup of several new mines. Annual SX-EW capacity was expanded to 405,000 tons during the year compared with 353,000 tons of copper in 1989. Reserves at the major producing companies were reevaluated with some significant increases, as shown in table 5.

South Atlantic Ventures Ltd.'s Oracle Ridge reportedly was the first underground mine to open in Oregon since World War II. Costing $6 million to construct, the mine would produce at the rate of 5,400 tons of copper per year, starting in January 1, 1991. Underground development encountered massive sulfide ore containing values as high as 21.53% copper and 4.45% zinc. Reserves were listed as 417,300 tons of ore grading 3.04% Cu, 2.92% zinc, 0.038 ounce per ton gold, and 1.10 ounces per ton silver. Magma Copper reopened its Superior Mine, AZ, Arimetco opened the Johnson Camp Mine, AZ, and Formosa Mining opened the Silver Butte Mine, OR. Kennecott received development and mining permits for the Flambeau, WI, project. A setback occurred

TABLE 5

MAJOR U.S. COPPER-PRODUCING COMPANY RESERVES IN 1990

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	544,345	0.68	3,702	3,702	9.7
Ray, AZ	100.0	568,030	.69	3,919	3,919	10.3
Silver Bell, AZ	100.0	91,938	.47	432	432	1.1
Continental, MT	49.9	367,360	.30	1,102	550	1.4
Total copper deposits	XX	1,571,673	.58	9,155	8,603	22.6
Byproduct deposits:						
Coeur, ID	50.0	342	.83	3	1	([2])
Galena, ID	37.5	758	.53	4	2	([2])
Troy, MT	75.0	53,872	.70	377	283	.7
Leadville, CO	50.0	756	1.28	10	5	([2])
West Fork, MO	100.0	7,813	3.32	259	259	.7
Total byproduct deposits	XX	63,541	1.03	653	550	1.4
Total reserves	XX	1,635,214	.60	9,808	9,153	24.1
Copper Range Co.:[3]						
White Pine, MI	100.0	175,994	1.11	1,954	1,954	5.1
Cyprus Minerals Co.:[4]						
Copper deposits	100.0	938,936	.42	3,943	3,943	10.4
Copper-molybdenum deposits	100.0	414,583	.34	1,410	1,410	3.7
Total reserves	XX	1,353,519	.40	5,353	5,353	14.1
Kennecott Corp.:[5]						
Bingham Canyon	100.0	997,900	.60	5,987	5,987	15.7
Magma Copper Co.:[6]						
Magma Superior	100.0	3,991	5.70	228	228	.6
San Manuel:						
Oxide pit	100.0	38,288	.42	160	160	.4
Oxide pit[7]	100.0	9,524	.89	85	85	.2
In situ leach ores	100.0	234,601	.35	828	828	2.2
Underground sulfide	100.0	88,555	.72	641	641	1.7
Underground sulfide[7]	100.0	128,530	.64	824	824	2.2
Kalamazoo Underground:						
Sulfide reserves	100.0	10,207	.72	73	73	.2
Deep sulfide[7]	100.0	280,903	.73	2,056	2,056	5.4
Pinto Valley:						
Dump leach (sulfide)	100.0	353,839	.12	414	414	1.1
Miami tailings leach	100.0	30,558	.33	101	101	.3
Open pit sulfide	100.0	342,719	.39	1,340	1,340	3.5
Undeveloped sulfide[7]	100.0	287,685	.39	1,134	1,134	3.0
Total reserves	XX	1,809,400	.44	7,884	7,884	20.7
Phelps Dodge Corp.:[8]						
Morenci, AZ	85.0	602,915	.79	4,763	4,049	10.6
Chino, NM	66.7	276,419	.70	1,935	1,290	3.4
Tyrone, NM	100.0	30,754	.72	221	221	.6
Burro Chief, NM leach[e]	100.0	43,908	.30	132	132	.3
Total reserves	XX	953,996	.74	7,051	5,692	15.0
Grand total, major companies	XX	6,926,023	.55	38,037	36,023	94.7

[e]Estimated. XX Not applicable.
[1]Source: ASARCO Incorporated 1990 Annual Report, p. 34.
[2]Less than 0.05%.
[3]Source: Metall Mining Corp. Annual Report 1990, White Pine Mine, p. 8.
[4]Source: Cyprus Minerals Co. 1990 Annual Report, p. 28.
[5]Source: RTZ Corp. Form 20F, ending Dec. 31, 1990.
[6]Source: Magma Copper Co. 1990 10K Report, p. 18.
[7]Additional reserves in and around shaft pillars and in lowest mine levels, not included in stated mine plan in 1990. Active reserves based on 70 cents per pound. Pinto Valley undeveloped reserves are peripheral to the current reserves and in the mine plan for beyond 2006 when current reserves are depleted.
[8]Source: Phelps Dodge Corp. 1990 Annual Report, p. 14.

in the development of the Montanore silver-copper project near Libby, MT, when Montana Reserves Co. encountered difficulties in financing its 45% stake in the project.

Gold Express Corp. of Denver, CO, announced plans to reopen the Copper Flat Mine in New Mexico. Expected to begin production in 1991, the mine would produce about 18,000 tons of copper in concentrates annually. The mine would also produce some gold, silver, and molybdenum. Since the old mill had been sold and moved to Papua New Guinea, a new mill was to be built. Michcan Inc., a Michigan investment group that included Peninsula Copper Industries, was proceeding on schedule with dewatering the Centennial Mine, MI.

Butte Hill Mine, MT, closed in 1990 because of low zinc prices. Copper Cliff Mine, ID, also closed in the third quarter owing to lower silver prices. Although new investors were examining its potential, the Van Dyke Mine, AZ, remained closed during the year.

Asarco, or its associated companies, operated mines in Australia, Canada, Mexico, Peru, and the United States. According to the company's annual report, Asarco and its associated companies together in 1990 accounted for about 12% of free world mine production of copper, 14% of silver, 14% of lead, and 9% of zinc. Five years ago the company supplied less than 25% of its copper and 5% of lead concentrate requirements; in 1990, it supplied about 70% of its copper needs and more than 50% of its lead requirements. By the time the copper mine expansion programs are completed in 1992, the company planned to be self-sufficient in copper concentrate requirements.

Asarco continued to expand and modernize its copper operations in Arizona. Copper production will be increased at the Ray Mine, AZ, by 58% to 165,000 tons per year and at the Mission Mine, AZ, by 42% to 112,000 tons per year. A $54 million plan to build a SX-EW plant at the Silver Bell Mine was announced. Silver Bell, which opened in 1952, was Asarco's first domestic open pit copper mine. Mining stopped there in 1984, owing to high operating costs. The new facility will produce 16,300 tons of cathode annually. Earlier plans to expand Ray Mine production had been modified to fund premine stripping and construction of a new tailings pond. An originally planned 18-mile tailings pipeline was canceled. The total cost of the Ray expansion was reset to $194 million. Late in the year, construction of a new concentrator was suspended because of unexpected permitting delays. These projects will allow Asarco to have a total mine output of 327,000 tons of copper per year.

In 1990, Asarco mined for its own account 218,000 tons of copper, compared with 198,000 tons in 1989, increasing the proportion of copper concentrates supplied to its smelters from internal sources to 70% of production from 67% in 1989. According to the company annual report, production at Asarco's mines was as follows in 1990: Mission, 72,400 tons; Ray, 110,500 tons; Continental, 37,100 tons; Silver Bell, 3,800 tons; Troy, 15,300 tons; Coeur, 800 tons; and at Galena, 800 tons.

Asarco was defendant in lawsuits in Arizona brought by Indian tribes and some other Arizona water users contesting the right of the company and numerous other individuals to use water and, in some cases, seeking damages for water usage. The lawsuits potentially affect the company's use of water at its Ray Unit, Hayden Plant, Mission complex, and other Arizona operations.[20]

According to the company's annual report, the White Pine Mine produced 42,800 tons in 1990 compared with 29,600 tons in 1989. The average grade of ore milled was 1.10% copper. Tons of ore milled in 1990 was 4.6 million, an average of 12,900 tons per day, compared with 11,700 tons per day in 1989. Production improvements continued, with average milling rates in excess of 14,500 tons per day for the final quarter. Copper Range spent about $17.2 million on replacing older mining equipment such as drill jumbos, load-haul dump equipment, and bolters. Copper Range also acquired an additional mill section that will increase milling capacity in excess of 5,400 tons per day to process the higher mine production anticipated for future years. The target output was 60,000 tons of copper per year within the next 3 years.[21]

Cyprus Minerals announced that the mill expansion at its Bagdad, AZ, copper mine had been completed and began operating August 20. The expansion increased Bagdad's annual copper production by 18,000 tons, to more than 100,000 tons. The addition of a fifth grinding line increased daily mill throughput from 54,400 tons to 68,000 tons of ore.

Copper output of 236,100 tons at Kennecott's Bingham Canyon Mine, UT, was up 3% compared with that of 1989, according to the company's annual report. In addition to gold and copper, 3.4 million ounces of silver and 5,200 tons of molybdenum were produced. Construction of the fourth concentrator line was 25% complete by yearend and was scheduled for startup in 1992. During its first 5 years of operation, the fourth line will increase production by about 32,000 tons per year of copper and 84,000 ounces per year of gold. Bingham Canyon was RTZ's largest producer of gold, even though production was 17% below that in 1989 as a result of lower grade ore being mined. RTZ reported 420,000 troy ounces of gold produced from the Bingham Canyon Mine in 1990.[22] The Wisconsin Third District Court of Appeals upheld an agreement between the town of Grant in Rusk County, WI, and Kennecott Corp. for mining copper near Ladysmith, paving the way for mine development. The ruling resolved another dispute between Kennecott's subsidiary, Flambeau Mining Co., and its environmental critics. The State of Wisconsin was expected to approve a series of permits needed to operate the 32-acre open pit mine in early 1991. Mine opponents were expected to continue to seek court injunctions to stop the mine, but company officials felt they would be able to start work at the site by mid-1991. Magma Copper's Pinto Valley Mining Div. near Miami, AZ, operated an open pit sulfide ore mine and concentrator. The open pit had an average grade of 0.41% copper. During 1990, the concentrator produced 260,400 tons of concentrate, containing 76,200 tons of copper. Pinto Valley's flotation capacity was improved in 1989, and in 1990, 14 haulage trucks were replaced with larger equipment, increasing productivity and reducing costs despite lower ore grades. Pinto Valley also had three leach operations; an in situ leach in the old Miami underground mine, closed since 1959; tailings treatment; and conventional leaching of sulfide waste from the open pit. Solutions from these three sources feed two SX-EW plants. SX-EW copper production was 14,500 tons in 1990. Magma's strategy was to supply 50% or more of the concentrate feedstock to its smelter from its own resources. To do this, Magma must develop new sulfide copper reserves, capable of supplying at least 245,000 tons of concentrates per year by 1997, when the San Manuel underground reserves will be depleted.

San Manuel underground mine has been in operation since 1956. The current underground plan extends into 1997, at a

rate of 42,000 tons per day, with an average ore grade of 0.65% copper. The plan included limited development and production from the Kalamazoo Mine. The Kalamazoo Mine started production in the third quarter of 1990 and was operating at 5,400 tons per day at yearend. Refined copper from this source will average 86,200 tons per year over the mine plan period. Magma also produced about 26,700 tons of SX-EW copper cathode from an open pit mine at San Manuel, from which copper oxide was mined for pad leaching, and from an in situ leaching operation that extracted copper from San Manuel underground oxide ore reserves. Production from the in situ leach operation, originally plagued with recovery problems, was 11,400 tons. This improvement was achieved as a result of an innovative well-to-well leaching technology.[23] Magma Copper's Superior Mining Div., near Superior, AZ, produced concentrates that were trucked to the San Manuel smelter. The underground mine and mill were closed in August of 1982 and, although the ore grade averaged 3.5% copper, the operation was too labor intensive to be profitable at the time, with about 1,400 employees producing 2,700 tons of ore per day. The current mine plan had an average ore grade of 6% copper. The operations were designed to use productive teamwork with employee participation in all development aspects. This permits only 312 employees to produce more than 1,000 tons of ore per day. The company planned to increase the production rate to 1,400 tons per day by the end of 1991, at which time the mine was expected to produce more than 63,500 tons of concentrate per year, with more than 18,000 tons of copper. An exploration program to develop new reserves was also underway.

Phelps Dodge Mining Co., the mining and metals division of Phelps Dodge Corp., was the world's second largest producer of copper. The corporation's U.S. mines produced 532,500 tons of copper, including partner shares, or about one-third of the copper mined in the United States.[24] Phelps Dodge operated open pit mines at Morenci, AZ, and at Tyrone and Santa Rita Mines, NM, and at two underground mines near Copiapo, Chile. Phelps Dodge owned an 85% interest in the Morenci complex. The Santa Rita Mine and Hurley, NM, smelter are owned by Chino Mines Co., a general partnership in which Phelps Dodge holds a two-third interest; Sumitomo Mining of Japan owns one-third. According to the company's annual report, recoverable copper production at Phelps Dodge mines was as follows: Morenci, 304,500 tons; Tyrone, 144,500 tons; Chino, 123,700 tons; and at Bisbee, 5,200 tons. Bulk sampling and metallurgical testing of ores were conducted at the Cochise Project near Bisbee, AZ. Tests are underway to estimate SX-EW recovery potential.

Phelps Dodge discovered additional mineralized material at its Coronado deposit near Morenci. The Coronado deposit contained combined sulfide and oxide mineralization in excess of 136 million tons grading 0.7% copper. Additional mining resources were also identified at Tyrone, which will allow this copper operation to continue at least through 1991. The average grade of ore mined at Morenci was 0.74% copper; at Tyrone, 0.79% copper; and at Chino, 0.67% copper. When the ore body at Phelps Dodge's Tyrone Mine, NM, is exhausted early in the 1990's, SX-EW production will continue for about 15 years more. The company planned for the Northwest Extension Project at Morenci to replace the Tyrone sulfide production lost when Tyrone closes in 1992. Phelps Dodge made progress on the $112 million expansion at Morenci, which was started in 1989 and scheduled to be complete by mid-1991. By 1993, about 50% of the production at Morenci may come from low-cost SX-EW facilities. The SX-EW capacity at Morenci will be expanded by 63,500 tons of cathode annually, beginning in mid-1991 and continuing through the end of the decade. A major part of this will be from the Northwest Extension Project. About $48 million also was spent on an in pit crushing and conveying system at the Morenci Mine. This system allowed the mine to phase out rail haulage and reduce haulage costs in the Morenci pit.

Phelps Dodge announced that it would cease work on its Copper Basin Project near Prescott, AZ, and would focus efforts on other sites, including the Cochise copper project in Bisbee, AZ, and La Candelaria in Chile. Phelps Dodge had terminated a proposed land exchange with the Forest Service and preparation of its related Environmental Impact Statement for the Copper Basin Project. The corporation had been attempting for about 20 years to complete a land exchange with the Forest Service adjoining its copper property for use in building surface facilities and a tailings impoundment. Environmental protests concerning the mine itself and rumors of a new smelter being constructed here were in large part responsible for disinterest in continuing the project at this time. The Copper Queen Branch completed test mining and leaching investigations at its Cochise Project. An open pit mine with heap leaching and an SX-EW plant were planned. Cost to construct this project was estimated as $80 to $90 million. Planned recovery rates were about 41,000 tons per year of copper cathode. Limited precipitate production was currently from leaching of the old Lavender Pit No. 7 dump.

Smelter Production.—Primary and secondary smelter production increased in 1990 compared with that of 1989. Eight primary smelters with a combined capacity of 1.37 million tons operated during the year. In addition, five secondary smelters with a combined capacity of 420,000 tons operated; however, one smelter was closed for nearly half of the year, reopening under new ownership.

According to the company's annual report, Asarco produced 258,800 tons of copper at its El Paso, TX, and Hayden, AZ, smelters. Hayden produced 164,700 tons, and El Paso produced 94,200 tons of copper.

Cyprus Minerals planned to use Mount Isa Mines' (MIM) Isasmelt process in a major modernization project at its Miami, AZ, smelter. The Isasmelt process was developed by MIM and the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia.[25] The new system will bring the smelter more in compliance with OSHA and air quality regulations and provide both capital and operating cost advantages. The rennovation was expected to cost $92.5 million and reduce operating costs. The copper concentrate capacity would increase, from 408,200 tons per year to 544,300 tons per year, and the copper capacity to 163,300 tons per year. The greater throughput of concentrates and increased use of oxygen would also increase acid recovery that would be used in leach operations at the Miami mining site and eliminate acid requirements from other sources. The matte grade also would be greatly improved by about 40%. The process used a single cylindrical reactor and a submerged Sirosmelt smelting lance in an oxygen-enriched, high-intensity smelting process that was easily controlled and had considerably lower energy needs. The process also eliminated the need for a concentrate dryer, reducing energy requirements and eliminating problems associated with a

dryer. The electric furnace was to be retained, but only for separating matte and slag, since the feed into it would be molten matte and not cold concentrate. The addition of the oxygen-enriched combustion process was expected to reduce the consumption of high-cost electric power for smelting. The smelter had been affected when, in January 1990, the Salt River Power Authority increased electric power rates by more than 100%. If the necessary State and Federal approvals are obtained, startup was anticipated by mid-1992.

At yearend, Kennecott Corp. had yet to reach a final decision on modernization of its Utah smelter. Kennecott reportedly was considering an investment of $200 million in pollution control equipment, including a double-contact acid plant by 1994, in an effort to reduce particulate emissions. Kennecott was also considering a new smelter with increased capacity since current capacity was insufficient to handle the expanded concentrate production at Bingham Canyon.

According to the company annual report, Magma Copper achieved a record smelter production of 253,000 tons of copper anode as the last of the technical problems associated with commissioning of its flash furnace were resolved. As a result, cash operating costs decreased substantially, from 80 cents per pound in the first quarter to 71 cents per pound in the fourth quarter. The flash furnace has a capacity to process more than 907,000 tons of new concentrate per year. Magma had about 21% of the copper smelting capacity in the United States and could produce more than 272,000 tons of refined copper per year. The company reported the smelter as the lowest cost smelting facility in the United States and among the lowest cost in the world; in addition, it met and exceeded all regulatory environmental requirements. The smelter operated at 100% of capacity for 1990, achieving 107% for the fourth quarter of the year. Other facilities using the Outokumpo flash smelting process reportedly undergo a furnace rebuild after processing 1 million tons of concentrates. Magma's smelter had processed more than 2.3 million tons of concentrate without a rebuild, and the company felt it would not be needed until 1992. About 903,500 tons of concentrate was processed in 1990. Magma provided 63% of feed stock.

Nassau Metals Corp., Gaston, SC, closed its secondary smelter and associated wire-rod mill in August while undergoing ownership changes. Renamed Gaston Copper Recycling Corp., the new company reopened near yearend under new ownership.

Texas Copper Corp. continued to acquire permits for construction of a new smelter in Texas City, TX. Final permits were anticipated by early 1992.

Refinery Production.—Ten electrolytic, 6 fire refineries, and 14 electrowinning plants operated during the year. Total U.S. refinery capacity was 2.47 million tons of copper. Refinery production from primary sources increased markedly as a result of increased SX-EW capacity, continued higher imports from Mexico by Magma Copper to feed its San Manuel facilities, and higher input from domestic blister. Refined copper from scrap was lower, largely owing to a temporary shutdown by one secondary plant and a decision by another plant to switch from smelting scrap at yearend. Refined imports were lower, and exports were nearly double that of 1989.

According to the company annual report, Asarco produced 437,600 tons of refined copper in 1990 compared with 447,100 tons in 1989. Asarco announced plans in 1990 to build a new, $54 million SX-EW plant at the Silver Bell Unit near Tucson, AZ. The facility was to have a capacity of 16,300 tons per year of copper cathode.

Magma's refined copper production, excluding copper from purchased and toll concentrates, increased by 34% to 213,200 tons in 1990 compared with 158,800 tons in 1989.[26] The company expected production from Magma sources to exceed 227,000 tons in 1991 owing to increased production from the Kalamazoo and Superior Mines, which began production in 1990. According to the company annual report, custom refining operations produced 89,800 tons of copper in 1990 compared with 78,926 tons in 1989. Several operating records were achieved, including an electrowon copper production of 52,600 tons, which compared with 42,200 tons in 1989. The increase was due to startup of the new well-to-well in situ leaching technology developed at San Manuel.

All three of Phelps Dodge Mining's mines achieved record SX-EW cathode production, according to the company annual report. Production from SX-EW plants comprised almost 40% of the company's total copper production and was expected to be about 45% in 1992. SX-EW production was 185,973 tons, including partner share, and increased 47% compared with that of 1989. Eventually, the company planned for SX-EW production to comprise about 50% of its copper production. The company's electrolytic refinery in El Paso had the capacity to produce about 390,000 tons of copper cathode per year. Refinery production at Phelps Dodge facilities totaled 383,900 tons in 1990. The company also produced 55,500 ounces of gold and 2.9 million ounces of silver as a byproduct of copper mining.

Phelps Dodge was undertaking a $9 million modernization program at the El Paso refinery. This was the first full year of production at the expanded Morenci SX-EW plant, which produced 91,000 tons of copper, according to the company annual report. The Chino Mines SX-EW plant produced about 41,000 tons of copper. A $112 million project to expand Morenci's capacity by an additional 63,500 tons of SX-EW cathode per year was expected to begin in mid-1991 and continue through the decade. The Tyrone plant began in 1984 at 13,600 tons per year and has been expanded three times to its current 49,900-ton-per-year capacity. The company planned to expand Tyrone SX-EW production in early 1992 to about 63,500 tons per year.

Other Copper Products.—Peninsula Copper Industries Inc. of Hubbell, MI, manufactured high-purity copper oxide using copper-bearing scrap in the form of electronic circuit board trimmings and copper-clad bimetallics. The bimetallic scrap is usually stainless steel or conventional mild steel that can be resold after the copper is removed. However, circuit board trimmings yield a metal-free, glass-fiber epoxy laminate that was unusable and was being sent to landfills. To resolve this problem, the firm was awarded a $208,000 State grant to build a production-scale plastics recycling plant to process about 8 million pounds of fiberglass-reinforced board scrap per year. Peninsula pilot tested a method using a heat-cleaning process to clean the glass fiber and produced sufficient quantities for testing in plastics compounding and molding equipment. Initial results indicated that the fibers can impart reinforcement properties that compared favorably with virgin chopped strand. Peninsula was planning on doubling its copper oxide capacity, but hoped to derive much of its additional copper from the nearby Centennial Mine, currently under development. Peninsula's oxides were used as ingredients in wood preservatives for pressure-treated lumber and for other in dustrial and agricultural applications.[27]

Mitsui Mining and Smelting Co. announced intention to expand its electrolytic copper foil plant at Hoosick Falls, NY. Oak-Mitsui Inc., a joint venture with Allied Signal Inc., was to operate the 7,000-ton-per-year copper foil plant. Mitsui Mining produced about 25% of the world's copper foil for printed circuits and other electronic uses. Prior to 1988, the United States and Canada comprised about one-third of the 60,000-ton-per-year market. Since that time, however, several Japanese companies have increased their share of the market so that by 1991, according to some analysts, the Japanese companies will collectively control about 90% of the world's production of electronic copper foil.

Copper Chemicals.—Of the many known copper compounds, only a few were used on a large scale. Copper sulfate, from a tonnage aspect, was the most important and was a feed stock for producing many other copper chemicals. Anhydrous copper sulfate ($CuSO_4$) is a white crystalline substance, but the usual commercial form is the pentahydrate ($CuSO_4 \cdot 5H_2O$), which contains about 26% copper. Copper sulfate was used as an algacide and fungicide and as a source of copper for plant and animal feed. Copper sulfate was also used to activate zinc and other sulfide minerals in froth flotation, as a print toner in photography, and in dyes, galvanic cells, and antiseptics. In recent years, agricultural uses, including fungicides and animal feed, accounted for the growth in demand. Domestic apparent demand for copper sulfate was about 48,000 tons in 1990. The estimated end-use distribution of shipments from domestic producers, which accounted for about 75% of demand, was 65% for agricultural uses, 28% for industrial uses, and 7% for water treatment.

Copper carbonate, once used widely for production of wood preservatives, is now used primarily as a chemical intermediate, competing with industrial-grade copper hydroxide. Copper oxide has replaced carbonate in wood preservatives, and zinc carbonate has replaced copper carbonate in drilling muds. Copper sulfate was produced from copper scrap, blister copper, copper precipitates, electrolytic refinery solutions, and spent electroplating solutions by at least six companies. Prior to the 1970's, most domestic production was from copper mine producers, but as new production began from scrap, other production became significant. Although organic fungicides largely replaced copper fungicides during the 1960s, greater concern for the environment has resulted in a return to increased use of copper. Copper hydroxide fungicides, first developed in the 1970's, have become favored for most fungicide applications. Copper sulfate and, in some instances, copper chloride are used as a starting material to make hydroxides; direct copper sulfate use is declining. The main U.S. markets for copper fungicides are California and Florida citrus production.

Though demand has been increasing in recent years, domestic production of copper sulfate has stabilized at about 34,000 tons per year. Thus, the market has become increasingly import dependent, as shown by the quadrupling of U.S. imports of copper sulfate, copper oxides, and hydroxides since 1985. According to the Bureau of Census statistics, U.S. imports were 380 tons of oxides and 335 tons of copper sulfate in 1970 and increased to 2,957 tons of oxides and 13,458 tons of copper sulfate in 1989. Imports of sulfate declined slightly in 1990 as domestic production increased. The largest U.S. import sources for copper sulfate have been Mexico and Peru; Australia for copper oxide; Australia and Norway for cuprous oxide pigment; and Mexico for other copper chemicals. Most U.S. exports of copper chemicals went to Canada and Far Eastern countries such as Korea, Singapore, and Taiwan. The European nations comprise the largest import market for copper sulfate. Among the world's consumers of copper sulfate, the Federal Republic of Germany was one of the largest importers, importing an average of 10,000 tons per year since 1982. Countries that have been significant producers of copper sulfate include France, Italy, Japan, Mexico, Peru, Spain, the United Kingdom, the United States, the U.S.S.R., and Yugoslavia. Japan, one of the few countries to report its production of copper sulfate, has more than doubled its production since the early 1950's, but consumes most of it domestically. At the same time, the United Kingdom has reduced its production of copper sulfate from about 56,000 tons in 1950 (almost all was exported) to less than 10,000 tons (2,500 tons exported) in 1987.

Sulfuric Acid.—In 1990, a total of 3.96 million tons of byproduct sulfuric acid was produced, up from that of the previous year, and from 1.86 million tons in 1973, a record year of copper production. About two-thirds of all sulfuric acid production was used by the U.S. fertilizer industry. Petroleum refining and petroleum products were next in importance, followed by use in leach extraction of copper ores. Leaching of copper ores used 1.8 million tons of sulfuric acid in 1989 and 2.0 million tons in 1990. Acid for copper leaching accounted for about 8% of total acid market.[28] Sulfuric acid, the waste product scourge of the 1970's, now has evolved into a more viable byproduct for many copper smelters in the United States. The domestic industry had feared oversupply when forced to install acid plants to contain sulfur dioxide emissions. The cost to neutralize the highly caustic liquid for lack of sufficient markets also was of concern. In 1990, the acid supply and demand was nearly balanced, aided by the increase in acid leaching of copper ores. For many copper producers, acid has become a viable coproduct, and they have become major suppliers; for others, however, it was still a liability. Producing the product was extremely capital intensive. The copper industry overall has had to absorb a cost penalty of about 7.5 cents per pound, according to figures from a recent U.S. Bureau of Mines study.[29] Retrofit capital costs were estimated to be on the order of $150 million per facility. Overall, they were of little economic benefit, even though they

TABLE 6

COPPER SULFATE PRODUCERS IN THE UNITED STATES IN 1990

Company	Plant location
BIT Manufacturing Inc.	Copperhill, TN.
CP Chemicals Inc.	Sewaren, NJ, and Sumpter, SC.
Kocide Chemical Corp.	Casa Grande, AZ.
Madison Industries Inc.	Old Bridge, NJ.
Phelps Dodge Corp.	El Paso, TX.
Southern California Chemical Co.	Santa Fe Springs, CA, Union, IL, Garland, TX.

did provide for cleaner air, a benefit that was hard to evaluate monetarily. Neutralization—a worst case scenario for the smelters—reportedly would cost about $20 million per year. Some smelters have been in the situation where acid sales did not even cover the transportation costs. In fact, some producers of the 1970's paid part of the shipping costs in order to keep the acid moving; however, the market has improved since then for some producers. For example, Asarco has created its own acid sale force and reported that it can sell all it produces. Potential new acid supplies from the new smelter in Texas were expected to be absorbed by industry in Florida, Texas, and the Southwest.[30]

The economics of acid production varies between producers, but most find that transportation costs are a major factor in sales. At Magma, acid production was reportedly not profitable because of shipping distances and competition. However, Magma used about 310,000 tons in the company's own leach operations; about 500,000 tons was sold under long-term contracts. The largest percentage of Magma's sales were to other mining companies for leaching ores in Arizona. Asarco used about 40% of its acid from the Hayden, AZ, smelter for leaching ore at the nearby Ray Mine Project. Kennecott sold all of its acid within the United States. The company itself used no acid for leaching. Kennecott was planning an acid transloading facility that would provide acid storage as well as serving as a distribution point to Western State area customers. Kennecott reportedly was breaking even with its acid production.[31]

Phelps Dodge reported that acid sales had been largely unprofitable. Costs at smelters were incurred in capturing the fugitive gases within the smelter and beyond the acid plants, and high capital and operating costs were incurred for the treatment and storage of the effluent generated from the acid plant gas scrubbing system.[32]

Of concern to the copper producers was the U.S. Government's plans to increase air quality regulations. The cost to recover an additional 5% sulfur could equal the cost to recover the 90% already being recovered. One hundred percent recapture was deemed impossible by the industry. In the Clean Air legislation under consideration in Congress, additional regulation of sulfur dioxide and particulates through taxation has been proposed. The industry could be taxed up to $60 per ton of pollutants emitted. Costs and problems associated with capturing 90% of the sulfur were seen as manageable by industry, but further control was seen as having a serious effect on the copper smelting industry.

World supplies of smelter-produced sulfuric acid were rising and were forecast to increase much faster than that produced from native sulfur. Over the 5-year period starting in 1989, one analyst predicted that overall smelter acid production capacity would increase by 14% to almost 33 million tons per year. Smelter acid from South American countries was forecast to rise by 48% to 4.5 million tons per year, 70% of which was expected to be from copper smelters. This was considered important since smelter acid production was inflexible, deriving from a desire to produce copper, and was not related to the state of the sulfur market. In conditions of oversupply, unwanted tonnages of acid cannot sit around, but must be disposed of and will have a marked effect on overall acid market prices. This situation was forecast to occur within the next 2 to 3 years, if all new smelters under consideration come on-stream.[33]

Consumption

Though U.S. reported and apparent consumption for copper plummeted during the fourth quarter in response to an overall downturn in the economy, annual consumption declined only slightly. According to data compiled by the Copper Development Association (CDA), total (domestic mill shipments plus net imports) copper and copper alloy shipments to the domestic market declined by almost 4%. This followed a decline of 3% in 1989. In general, semifabricator demand for unwrought copper outperformed the market sectors in which it was consumed. For example, while annual apparent consumption for copper declined by less than 1%, housing starts declined by 13%, and investment in private and residential construction declined by 3%. Building construction was the largest end-use market for copper. The relatively strong unwrought copper demand was attributed to an increase in exports, recapture of domestic markets, and growth in the electronics and electronics product market sector. As a result, net imports of brass and wire mill products declined.

In addition to increased self-reliance on brass mill products, the 4-year trend toward increasing self-sufficiency for unwrought copper continued. Primary refined production plus copper recoverable from old scrap accounted for more than 97% of domestic demand. During the second half of the year, the United States was a net exporter of refined copper. While eastern consumers of copper continued to import copper from Canada, western producers became significant exporters of refined copper to Asian markets. Shorter transit times and higher reliability, compared with producers in Africa and South America, encouraged Asian consumers to buy their refined copper in the United States.

According to CDA shipment data, demand for mill products in building construction, industrial machinery, consumer and general products, and transportation equipment declined by 8%, 8%, 6%, and 1%, respectively; shipments to electrical and electronic products increased by 4%. According to CDA data, building construction was the largest market sector for copper products, accounting for 40% of demand, followed by electrical and electronic products, 26%; industrial machinery and equipment, 14%; transportation equipment, 11%; and consumer and general products, 9%.

Refined copper or directly melted scrap was consumed at about 20 wire rod mills, 40 brass mills, and more than 700 foundries, chemical plants, and miscellaneous manufacturers. According to U.S. Bureau of Mines estimates, as a percentage of apparent demand, 72% of the copper used in all market sectors was consumed in electrical applications; 15% in construction; 5% in machinery; 3% in transportation; 1% in ordnance; and 3% in miscellaneous uses. Following a significant growth in electrical applications during the 1970's and 1980's, this demand pattern stabilized over the past several years.

Prices and Stocks

On average, the price for refined copper remained relatively high during 1990, though it fell below that of record-high prices set in 1989. Though volatile by historical standards, with the producer price ranging from a low of $1.02 in January to a high of $1.40 in September, prices were more stable in 1990 than those in 1989, when the spread between high and low was $0.57 per pound. Domestic inventories continued to remain low throughout the year, and at the average prevailing rate of consumption, accounted for only about a 15-day supply. Thus, even small changes in availability, or perceived availability of

TABLE 7

APPARENT CONSUMPTION OF COPPER, BY END-USE SECTOR[1]

(Thousand metric tons of copper and percent of consumption)

Year	Electrical[2]		Construction		Machinery		Transportation		Ordnance		Other uses		Total consumption (quantity)[3]
	Quantity	Percent	Quantity	Percent	Quantity	Percent	Quantity	Percent	Quantity	Percent	Quantity	Percent	
1960	755	52	261	18	203	14	102	7	29	2	102	7	1,452
1961	728	48	303	20	228	15	106	7	30	2	121	8	1,517
1962	820	50	328	20	246	15	115	7	33	2	98	6	1,640
1963	822	48	377	22	274	16	120	7	34	2	86	5	1,712
1964	870	49	409	23	231	13	124	7	36	2	107	6	1,776
1965	1,031	52	416	21	238	12	139	7	40	2	119	6	1,982
1966	1,064	48	465	21	266	12	177	8	155	7	89	4	2,216
1967	918	50	367	20	220	12	129	7	147	8	55	3	1,836
1968	974	51	382	20	210	11	134	7	134	7	76	4	1,909
1969	1,009	49	432	21	247	12	144	7	144	7	82	4	2,058
1970	1,000	55	346	19	182	10	127	7	91	5	73	4	1,819
1971	1,038	55	377	20	189	10	132	7	57	3	94	5	1,886
1972	1,264	59	386	18	193	9	129	6	64	3	107	5	2,142
1973	1,378	62	378	17	178	8	133	6	44	2	111	5	2,223
1974	1,287	60	365	17	214	10	129	6	43	2	107	5	2,145
1975	914	62	236	16	118	8	88	6	44	3	74	5	1,473
1976	1,154	60	327	17	154	8	154	8	19	1	115	6	1,924
1977	1,242	60	373	18	186	9	145	7	21	1	103	5	2,070
1978	1,422	60	427	18	190	8	166	7	47	2	118	5	2,370
1979	1,412	58	463	19	219	9	170	7	24	1	146	6	2,434
1980	1,438	66	327	15	174	8	109	5	22	1	109	5	2,179
1981	1,590	70	273	12	159	7	136	6	23	1	91	4	2,271
1982	1,251	71	229	13	123	7	70	4	18	1	70	4	1,762
1983	1,368	68	322	16	161	8	80	4	20	1	60	3	2,012
1984	1,397	66	359	17	148	7	106	5	21	1	85	4	2,116
1985	1,480	69	343	16	150	7	86	4	21	1	64	3	2,144
1986[r]	1,411	66	385	18	150	7	107	5	21	1	64	3	2,138
1987[r]	1,538	70	373	17	132	6	66	3	22	1	66	3	2,197
1988[r]	1,594	72	332	15	133	6	66	3	22	1	66	3	2,214
1989[r]	1,570	72	327	15	131	6	65	3	22	1	65	3	2,181
1990	1,561	72	325	15	108	5	87	4	22	1	65	3	2,168

[r]Revised.

[1]Copper Development Association (CDA) categories have been redistributed on a copper content basis (the alloy component has been subtracted). The electrical component has been extracted from all end-use categories except electrical and ordnance. Adjustments were also made for the new scrap component, which was subtracted. Ordinance data reflect U.S. Department of Commerce ACM military shipments to 1983; estimated data, thereafter, reflect CDA data for 1989.

[2]Includes wire and other forms used in electrical, communications, and other special usés.

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

copper, significantly affected prices. Prices were at the lowest level of the year in January, having fallen sharply during the fourth quarter of 1990. Prices rose during the first three quarters of the year, though prices dipped temporarily in June owing to a modest rise in the more readily visible COMEX stocks. Prices during the first three quarters of the year were buoyed by global disruptions to supply rather than by strong demand. Production shortfalls in Chile, Peru, and Zaire, along with the continued shutdown of the Bougainville Mine in Papua New Guinea, all contributed to global tightness in supply.

The buildup in domestic inventories was moderated by changing trade patterns, the United States having become a net exporter of refined copper during the second half of the year. Increasing U.S. exports of refined copper to Asian markets resulted in continued low domestic inventories despite weak domestic consumption and record production. Though COMEX inventories remained low throughout the year, peaking at only 20,000 tons in December, LME inventories were more sensitive to foreign supply-and-demand imbalance. LME inventories, which rose to more than 130,000 tons in November 1989, declined through the first half of 1990. In early July, with spot prices on LME exceeding those on COMEX by about 6 cents per pound, surplus copper began to accumulate preferentially on the LME, more than doubling by the end of the month to 105,000

tons. However, this sudden rise did not have an immediate impact on world prices, as prices remained strong through September. Copper prices fell throughout the fourth quarter as world inventories rose to the highest level since 1986. Domestic demand dropped throughout the fourth quarter, demand in December being at the lowest monthly level in more than 4 years, and domestic inventories rose to the highest level of the year.

World Review

***Industry Structure.*—Market Summary.**—World production of refined copper increased only nominally in 1990, while demand, which had risen steadily following the 1982 recession, remained unchanged. For the third consecutive year, the balance between supply and demand for refined copper remained very close. World mine production, which had been expected to rise during the year, was essentially unchanged, as production increases in the United States and Europe were offset by production shortfalls in Africa, Chile, and Indonesia.

Stocks of refined copper held on COMEX and the LME declined slightly during the first half of the year before rallying in the second half to register a net yearend gain of about 70,000 tons. World producer and consumer inventories were estimated to have remained unchanged. Though overall stock levels increased slightly, they remained low by historical standard and represented only about a 5-week supply at the prevailing rate of consumption.

While overall world consumption of refined copper remained unchanged or even declined slightly, there were distinct regional differences. By yearend, economic recession in Canada and the United States was well documented. In the United States, weak automobile sales and a decline in new home and commercial construction led the overall economic decline. During the fourth quarter of the year the GNP declined by about 2%.

In Europe, overall copper demand was stagnant. Demand in the Federal Republic of Germany declined slightly, as a more than 2% growth in the Western states' demand was more than offset by a dramatic decline in the Eastern states. Unification buoyed demand for housing and consumer goods in the Western states, where residential construction was estimated to have increased by about 10%. The overall consumption decline in Germany was balanced by growth in Belgium, France, and Italy. Consumption in the United Kingdom was unchanged, despite a steep decline in residential and commercial construction. Increased exports to other EC countries served to stabilize their demand.

In Asia, according to preliminary data published by the World Bureau of Metal Statistics (WBMS), demand grew by about 8%. Consumption in Japan grew by almost 9%, as demand for wire mill products surged owing to growth in residential and commercial construction and increased automobile production. Demand declined in Taiwan. Taiwan's demand had surged in 1989, owing to increased exports afforded by strikes at Korean rod producers. Conversely, Korean consumption, according to WBMS, surged by almost 30% in 1990.

Mine Production.—Despite continued projections of a significant increase in world production from new and expanded projects, mine production of copper increased by less than 1% during 1990. Significant setbacks in Africa and Chile and the continued closure of the 180,000-ton-per-year Bougainville Mine in Papua New Guinea resulted in production falling below many analyst's projections.

In Chile, mine production, which had risen continuously for more than 10 years, declined slightly, principally owing to production problems at CODELCO-Chile's four mining divisions. Production by CODELCO-Chile, the world's largest copper-producing company, declined by about 50,000 tons to 1.195 million tons. Production by CODELCO-Chile was expected to remain stable or even decline further over the next several years. At the Chuquicamata Mine, a motor fire in February placed one of four ball mills in its No. 2 concentrator out of commission for most of the year. That, coupled with mine stability problems, and a 10-day slowdown by haulage truck drivers resulted in a 25,000-ton shortfall in production. High-grade slag piles from the Chuquicamata smelter, which were being reprocessed at the El Salvador division, were exhausted. The production decline at Chuquicamata was moderated by a concentrator expansion, completed in 1989, which had its first full year of operation.

At the El Teniente Mine, the world's largest underground copper mine, a series of three major rock bursts, beginning in January, led to the closure of sublevel six at midyear and an almost 9% (28,000 tons) drop in production. The section was not opened until April 1991, following a $60 million investment in concrete arch supports. As a result of the investment and lost production, the newly expanded mill operated at only about 75% of capacity, and production costs rose significantly. A permanent loss of sublevel six would have had serious implications for El Teniente as a significant portion of future production was expected to come from this area of the mine. Though final go-ahead had not been given, CODELCO-Chile was considering several new projects to compensate for declining production. The most ambitious was the 150,000-ton-per-year Chuqui Norte Project, an open pit oxide leach project 2 kilometers from the current pit. Other potential projects were: a second oxide dump-leach project and a low-grade, heap-leach project at Chuquicamata; development of an open pit in the Quebrada sulfide deposit east of El Teniente; an in situ oxide leach project in the caved area above El Teniente; and expansion of Andina's concentrator and tailings capacity by one-third to 180,000 tons of copper per year.

Despite the prognosis for a decline in production from CODELCO-Chile, growth in private-sector copper production was expected to result in continued growth in Chilean mine production. La Escondida Mine began operations during the fourth quarter of the year, and the first concentrate shipments left Chile in December, approximately 6 months ahead of schedule. The mine was expected to reach its 320,000-ton-per-year capacity by mid-1991. The $400 expansion of Exxon's Los Bronces copper project was expected to be completed by June 1992. Other major copper projects still in the formative stage, but likely to come on-stream within the next several years, included: the 75,000-ton-per-year Quebrada Blanca oxide leach project; Rio Algom's 40,000-ton-per-year Cerro Colorado sulfide-bacterial leach project; the Zaldivar underground heap-leaching and electrowinning project, purchased by Outokumpu Oy of Finland in November 1989 and projected to produce 40,000 tons of cathode per year by mid-1993; and Phelps Dodge's large La Candelaria project, projected to produce 100,000 tons of copper per year in concentrate by 1995. A detailed engineering and feasibility study was completed for La Candelaria in May, though the project had been delayed because of a legal dispute concerning improper land claim documents.

Mine production in Canada rose substantially, owing to continuous operations at

Highland Valley, Canada's largest copper mine, where an extended strike in 1989 resulted in an estimated 56,000 tons of lost production. Increased production from a group of smaller mines that started or restarted production in 1989 also contributed to the production increase and offset closure of Noranda's Brenda Mine in June, as well as production disruptions at several other mines. Canada was the site of extensive exploration and development activity during the year. In British Columbia, Geddes Resources Ltd. continued work on its Windy Craggy deposit, where reserves of at least 165 million tons grading 1.95% copper had been identified. In October, the company announced the discovery of a new Ridge Zone, which contains additional reserves. In January, the Provincial government rejected a stage 1 environmental and socioeconomic impact assessment for the project on the basis that measures to guard against potential acid mine drainage were inadequate.

At yearend, a revised mine plan was submitted that called for expansion of underground operations at the expense of open pit mining in an effort to reduce generation of acid-generating waste rock. Windy Craggy is in a sensitive wilderness area near the Alaskan border.

Other exploration activity in British Columbia included work at the Expo and Red Dog properties near Island Copper, and the Mount Milligan property, where reserves were estimated at more than 400 million tons grading 0.2% copper. In Manitoba, Hudson Bay Mining and Smelting Co. announced the discovery of new reserves at its Trout Lake Mine, and in Ontario, Minnova Inc. discovered a deep massive sulfide deposit at its Winston Lake Mine. New reserves were also identified in New Brunswick, Newfoundland, Ontario, Quebec, Saskatchewan, and the Yukon.[34]

In Peru, prolonged strike activity resulted in an 11% drop in mine production and an even greater drop in refined production. Southern Peru Copper Corp.'s Toquepala and Cuajone Mines were closed for more than 50 days over the March-May period, and Tintaya was closed for 26 days in March and April. Centromin Peru's Cobriza Mine was closed for a week in October, and Minero Peru's Cerro Verde Mine was closed for almost 4 weeks beginning in mid-August.

In Mexico, production rose owing to the continuous operation of the Cananea open pit, which had been closed for several months in 1989 when the Government declared the mine bankrupt, shut the mine, and dismissed the workers. After three failed attempts over the past several years, the Government was successful in selling the assets of Cia Minera de Cananea to a partnership between Grupo Industrial Minera Mexicana (79%), owner of Mexico de Cobre, which operates Mexico's La Caridad Mine, and Acec-Union Miniere of Belgium. The sale price was reported to be $475 million in cash.

In Papua New Guinea, the Bougainville open pit remained closed throughout the year. Initially closed in May 1989 owing to rebel activity, the mine was placed on care and maintenance in January 1990. Peace talks were scheduled to resume in January 1991 following removal of a Government economic blockade of the island, though there was little optimism regarding the near-term reopening of the mine.

In the Philippines, mine production declined slightly from the low level of the previous year as natural disasters continued to plague production. An earthquake in Benguet Province on Luzon forced the closure of Philex Mining's Santos Tomas Mine in July for 9 days, and typhoons caused a second closure in August. In November, a typhoon resulted in the shutdown of Atlas Consolidated Mining's operations on Cebu Island. Production was not fully restored until the end of December. Near yearend, Marcopper announced that its Tapian copper mine will close prematurely in 1991, about 1 year earlier than anticipated. The 26,000-ton-per-year San Antonio Mine, which was under development and would replace the lost capacity at Tapian, was not expected on-stream prior to the shutdown of Tapian. At yearend, Marcopper was seeking the necessary $40 million to complete development of San Antonio.

In Indonesia, production from Freeport-McMoRan Copper Co. Inc.'s Ertsberg complex rose significantly, with startup of production of the new Grasberg copper-gold ore body. In November 1989, Freeport announced that it had secured $550 million in financing for debt restructuring of Freeport Indonesia Inc. and mine expansion. By the third quarter of 1990, a first stage mill expansion, from 20,000 to 32,000 tons of ore per day, had been completed, and work was underway to further expand production to 52,000 tons per day. Proven reserves at Grasberg continued to be expanded, with 10.9 billion pounds of payable copper having been identified by midyear. By the end of the third quarter, Grasberg was accounting for 45% of the ore milled at the Ertsberg complex.

In Europe, the major mine development was the increased production from Portugal's Neves Corvos underground mine. Neves Corvos, which started in 1988, produced 55% more copper in concentrate than during 1989, according to the RTZ Corp. annual report. RTZ, which owned 49% of Neves Corvo, has emerged as the world's leading international copper mining company with ownership of the Bingham Canyon Mine (100%) in the United States and interests in other major copper mines in other countries, including Bougainville (26%), La Escondida (30%), Highland Valley (17%), and Palabora (39%). The large increase in Neves Corvo production in part reflected the startup in the first quarter of 1990 of a copper-tin recovery plant, which had a capacity to produce 35,000 tons of copper in concentrate per year.

In Africa, mine production fell sharply owing to problems in Zaire. A cave-in in September at the Kamoto Mine of La Generale des Carrieres et des Mines du Zaire (Gecamines) resulted in the loss of about 50,000 tons of copper production. The mine, which had a capacity of 150,000 tons of copper per year, had accounted for about 30% of Gecamines production. At yearend, the mine was reported to be operating at about 15% of capacity, and the outlook for early restoration of production was bleak.

Mine production of copper in centrally planned, or formerly centrally planned economy countries, was relatively stable during 1990, having fallen significantly the previous year. Production probably declined in Bulgaria owing to the reported closure of the Medet Mine, though preliminary estimates for Bulgarian production indicated no decline. Environmental pressure at the smelters and refiners and opening of centrally planned economy countries to free market forces was expected to result in a near-term decline of copper mine production in those countries.

Mine production in Australia increased owing to increasing production from Olympic Dam, which began production during 1989, and new production from several smaller byproduct mines. The largest of the byproduct mines was the Thalanga copper-lead-zinc mine, which began production in February. Thalanga, a joint venture between Pancontinental Mining Ltd. (50%), Agip Australia Pty. Ltd. (25%), and

Outokumpu Australia Pty. Ltd. (25%), was expected to produce about 10,000 tons per year of copper in concentrate over 20 years. Additional capacity was expected on-stream in 1991 when the Boddington Project in Western Australia, Australia's largest gold producer, begins production of about 3,500 tons per year of copper in concentrates at its new flotation plant. Olympic Dam was considering a stage 2 expansion, which would boost capacity by about 20,000 tons.

Smelting and Refining.—Concern over the adequacy of world smelting capacity became a significant issue during 1990. World copper mine production was expanding with the opening of several major mines and the incremental increases in U.S. capacity. Smelter closures in the United States during the early and mid-1980's resulted in a deficit of domestic smelting capacity and the transformation of the United States to a significant exporter of copper concentrates. Though some countries in Africa and South America were experiencing setbacks in mine production, the remote location of their smelters resulted in only limited smelting capacity availability for other mines. In recent years, Zambia has been toll smelting a small amount of concentrates for Zaire.

Spot treatment and refining charges, which had been high by historical standards during most of 1989 owing to a surplus of concentrates, began to decline at yearend. The sustained closure of the Bougainville and other supply disruptions helped sustain lower prices through midyear, but by yearend, world stocks of concentrates showed signs of increasing, and spot treatment and refining charges in Japan, as reported by the Commodities Research Unit Ltd. of London, began to rise. Charges, which had dipped below 14 cents per pound during the second quarter, rose to more than 22 cents per pound by yearend. With the opening of La Escondida Mine at yearend and incremental expansions at several other major concentrate exporting mines, the concentrate surplus was expected to increase in 1991, along with treatment and refining charges.

Numerous new smelter or expansion projects came under consideration throughout the year. In the United States, Texas Copper Corp., a subsidiary of Mitsubishi Metal Corp., continued to seek the water and air discharge permits necessary to construct a 180,000-ton-per-year Mitsubishi continuous smelter in Texas City, TX. Startup, initially scheduled for 1991, continued to be delayed by the permitting process. In Utah, Kennecott was considering alternatives, including total replacement, for its Noranda-type smelter, which had insufficient capacity to process Bingham Canyon's expanded capacity and was also facing increasingly stringent State environmental regulations. Other domestic smelter projects included furnace replacement at Asarco's El Paso smelter and renovation and expansion at Cyprus's Miami, AZ, smelter. In Chile, where significant growth in mine capacity has and is expected to continue to occur, both CODELCO and ENAMI pursued options for joint development with the private sector for new smelter capacity. ENAMI was considering expanding its Paipote smelter by 70,000 tons per year. In December, following completion of a joint feasibility study for a 200,000-ton smelter by RTZ, BHP, CODELCO, Anglo American, Outokumpu, and Billiton Metals, RTZ and BHP announced withdrawal of their support for the project. Higher-than-projected construction costs led to economic infeasibility, given prevailing treatment and refining charges. By yearend, it appeared that a similar option was still being considered by ENAMI and Brazilian, Chilean, and Canadian private interests. A feasibility study was to begin in 1991. Cia Minera Disputada de las Condes, which operated the 44,000-ton-per-year Chargres smelter, was reported to be studying the feasibility of expanding capacity to 125,000 tons. Increased production from its Los Bronces Mine, scheduled to come on-stream by 1992, would boost Disputada's concentrate production to about 200,000 tons of contained copper per year. Disputada currently markets its excess concentrate production. In Brazil, Cia Metalquimica do Maranho Ltda. (CMM) planned to construct a 100,000-ton-per-year smelter-refinery complex at Sao Luiz de Maranho to coincide with the 1993 startup of the Salobo Mine near Carajas. A planned expansion of Caraiba Metais' smelting-refining capacity, from 168,000 to 225,000 tons per year, was postponed indefinitely owing to depressed domestic demand. In addition, Brazilian tariff reductions on imported refined copper from 10% to 5% in October, with the tariff on imports from Chile and Peru being only 25% of the general tariff rate, adversely impacted Caraiba's treatment and refining margins.

Several other countries were also investigating the possibility of building smelters to accommodate new or expanded mine production. In Portugal, Outokumpu, along with a consortium of seven Portuguese companies, was studying the feasibility of building a 200,000-ton-per-year Outokumpu smelter, scheduled for startup in 1994. Outokumpu, the Portuguese Government, and private Portuguese companies each would have a one-third interest in the operating company Metalurgia do Cobre Lda. (METCOB). About one-half of the smelter feed would come from the Neves Corvo Mine. In Indonesia, Metallgesellschaft, Freeport, and the state-owned petrochemical company, PT Petrokimia Gresik, were reportedly investigating the construction of a 120,000-ton-per-year smelter to handle expanding production from Grasberg. In Thailand, Padaeng Industry Co., in partnership with Mitsubishi, Mitsui, and Mount Isa Mines Co., was undertaking a feasibility study for construction of a 150,000-ton-per-year smelter, which would depend entirely on imported concentrate. In Canada, a feasibility study funded by local business and Federal and Provincial governments concluded that construction of a 200,000-ton-per-year copper smelter near the Alcan aluminum smelter in Kitimat, British Columbia, was economically viable. However, though determined to be economic and well-positioned to process local concentrates and export copper to Asian markets, some concerns were raised over possible enviromental impact and markets for byproduct acid production. In Mongolia, the Government was soliciting financial assistance from Japan to construct a 60,000-ton-per-year smelter to treat about one-half of the concentrates produced at the Erdenet Mine.

Several existing smelters were undergoing or expected to undergo expansions. In the Philippines, Government approval was given to expanding capacity at the PASAR smelter and refinery from 138,000 tons per year to 172,000 tons per year.

In Australia, CRA Ltd.'s Electrolytic Refining and Smelting Co. of Australia Ltd. commissioned a new 80,000-ton-per-year smelter in March 1991 and officially changed its name to Southern Copper Ltd. The smelter replaced a 40,000-ton-per-year smelter that closed in September 1990. Startup had been delayed by about 6 months owing to labor, weather, and equipment problems. At the Mount Isa smelter, replacement of the reverberatory furnace with an Isamelt unit was planned for 1992. The new furnace was expected to boost

capacity by 15,000 tons of copper per year. In Japan, Mitsubishi began reconstruction of its Naoshimi smelter, where it was replacing two furnaces with a Mitsubishi system that would equal the 17,000 tons per month of combined capacity for both existing furnaces. Though no overall increase in capacity was announced, production costs were expected to be reduced by 20% to 40%. Modifications were planned at several other Japanese smelters that would collectively increase capacity by about 60,000 tons per year. In Hamburg, Germany, Norddeutsche Affinerie Aktiengesellschaft (NAA) was planning to replace its blast furnaces with an electric furnace that would boost its scrap-handling capacity by about 60,000 tons per year. In March, Taiwan's 50,000-ton-per-year Taipower smelter was closed owing to protests over sulfuric acid emissions. It appeared that the smelter would remain closed indefinitely. The 30,000-ton-per-year smelter planned for the Saindak, Pakistan, project was delayed owing to financial problems relating to infrastructure that was to be provided by the Pakistan Government. If the Government cannot build a powerplant by 1992, a fee of $15,000 per day will be owed under contract to the Metallurgical Construction Corp. (MCC) of China, which is constructing the smelter.

Capacity.—Compared with that of 1989, world mine capacity increased by only 1.6%, smelter capacity by 3%, and refinery capacity by 2.7%. Copper mine, smelter, and refinery capacity for 1990 is shown in table 8. World capacity utilization (83%) at mines continued to be low in 1990, owing to continued disruptions at mines, discussed in the previous section. Since 1974, average annual world mine production has ranged between 79% and 85% of available capacity, being highest during periods of peak demand and low available capacity, such as existed in 1987, a year of high-capacity (85%) utilization.

The data in table 8 are rated annual production capacity for mines, smelters, and refineries as of December 31, 1990. 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 routing operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Capacity at mines represents the potential copper production contained in concentrates for many producers, but for some major producers—such as Chile, the United States, and Zambia—it represents copper recoverable at the smelter level, based upon known recovery factors. SX-EW capacity is counted as smelter-level capacity only when the material must be further refined. It is otherwise counted as mine and refinery capacity, bypassing the smelter level. Past and present production potential are taken into consideration when rating a mine, especially where an engineering estimation is not available or seems inappropriate in the case of decreased ore grades. Generally, the rated capacity is based upon 360 days per year and 2 to 3 shifts per day. For new facilities, capacity is prorated for the year in which it started, but the full capacity is used for the year in which a facility closes. Mines and plants generally are not counted if they are not operating at any time during the year, except where it may be reasonably expected that a shutdown may be temporary, i.e., usually less than 2 years. The closed mine at Bougainville, Papua New Guinea, was not counted as available capacity during the year, because its closure has exceeded 2 years. The cost to reactivate this mine was considered almost that of a new mine, and so clearly falls into the long-term closure category.

Reserves.—The definitions for reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals." In this system, the reserve base is the measured plus indicated (demonstrated) resource from which reserves are estimated. Reserves are that part of the reserve base thought to be economically recoverable with existing technology at operating or developing properties. Among individual countries, Chile (22%) has the largest share of the reserve base, followed by the United States (16%), the U.S.S.R. (9.7%), and Australia (7.3%). Peru, Zaire, and Zambia also have large copper reserves, with about 5% each.

More than 90% of U.S. copper reserves was in five States—Arizona, Michigan, Montana, New Mexico, and Utah. The U.S. Geological Survey estimated total world land-based copper resources, composed of the reserve base and a larger body of less well characterized resource, was about 1.6 billion metric tons. Copper reserves reported at operating or developing properties were sufficient to meet a project cumulative demand of almost 118 million tons of primary copper through the year 2000. In addition, some of the material already identified in the reserve base, which was presumed to be uneconomic to mine, may become economic with new technology and/or higher copper prices. However, the rate of increase in the reserve base has declined since 1976. The world reserve base, including measured and indicated ore, increased by about 140% from 1965 to 1976, corresponding to a 56% growth in world production and 48% growth in consumption over the same period. Since 1976, however, the reserve base has increased by only 18% and production by only 24%, while consumption grew by an impressive 39%. Since the late 1970's the preoccupation with gold exploration and general neglect of base metal exploration led to a significant decline of reserves in Canada, Peru, the Philippines, and other countries. Unless substantial new discoveries are made immediately, some countries' output will decline by the late 1990's.

OUTLOOK

Trends in Consumption

U.S. refined copper consumption was almost 1% lower than that in 1989, reflecting the effects of depressed domestic construction, automobile, and other markets during the last 3 months of the year. World demand, on the other hand, increased by 1.2% compared with that of 1989. Demand growth rates for select periods within the 1950 to year 2000 time span have varied significantly, as shown in table 10.

Temporary, extreme changes in growth rates have occurred in response to war time demands, development and reconstruction efforts, and economic recessions. Growth rates in the United States have reflected these extremes over the years, but have generally continued along the longer term growth rate (1950-88) of 1.35% per year. As a result of the 1990-91 recession, U.S. consumption is anticipated to drop below the average growth trend line, but then is expected to rebound, resulting in an average annual growth rate of 1.96% between 1990 and the year 2000. World demand, on the other hand, while slowed by

TABLE 8

WORLD MINE, SMELTER, AND REFINERY CAPACITIES IN 1990

(Thousand metric tons, primary and secondary copper)

Continent and country	Rated capacity		
	Mine	Smelter	Refinery
North America:			
Canada	987	627	640
Mexico	380	380	190
United States	1,864	1,790	2,472
Total	3,231	2,797	3,302
Central and South America:			
Brazil	35	160	195
Chile	1,735	1,454	1,302
Peru	413	362	275
Other[2]	8	7	6
Total	2,191	1,983	1,778
Europe:			
Albania	19	15	14
Austria	—	45	50
Belgium	—	172	480
Bulgaria	51	131	80
Czechoslovakia	11	25	27
Denmark	—	5	5
Finland	16	100	100
France	1	17	47
Germany, Federal Republic of:			
Eastern states	6	55	86
Western states	—	389	537
Hungary	—	4	30
Italy	1	72	104
Netherlands	—	8	—
Norway	25	35	40
Poland	460	415	420
Portugal	172	10	10
Romania	31	118	85
Spain	40	196	252
Sweden	88	110	107
Turkey	72	81	123
U.S.S.R.	700	1,055	1,090
United Kingdom	1	80	159
Yugoslavia	145	179	174
Other	2	—	—
Total	[3]1,839	3,317	4,020
Of which:			
Nonmarket economy	1,272	1,763	1,746
Market economy	567	1,554	2,274
Africa:			
Botswana	26	26	—
Morocco	29	—	—
Namibia	50	60	—
South Africa, Republic of	209	256	172
Zaire	729	550	250
Zambia	597	506	605
Zimbabwe	16	35	28
Other[1]	1	2	3
Total	1,657	1,435	1,058
Asia:			
Burma	10	—	—
China	428	655	490
India	75	58	48
Indonesia	170	—	—
Iran	97	100	70
Japan	22	1,251	1,201
Korea, North	15	—	25
Korea, Republic of	5	185	200
Malaysia	30	—	—
Mongolia	180	—	—
Oman	20	22	20
Philippines	241	138	138
Taiwan	—	60	62
Total	[3]1,292	2,469	2,254
Of which:			
Nonmarket economy	623	655	515
Market economy	669	1,814	1,739
Oceania:			
Australia	383	295	324
Papua New Guinea	172	—	—
Total	555	295	324
Total world	10,765	12,296	12,736
Of which:			
Nonmarket economy	1,901	2,418	2,261
Market economy	8,864	9,878	10,475

[1]Includes mine capacity of 1,000 tons for Republic of Congo (Brazzaville), a nonmarket economy country.

[2]Includes mine capacity of 5,000 tons for Cuba, a nonmarket economy country.

[3]Data do not add to total shown because of independent rounding.

TABLE 9

COPPER RESERVES AND RESERVE-BASE

(Million metric tons, contained copper)

Area and country	Reserves	Reserve base
North and Central America:		
Canada	12	23
Mexico	14	20
Panama	—	12
Puerto Rico	—	2
United States	55	90
Other	—	1
Total	81	148
South America:		
Argentina	—	7
Brazil	1	11
Chile	85	120
Peru	8	31
Other	—	3
Total	94	172
Europe:		
Finland	1	1
Norway	1	1
Poland	10	15
Portugal	3	3
Spain	1	1
Sweden	1	1
U.S.S.R.	37	54
Yugoslavia	4	4
Other	2	2
Total	60	82
Africa:		
Namibia	1	1
South Africa, Republic of	2	2
Zaire	26	30
Zambia	12	30
Other	1	1
Total	42	64
Asia:		
China	3	8
India	3	6
Indonesia	3	8
Iran	3	5
Japan	1	1
Mongolia	3	3
Philippines	10	16
Turkey	1	2
Other	3	3
Total	30	52
Oceania:		
Australia	7	21
Papua New Guinea	7	13
Total	14	34
Grand total	321	552

TABLE 10

COPPER CONSUMPTION TRENDS

Period	United States	Market economy countries	World total
		Copper consumed (thousand metric tons)	
1950	1,337	2,502	2,774
1988	2,213	8,324	10,598
1990	2,168	8,700	10,994
2000 (forecast)	2,620	11,100	14,630
		Annual growth rates (percent)	
1950-88 (actual)	1.34	3.18	3.60
1990-2000 (forecast)	1.96	2.60	2.90

the recession, is expected to average a 2.9% growth annually over the next decade. The lower growth rates typical of the 1970's and 1980's are not expected to prevail. Contrarily, there were many reasons to assume that copper consumption would follow higher growth rates than the previous two decades, as discussed below.

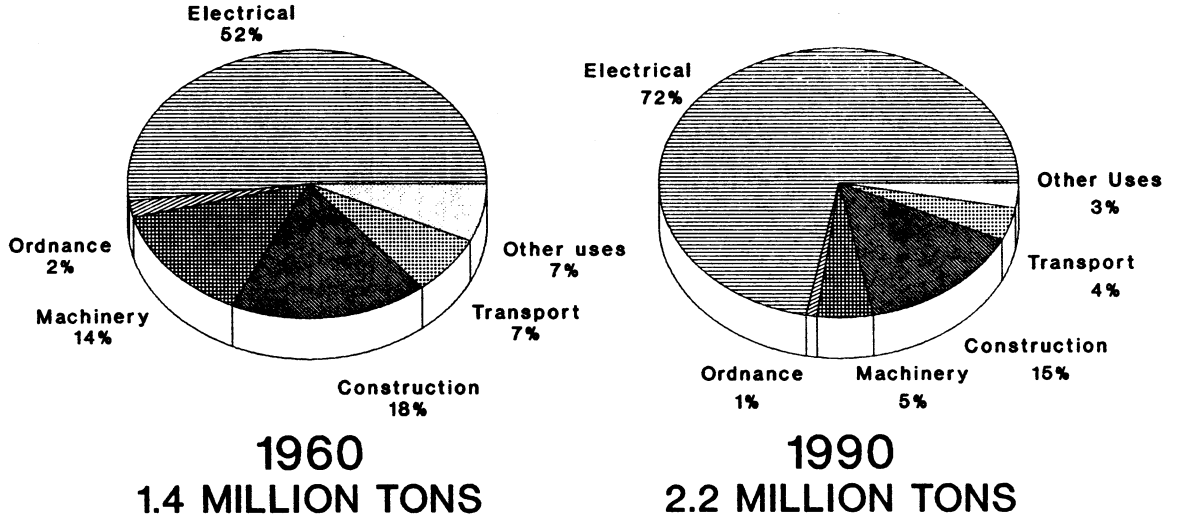
Any analysis of copper consumption at regional and country levels needs to recognize that the figures reported reflect the level of copper fabricating activity rather than that of "final" consumption by the country's society. Measured copper consumption at the semifabricate level does not take into account imports or exports of semifabricates or, more importantly, of manufactured goods containing copper. Since the early 1970's, copper consumption rates in the United States have been affected by loss of domestic market share to imports. The United States has been a net importer of copper semifabricates and of manufactured goods containing copper. A true measure of "societal" or per capita demand for copper would include copper contained in net imports of these goods. Countries such as Belgium, Germany, and Japan, and other net exporters of copper semifabricates should have their societal consumption reduced by these items. A recent study[35] by the University of Arizona indicated that the U.S. societal consumption could be increased in 1985 by as much as 500,000 tons of copper owing to imports of copper in semifabricates and finished goods. The sharp rise and subsequent fall in Japanese copper consumption in 1984 and 1985, respectively, reflected in part changes in the level of copper wire exports. A considerable part of world production and trade in semifabricates takes place between developed countries. The less developed countries (LDC's) tend to be net importers of semifabricates.

Although consumption has been reduced in many traditional end uses owing to substitution, downsizing, and changes in technology, copper consumption for all electrical uses has expanded significantly, both in total amount as well as in percent market share. In the United States, as shown in figure 1 and table 6, copper in all electrical uses has expanded market share from 52% in 1960 to more than 70% in 1990. Not only was there no suitable substitute for copper in many of these uses, but there has been a proliferation of electrical gadgetry of all types. For example, while the nonelectrical uses in automobiles, such as in radiators, have decreased significantly, copper used in the wiring harness has been enough to actually increase the total amount of copper used per vehicle. This change in makeup of copper end-use distribution has had several effects, including an influence on the availability of old scrap and on the tight correlation of total copper consumption with the gross private domestic investment (GPDI) trend for the United States. The electrical sector historically has shown the highest correlation with the GPDI among all copper end-use sectors. A high demand for copper products is associated with the high standard of living associated with increased electrical uses.

Another way of looking at copper demand and its association with standards of living is to compare copper demand with population growths, as shown in figure 2. U.S. per capita demand for copper, while

FIGURE 1

U.S. COPPER CONSUMPTION, BY END USE, PERCENT OF TOTAL, 1960 AND 1990



Source: U.S. Bureau of Mines, Sept. 1991

significantly affected by periodic recessions, has remained remarkably stable despite substitutions and loss of industry capacity to imports of manufactured goods. Global per capita use of copper, on the other hand, has exhibited an almost steady increase of 1.66% per year between 1950 and 1990. If this long-term growth trend in copper per capita demand continues, population pressure alone could result in requirements for about 15.7 million tons of copper in the year 2000, significantly above the current forecast. In recent years, per capita copper growth in demand has been less than 1% per year; if these lower rates prevail, demand in 2000 might be somewhat lower than the long-term trend would indicate. At the same time, however, the noticeable gap between the average 4.7 pounds per person consumed for the world and the 20 pounds per person for the United States illustrates the considerable growth potential for attaining an equivalent standard of living.

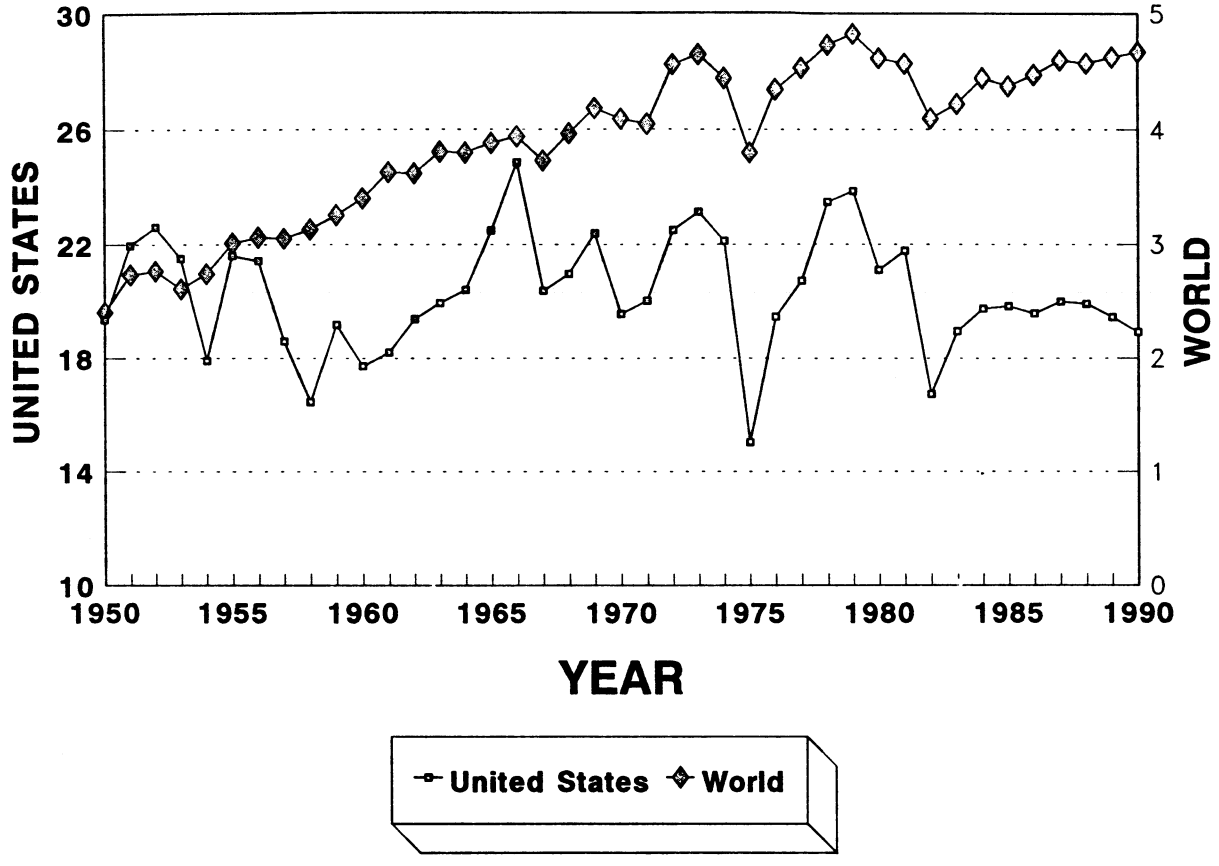
Trends in Supply

Based on the optimistic capacity projections, shown in table 11, world mine production, estimated at 85% of this capacity, could exceed 11 million tons of copper by 2000, with Chile and the United States contributing 21% and 17%, respectively. Most of the increases in mine capacity will be in South and North America, with Chile being the most important source. In Chile, several new projects are slated for development over this period, as well as anticipated mine expansions at mines such as Escondida, which may be expanded to nearly twice its original size. In the United States, expectations are that only a few new mines will be brought on-stream within this period. Several in Arizona, Montana, and Wisconsin are under consideration. In Canada, several projects are projected for this period, but some, such as Windy Craggy, could be delayed or even halted by strong environmental objections. Australia, Indonesia, and Papua New Guinea are also expected to markedly increase their respective shares of world mine capacity. Small shares are indicated than at present for Canada, Peru, Zaire, and Zambia. Most capacity in the year 2000 will come from mines now operating or being developed. The forecast capacity of table 11 is optimistic in that about 11% of the projected capacity for 2000 is highly speculative, and if successful, will come from deposits currently in exploration stages. These are known deposits that do not have firm commitment for development or financing, and their production status only can be postulated. Some reopened capacity from currently closed or uneconomic mines is also included for this period. World copper capacity from SX-EW production will increase to about 13% of total mine capacity compared with about 10% in 1992.

Historically, old scrap consumption for the world has averaged 18% of world demand, and it is dubious that this rate will

FIGURE 2

U.S. AND WORLD PER CAPITA DEMAND



Source: U.S. Bureau of Mines and Bureau of the Census, May 1991.

change over the forecast period. Primary copper has contributed more than 80% of world copper demand. The U.S. scrap resource from items in service is estimated to exceed 69 million tons or 38% of the world's total scrap resource. The rate of old scrap recovery, however, is limited by copper's long service life and use in durable goods. Historically, the largest smelters and refiners have been in or near the large refined copper-consuming industrialized countries to support their manufacturing industries. Since the early 1970's, however, several Asian and South American countries have been increasing their refined copper production capacity. The largest producer in Asia is Japan, followed by a rapidly growing China. In South America, the largest producer is Chile, which has developed its refined capacity principally for export. Australia has also begun to develop its refined copper industry in recent years. The copper industry of central Africa, because of its isolated location, size of the mine production, and energy availability, developed smelting and refining facilities early in its mine development period; its production is mostly exported. Elsewhere, however, with ready access to ports, low-cost ocean transport, and lacking energy resources necessary for economic operation of a smelter and refinery, many mine-producing countries were initially encouraged not to develop downstream processing. This was further promoted by industrialized countries with poor copper resources that have invested heavily in mine development in other countries in order to ensure long-term concentrate supplies. This has resulted in significant Japanese and European ownership of the world's copper mines. However, as environmental requirements become more stringent in the industrialized nations and the mine-producer nations strive to develop their manufacturing industries, it is anticipated that there will be an increased move to build new smelters and refineries nearer to the mine source. Building a new greenfield smelter may be perceived as more affordable where the process of permitting is quicker and easier.

Forecast Supply and Demand Trends

The major refined copper-consuming countries, or areas, of the world in 1990 were Western Europe (28.5%), the United States (19.1%), Japan (14%), the U.S.S.R. (10.2%), and China (5.3%). Copper demand was forecast to grow at a 1.97% rate in the United States and at a 2.66% rate in the world between 1990 and 2000. While consumption in Europe, Japan, and the United States was expected to increase at a relatively lower rate, other countries were

TABLE 11

WORLD COPPER MINE CAPACITY TRENDS

(Thousand metric tons recoverable copper)

Area and type of mine capacity	At operating mines			At developing mines			Potential in exploration			At mines closed in 1991			Total capacity		
	1992	1996	2000	1992	1996	2000	1992	1996	2000	1992	1996	2000	1992	1996	2000
Africa:															
SX-EW	473	473	453	5	5	5	—	5	5	—	—	—	478	483	463
Other	1,160	957	731	15	44	44	—	2	2	25	83	93	1,200	1,086	870
Total	1,633	1,430	1,184	20	49	49	—	7	7	25	83	93	1,678	1,569	1,333
Asia/Middle East:															
SX-EW	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Other	1,420	1,493	1,568	2	117	117	—	20	92	—	—	—	1,422	1,630	1,777
Total	1,420	1,493	1,568	2	117	117	—	20	92	—	—	—	1,422	1,630	1,777
Europe:															
SX-EW	1	1	1	—	—	—	—	—	—	—	—	—	1	1	1
Other	1,869	1,970	1,967	16	19	19	—	20	35	—	1	1	1,885	2,009	2,022
Total	1,870	1,971	1,968	16	19	19	—	20	35	—	1	1	1,886	2,010	2,023
Oceania:															
SX-EW	3	3	3	—	—	—	—	2	2	—	—	—	3	5	5
Other	548	498	485	20	72	59	—	4	14	100	200	200	668	774	758
Total	551	501	488	20	72	59	—	6	16	100	200	200	671	779	763
North America:															
SX-EW	467	513	473	21	63	63	—	—	51	5	5	5	493	581	592
Other	2,848	2,511	2,269	73	324	323	—	234	510	34	97	78	2,955	3,166	3,180
Total	3,315	3,024	2,742	94	387	386	—	234	561	39	102	83	3,448	3,747	3,772
South America:															
SX-EW	186	220	186	35	281	421	—	12	67	—	—	—	221	513	674
Other	2,450	2,277	2,150	54	265	255	—	39	680	—	—	—	2,504	2,581	3,085
Total	2,636	2,497	2,336	89	546	676	—	51	747	—	—	—	2,725	3,094	3,759
World:															
SX-EW	1,130	1,210	1,116	61	349	489	—	19	125	5	5	5	1,196	1,583	1,735
Other	10,295	9,705	9,170	180	841	817	—	319	1,333	159	381	372	10,634	11,246	11,691
Total	11,425	10,916	10,286	241	1,190	1,306	—	338	1,458	164	386	377	11,830	12,829	13,426

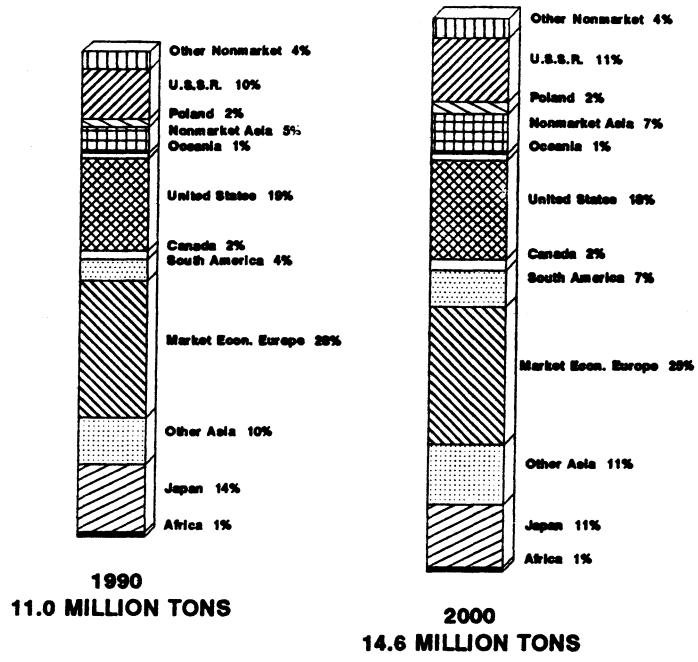
expected to surpass these rates as their economies develop. The Asian and South American markets were forecast to show the fastest growth in copper manufactures during the 1990's, as shown by the consumption trends of figure 3. Between 1975 and 1990, demand for refined copper in Asia, the majority of which was composed of Japan (59%), rose by an impressive 176% to reach 2.6 million tons. The 20% growth in U.S. semifabricate production since 1975 seems negligible compared with that of the Asian countries. Japanese growth in copper consumption began in the late 1960's, whereas Korea and Taiwan started in the 1980's. Refined copper production and consumption in Japan and other Asian countries were developed largely to feed growing export-oriented semifabricate and manufacturing industries. These goods were largely destined for North American and European markets.

In 1990, the top importers of semifabricates were France, Germany, Italy, and the United States. Production of semifabricates in Japan totaled 2.3 million tons in 1990, but imports of like items were only about 33,000 tons while exports were 166,000 tons. U.S. net imports of brass mill semifabricates have increased steadily since the 1950's, as shown in figure 4. However, since 1984, this trend has been reversed, with domestic mills recapturing some domestic markets as well as increasing exports. The United States, while producing 2.7 million tons of copper and brass mill products in 1990, imported 195,000 tons while exporting 118,000 tons. This contrasts with U.S. imports of 247,827 tons and exports of 58,950 tons in as recent as 1987. U.S. exports of copper semifabricates have been largely to Canada, Mexico, and Europe.

New opportunities for international trade in semifabricates, such as wire, bar, rod, sheet, and tube, will occur in the LDC's and developed countries alike over the forecast period. According to a United Nations

FIGURE 3

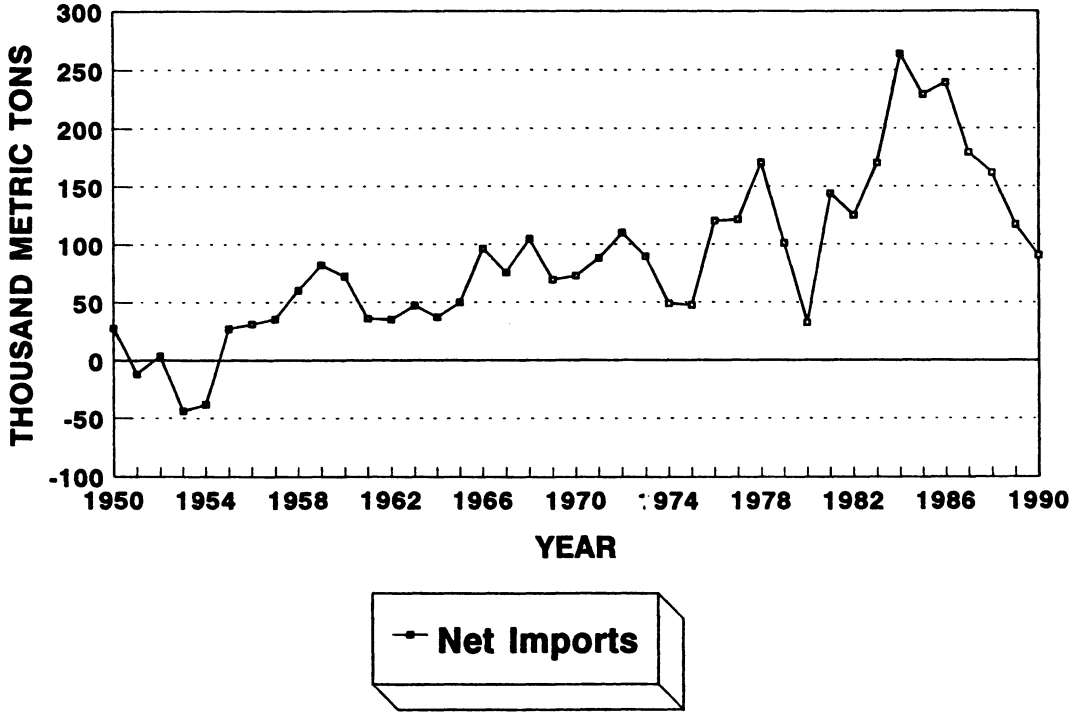
WORLD REFINED COPPER CONSUMPTION, PERCENT OF WORLD TOTAL, IN 1990 AND 2000



Source: U.S. Bureau of Mines, Sept. 1991.

FIGURE 4

U.S. NET IMPORTS OF COPPER AND BRASS MILL PRODUCTS



Source: Bureau of the Census.
(Copper wire rod is excluded.)

report, many LDC's have become growing importers of semifabricates.[36] Developing country imports of semifabricates rose from an average of 90,000 tons gross weight in the 1970's to almost 400,000 tons in the early 1980's and made up most of the increase in world trade in these products over this period. Japanese imports of semifabricates also were anticipated to increase further because of increasing domestic production costs and a growing domestic consumption in all sectors, but especially the electrical sector.

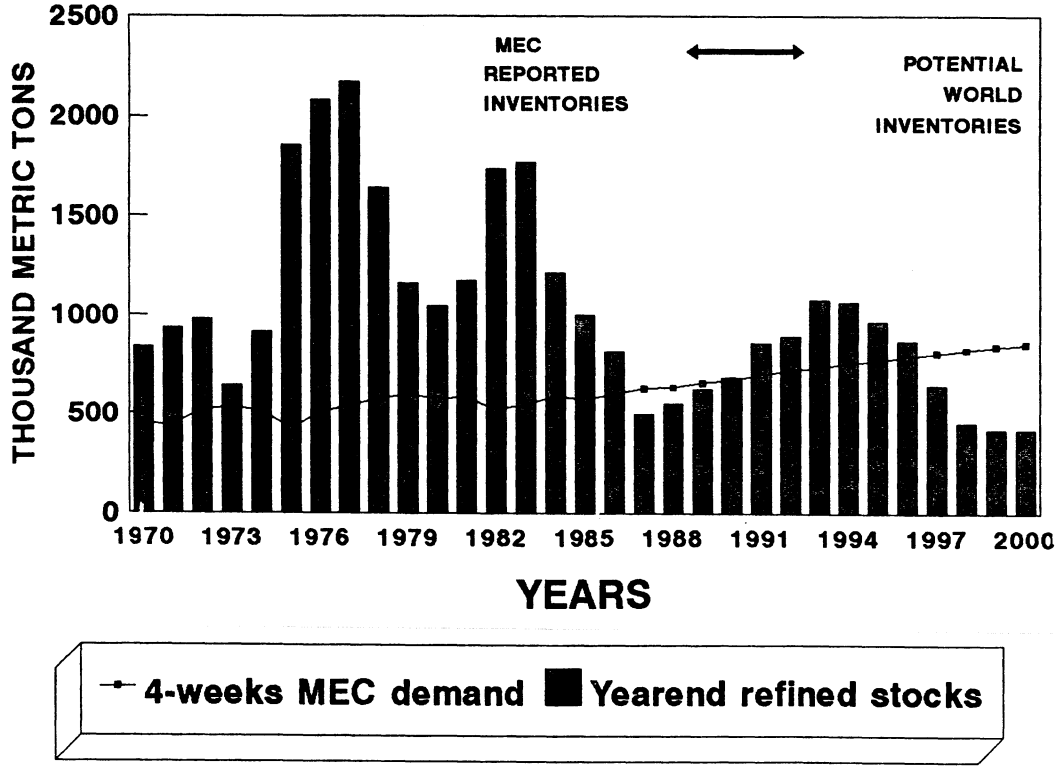
Some restrictions on the demand growth also will continue over the short term. The North American, or world recession, will have a negative short-term effect on demand for copper because real industrial growth will be restrained. Political, monetary, and social problems for some of the African, East European, Southeast Asian, and South American countries could continue and could intensify further. Consumption in these countries, therefore, could be expected to exhibit minimal growth. However, world prospects for strong, continued growth in copper consumption can be anticipated as most nations continue to improve their standard of living. The domination of copper in the many electrical and electronic applications of modern society will counterbalance the effects of substitution by other materials in some uses. The main deterrent for growth would be that of economic stagnation.

The projected balance between supply and demand forecasts is shown in figure 5. Estimated refined inventories are compared to projected average monthly MEC consumption. This forecast indicates a period of inventory surplus over the period 1992-96. The current economic recession may heighten or lengthen the period, but it is expected to be of relatively short duration as consumption rises to exceed increased copper production. The near-term period of oversupply will be followed by a renewed period of supply deficit as available mine production capacity proves insufficient to meet demand growth, as a result of mine closings, decreased ore grades at some mines, and a lack of major expansions or new projects planned for the late 1990's. Projected cumulative mine production over the next 10 years might reach 113 million tons, but this optimistic goal is still 5 million tons short of the demand forecast for the same period.

Fully 21% of future world supply in 2000 must come from new deposit production. It takes between 5 and 12 years for planning, developing, commissioning, and achieving capacity for a new copper mine. In projecting supply, it was also assumed that mine development, expansions, and production would occur in an orderly fashion with few impediments. However, if the past few years are any example, numerous obstacles could reduce production below forecast production and further exacerbate the projected deficit. Obtaining environmental clearances and mining permits can delay project development for months, if not years. Uncertainty and disruption of supply has been a hallmark of copper production over history. Because almost 60% of MEC mine capacity is composed of 29 mines of greater than

FIGURE 5

REFINED COPPER INVENTORIES AND AVERAGE MONTH'S MARKET ECONOMY COUNTRY (MEC) DEMAND



Source: U.S. Bureau of Mines, Oct. 1991.

100,000-ton-per-year size each, a temporary mine shutdown can have significant impact on the market. There is currently no emergency stockpile of supplies, such as existed in the U.S. Government stockpile during the 1960's during the crisis years of the Vietnam war. Many market, monetary, and governmental regulatory problems are also on the horizon. Some trade practices in copper scrap, for example, may be hampered by regulations emanating from the Basel Convention.

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[1]All quantities in this chapter are given in metric tons unless otherwise specified.

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[27]American Metal Market. Peninsula Copper Eyes Plastics Recycling Gateway. Oct. 30, 1990, p. 4.

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[29]Work cited in footnote 19.

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[31]Work cited in footnote 30.

[32]Work cited in footnote 30.

[33]Work cited in footnote 30.

[34]Bokovay, G. Copper. Canadian Minerals Yearbook, 1990, pp. 24.1-24.28.

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TABLE 12

MINE PRODUCTION OF RECOVERABLE COPPER IN THE UNITED STATES, BY MONTH AND BY STATE

(Metric tons)

	1986	1987	1988	1989[r]	1990
Month:					
January	98,725	101,563	110,863	127,219	126,708
February	86,953	92,154	102,507	121,520	115,289
March	96,343	105,904	120,936	134,238	123,485
April	93,840	98,040	111,851	125,551	124,211
May	97,117	104,404	120,981	127,892	133,888
June	95,879	102,007	115,826	121,788	134,328
July	94,777	104,000	116,131	122,547	137,461
August	94,418	107,004	128,163	127,547	137,010
September	97,201	105,180	120,031	122,519	136,860
October	99,969	104,586	123,646	125,204	141,945
November	92,253	108,324	121,308	118,197	139,909
December	96,738	110,430	124,685	123,596	136,097
Total	1,144,213	1,243,596	1,416,928	1,497,818	1,587,191
State:					
Arizona	786,111	751,031	842,728	898,466	978,767
Michigan, Montana, Utah	78,950	222,432	295,489	314,313	322,301
New Mexico	W	246,532	258,660	259,640	262,815
Other States[1]	279,152	23,601	20,051	25,399	23,308
Total	1,144,213	1,243,596	1,416,928	1,497,818	1,587,191

[r]Revised. W Withheld to avoid disclosing company proprietary data, included in "Other States."
[1]Includes Colorado, Idaho, Illinois, Missouri, and Tennessee; in addition, 1986 includes California, Nevada, and New Mexico; 1987 includes Washington; 1988 and 1989 include California and Nevada; and 1990 includes California, Kentucky, and Nevada.

TABLE 13

TWENTY-FIVE LEADING COPPER-PRODUCING MINES IN THE UNITED STATES IN 1990, 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	335
2	Bingham Canyon	Salt Lake, UT	Kennecott, Utah Copper Corp.	do.	245
3	Tyrone	Grant, NM	Phelps Dodge Corp. and Burro Chief Copper Co.	Copper ore, concentrated and leached	170
4	San Manuel	Pinal, AZ	Magma Copper Co.	Copper-molybdenum ore, concentrated and leached	130
5	Chino	Grant, NM	Phelps Dodge Corp.	do.	150
6	Ray	Pinal, AZ	ASARCO Incorporated	Copper ore, concentrated and leached	125
7	Sierrita	Pima, AZ	Cyprus Sierrita Corp.	Copper-molybdenum ore, concentrated and leached	117
8	Bagdad	Yavapai, AZ	Cyprus Bagdad Copper Co.	do.	116
9	Pinto Valley	Gila, AZ	Pinto Valley Copper Corp.	do.	92
10	Mission Complex	Pima, AZ	ASARCO Incorporated	Copper ore, concentrated	70
11	Inspiration	Gila, AZ	Cyprus Miami Mining Corp.	Copper ore, leached	65
12	White Pine	Ontonagon, MI	Copper Range Co.	Copper ore, concentrated	50
13	Continental	Silver Bow, MT	Montana Resources Inc.	Copper-molybdenum ore, concentrated	50
14	Troy	Lincoln, MT	ASARCO Incorporated	Copper-silver ore, concentrated	18
15	Twin Buttes	Pima, AZ	Cyprus Sierrita Corp.	Copper ore, leached	20
16	San Xavier	do.	ASARCO Incorporated	Copper ore, concentrated	15
17	Casteel	Iron, MO	The Doe Run Co.	Lead-copper ore, concentrated	NA
18	Miami	Gila, AZ	Pinto Valley Copper Corp.	Copper ore, leached	10
19	Silver Bell	Pima, AZ	ASARCO Incorporated	do.	5
20	Lakeshore	Pinal, AZ	Cyprus Case Grande Corp.	do.	5
21	Superior (Magma)	do.	Magma Copper Co.	Copper ore, concentrated	5
22	Tonopah	Esmeralda, NV	TW MNR Associates	do.	NA
23	Mineral Park	Mohave, AZ	Cyprus Minerals Co.	do.	NA
24	Fletcher	Reynolds, MO	The Doe Run Co.	Lead-zinc ore, concentrated	NA
25	Magmont	Iron, MO	Cominco American Incorporated	do.	NA

NA Not available.

TABLE 14

MINE PRODUCTION OF COPPER-BEARING ORES AND RECOVERABLE COPPER CONTENT OF ORES PRODUCED IN THE UNITED STATES, BY SOURCE AND TREATMENT PROCESS

(Metric tons)

Source and treatment process	1986		1987		1988		1989		1990	
	Gross weight	Recoverable copper	Gross weight	Recoverable copper	Gross weight	Recoverable copper	Gross weight	Recoverable copper	Gross weight	Recoverable copper
Mined copper ore:										
Concentrated	170,020,000	906,072	201,434,000	991,857	222,268,000	1,113,287	230,526,000	r1,126,742	240,617,000	1,153,596
Leached[1]	2,456,000	135,448	1,198,000	162,324	1,308,000	r227,992	r6,775,000	r311,885	8,882,000	r393,463
Total	172,476,000	1,041,520	202,632,000	1,154,181	223,576,000	1,341,279	r237,301,000	r1,438,627	249,499,000	1,547,059
Copper precipitates shipped; leached from tailings, dump, and in-place material	111,050	79,031	110,511	70,136	69,683	49,299	47,388	34,485	27,204	19,817
Other copper-bearing ores[2]	6,401,000	23,663	[3]6,041,000	19,279	10,685,000	26,351	r15,285,000	24,707	11,170,000	20,315
Grand total[4]	XX	1,144,213	XX	1,243,596	XX	1,416,928	XX	r1,497,818	XX	1,587,191

rRevised. XX Not applicable.

[1]Includes electrowon from concentrates roast-leached.

[2]Includes copper-lead ore, gold ore, gold-silver ore, lead ore, lead-zinc ore, molybdenum ore, silver ore, tungsten ore, zinc ore, fluorspar, flux ores, cleanup, ore shipped directly to smelters, and tailings.

[3]Does not include lead ore to avoid disclosing company proprietary data.

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

TABLE 15

RECOVERABLE COPPER, GOLD, AND SILVER CONTENT OF CONCENTRATED COPPER ORE IN 1990

State	Ore concentrated (thousand metric tons)	Recoverable metal content				Value of gold and silver per metric ton of ore
		Copper		Gold (troy ounces)	Silver (troy ounces)	
		Metric tons	Percent			
Arizona	149,921	682,009	0.47	36,029	5,272,184	$0.26
Other[1]	90,696	471,587	.52	W	10,554,214	W
Total or average	240,617	1,153,596	.49	W	15,826,398	W

W Withheld to avoid disclosing company proprietary data.
[1]Includes Idaho, Michigan, Montana, Nevada, New Mexico, and Utah.

TABLE 16

BLISTER AND ANODE COPPER PRODUCED IN THE UNITED STATES, BY SOURCE OF MATERIAL

(Metric tons)

Source	1986	1987	1988[r]	1989	1990
Ores and concentrates, domestic and foreign	908,087	972,141	1,042,961	1,120,445	1,158,461
Secondary materials	287,841	276,640	331,612	359,066	304,860
Total	1,195,928	1,248,781	1,374,573	1,479,511	1,463,321

[r]Revised.

TABLE 17

REFINERY PRODUCTION IN THE UNITED STATES

(Metric tons)

	1986	1987	1988	1989	1990
PRIMARY					
Electrolytic[1]	948,623	965,621	1,178,028	1,164,948	1,183,170
Electrowon	125,357	161,287	227,992	311,885	393,463
Fire-refined	W	W	W	W	W
Total[2]	1,073,981	1,126,908	1,406,020	1,476,833	1,576,633
SECONDARY					
Electrolytic	292,686	311,312	347,442	376,595	328,196
Fire-refined	113,258	103,426	98,985	[r]103,424	112,561
Total[2]	405,944	414,738	446,427	[r]480,018	440,757
Grand total[2]	1,479,925	1,541,646	1,852,447	[r]1,956,851	2,017,390
Primary domestic materials[3]	[r]1,032,968	[4]1,126,908	[r]1,282,370	1,351,748	1,502,014
Primary foreign materials[3]	41,013	W	123,650	125,085	74,620
Secondary materials	405,944	414,738	446,427	[r]480,018	440,757
Total[2]	1,479,925	1,541,646	1,852,447	[r]1,956,851	2,017,390

[r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Includes fire-refined copper.
[2]Data may not add to totals shown because of independent rounding.
[3]The separation of refined copper into metal of domestic and foreign origins can only be approximated at this stage of processing.
[4]Includes primary foreign materials.

TABLE 18

APPARENT CONSUMPTION OF COPPER POWDER AND FLAKES IN THE UNITED STATES

Year	Production (metric tons)	Imports		Exports		Apparent consumption[2] (metric tons)
		Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value (thousands)	
1978	16,992	1,153	$4,300	1,713	$4,597	16,432
1979	17,411	1,062	4,832	1,781	6,453	16,692
1980	13,203	896	4,675	1,766	6,397	12,333
1981	13,594	1,239	5,635	1,129	4,441	13,704
1982	9,686	1,064	4,521	959	3,834	9,791
1983	11,455	1,400	5,300	786	2,799	12,069
1984	12,783	1,490	r5,594	893	3,419	13,380
1985	9,776	1,143	r4,864	1,141	4,074	9,778
1986	7,898	1,277	r5,462	1,367	5,353	7,808
1987	8,440	1,154	r6,099	2,240	11,239	7,354
1988	9,370	1,430	r9,514	2,664	11,074	8,136
1989	r8,591	1,369	r9,042	2,452	9,842	r7,508
1990	8,525	1,486	9,658	2,447	9,021	7,564

rRevised.
[1]C.i.f. value at U.S. port.
[2]Production plus imports minus exports.

Sources: Bureau of Mines and U.S. Department of Commerce, Bureau of the Census.

TABLE 19

PRODUCTION, SHIPMENTS, STOCKS, IMPORTS, AND EXPORTS OF COPPER SULFATE IN THE UNITED STATES

(Metric tons)

Year	Production		Shipments[1]	Stocks, Dec. 31	Imports	Exports
	Quantity	Copper content				
1986	34,154	8,616	33,540	4,967	2,683	NA
1987	33,340	8,418	35,338	2,969	4,765	NA
1988	34,184	8,630	32,943	4,210	10,992	NA
1989	33,187	8,349	33,912	3,485	13,456	571
1990	35,294	8,893	36,412	2,367	12,254	559

NA Not available.
[1]Includes consumption by producing companies.

TABLE 20

BYPRODUCT SULFURIC ACID (100% BASIS) PRODUCED IN THE UNITED STATES[1]

(Metric tons)

Plant type	1986	1987	1988	1989	1990
Copper[2]	2,308,804	2,542,602	2,892,655	3,075,859	3,380,940
Lead[3]	122,228	116,311	133,672	155,899	165,283
Zinc[4]	379,803	410,460	416,617	409,564	412,682
Total	2,810,835	3,069,373	3,442,944	3,641,322	3,958,905

[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 21

COPPER RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1986[r]	1987	1988	1989[r]	1990
KIND OF SCRAP					
New scrap:					
Copper-base	624,176	689,999	764,490	737,088	750,707
Aluminum-base	22,891	25,871	24,104	23,761	23,124
Nickel-base	221	240	118	45	42
Zinc-base	27	12	—	—	—
Total	647,315	716,122	788,712	760,894	773,873
Old scrap:					
Copper-base	463,234	481,460	498,797	530,499	502,040
Aluminum-base	15,859	16,401	19,271	16,957	33,227
Nickel-base	84	70	86	78	77
Zinc-base	36	6	25	27	28
Total	479,213	497,937	518,179	547,561	535,372
Grand total	1,126,528	1,214,059	1,306,891	1,308,455	1,309,245
FORM OF RECOVERY					
As unalloyed copper:					
At electrolytic plants	292,686	311,312	347,442	376,595	328,196
At other plants	121,760	112,445	109,036	112,687	121,705
Total	414,446	423,757	456,478	489,282	449,901
In brass and bronze	662,242	736,725	800,221	774,701	800,332
In alloy iron and steel	1,348	973	763	551	578
In aluminum alloys	45,171	47,932	45,632	41,719	55,436
In other alloys	354	506	327	254	278
In chemical compounds	2,967	4,166	3,470	1,948	2,720
Total	712,082	790,302	850,413	819,173	859,344
Grand total	1,126,528	1,214,059	1,306,891	1,308,455	1,309,245

[r]Revised.

TABLE 22

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	Fron new scrap		From old scrap		Total[1]	
	1989[r]	1990	1989[r]	1990	1989[r]	1990
Ingot makers	22,546	19,960	122,578	123,850	145,124	143,810
Refineries[2]	143,471	129,247	336,547	311,510	480,018	440,757
Brass and wire-rod mills	548,343	570,025	36,086	32,626	584,430	602,651
Foundries and manufacturers	22,398	31,159	33,669	31,650	56,067	62,810
Chemical plants	329	316	1,619	2,404	1,948	2,720
Total	737,088	750,707	530,499	502,040	1,267,587	1,252,748

[r]Revised.

[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 23

PRODUCTION OF SECONDARY COPPER AND COPPER-ALLOY PRODUCTS IN THE UNITED STATES, BY ITEM PRODUCED FROM SCRAP

(Metric tons)

Item produced from scrap	1989[r]	1990
UNALLOYED COPPER PRODUCTS		
Electrolytically refined copper	376,595	328,196
Fire-refined copper	103,424	112,561
Copper powder	8,591	8,525
Copper castings	673	618
Total[1]	489,282	449,901
ALLOYED COPPER PRODUCTS		
Brass and bronze ingots:		
Tin bronzes	19,298	15,619
Leaded red brass and semired brass	117,465	117,747
High-leaded tin bronze	8,137	9,022
Yellow brass	8,181	6,962
Manganese bronze	9,184	10,266
Aluminum bronze	7,409	8,968
Nickel silver	4,701	2,986
Silicon bronze and brass	5,702	5,200
Copper-base hardeners and master alloys	10,771	10,379
Miscellaneous	4,113	3,881
Total[1]	194,961	191,031
Brass mill and wire rod mill products	713,792	744,224
Brass and bronze castings	46,892	55,773
Brass powder	259	288
Copper in chemical products	1,948	2,720
Grand total[1]	1,447,134	1,443,938

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

TABLE 24

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]							
1989[r]	157,918	5,905	10,359	20,244	501	34	194,961
1990	154,053	5,952	10,468	20,129	397	32	191,031
Secondary metal content of brass mill products:							
1989	[r][3]583,116	585	2,180	125,059	2,851	1	[r][3]713,792
1990	[3]603,742	288	4,321	133,209	2,645	19	[3]744,224
Secondary metal content of brass and bronze castings:							
1989	[r]42,349	922	1,303	2,005	138	175	[r]46,892
1990	49,759	1,116	1,749	2,954	63	131	55,773

[r]Revised.
[1]Data may not add to totals shown because of independent rounding.
[2]About 96% from scrap and 4% from other than scrap in 1989 and in 1990.
[3]Includes copper recovered from scrap at wire mills to avoid disclosing company proprietary data.

TABLE 25

CONSUMPTION OF COPPER-BASE SCRAP IN 1990[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	9,506	10,234	9,573	9,746	14,903	15,403	8,700	11,322	11,760	11,313	11,459	10,031	133,951
Brass and wire-rod mills	22,696	21,110	26,959	21,831	19,241	22,420	18,161	21,845	21,304	22,277	20,954	17,329	256,127
Foundries and other manufactures	2,838	2,838	2,838	2,838	2,838	2,838	2,838	2,838	2,838	2,838	2,838	2,838	34,050
No. 2 mixed heavy and light:													
Smelters, refiners and ingotmakers	29,897	22,446	28,193	25,610	18,363	22,901	18,665	22,500	19,396	23,419	21,181	18,677	271,248
Brass and wire-rod mills	5,473	5,713	5,213	9,134	5,948	6,055	2,953	6,184	5,017	5,228	4,089	3,292	64,298
Foundries and other manufactures	593	593	593	593	593	593	593	593	593	593	593	593	7,112
Total unalloyed scrap:													
Smelters, refiners and ingotmakers	39,404	32,680	37,766	35,356	33,266	38,404	27,366	33,822	31,156	34,732	32,640	28,708	405,198
Brass mills	28,169	26,822	32,172	30,965	25,190	28,474	21,115	28,029	26,321	27,505	25,042	20,620	320,425
Foundries and other manufactures	3,430	3,430	3,430	3,430	3,430	3,430	3,430	3,430	3,430	3,430	3,430	3,430	41,162
Red brass:[2]													
Smelters, refiners and ingotmakers	4,329	4,431	4,729	4,227	4,714	4,583	3,735	3,947	4,340	4,580	4,077	3,182	50,874
Brass mills	765	603	770	509	W	702	479	W	533	585	W	W	7,165
Foundries and other manufactures	1,410	1,410	1,410	1,410	1,410	1,410	1,410	1,410	1,410	1,410	1,410	1,410	16,915
Leaded yellow brass:													
Smelters, refiners and ingotmakers	1,543	1,727	1,988	1,923	1,904	2,119	1,882	1,507	1,799	2,273	1,791	1,513	21,968
Brass mills	20,773	19,092	21,047	19,835	20,862	19,505	15,833	18,734	16,986	18,378	15,341	13,662	220,047
Foundries and other manufactures	277	277	277	277	277	277	277	277	277	277	277	277	3,321
Yellow and low brass:													
All plants	10,777	9,218	8,899	18,160	8,917	10,663	8,523	8,902	10,377	9,032	8,750	8,499	120,716
Cartridge cases and brass:													
All plants	7,158	7,167	7,904	11,977	12,192	12,286	8,147	6,456	5,771	6,023	6,742	4,903	97,726
Auto radiators:													
Smelters, refiners and ingotmakers	7,512	7,122	8,015	6,970	7,201	7,053	6,548	7,396	7,245	7,241	8,522	7,062	87,885
Foundries and other manufacturers	589	589	589	589	589	589	589	589	589	589	589	589	7,062
Bronzes:													
Smelters, refiners and ingotmakers	1,079	1,122	1,159	1,206	1,219	1,255	994	1,017	1,284	1,196	1,087	745	13,364
Brass mills	469	431	457	383	502	534	318	506	427	424	393	401	5,244
Nickelcopper alloys:													
All plants	2,600	2,162	2,532	2,253	1,582	1,478	1,149	1,825	1,317	1,659	1,602	1,144	21,303
Low-grade and residues:													
Smelters, refiners and other manufacturers	9,915	10,784	11,088	10,889	12,357	11,142	10,846	11,034	9,845	10,649	13,342	14,504	136,395
Other alloy scrap:[3]													
Smelters, refiners and ingotmakers	2,160	1,680	2,180	2,458	2,202	1,696	2,047	1,663	1,575	1,944	1,982	1,770	23,358
Brass mills and other manufacturers	729	602	675	843	W	639	597	W	576	716	W	W	7,744
Total alloyed scrap:[4]													
Smelters, refiners and ingotmakers	29,484	29,403	32,580	31,029	32,892	31,053	29,063	29,897	29,866	31,159	34,416	31,792	372,635
Brass mills	39,725	36,138	38,263	50,006	41,328	42,003	32,432	33,784	31,610	32,941	29,771	25,960	433,961
Foundries and other manufacturers	2,874	2,874	2,874	2,874	2,874	2,874	2,874	2,874	2,874	2,874	2,874	2,874	34,492
Total scrap:													
Smelters, refiners and ingotmakers	68,888	62,083	70,347	66,384	66,159	69,357	56,429	63,719	61,022	65,891	67,056	60,499	777,833
Brass and wire-rod mills	67,895	62,960	70,435	80,971	66,518	70,477	53,547	61,814	57,931	60,446	54,813	46,581	754,386
Foundries and other manufacturers	6,305	6,305	6,305	6,305	6,305	6,305	6,305	6,305	6,305	6,305	6,305	6,305	75,654

W Withheld to avoid disclosing company proprietary data; included in "Total alloyed scrap."

[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.

[4]Includes data indicated by symbol W.

TABLE 26

CLOSING STOCKS OF COPPER-BASE SCRAP IN 1990

(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	11,492	4,857	5,852	5,973	7,696	5,738	8,039	7,576	5,684	5,984	6,372	6,606
No. 2 mixed heavy and light	17,729	17,210	15,465	16,597	16,358	16,390	16,409	17,806	14,872	16,547	15,262	13,091
Total unalloyed scrap	29,221	22,067	21,317	22,570	24,054	22,128	24,448	25,382	20,556	22,531	21,634	19,697
Alloyed scrap:												
Red brass[1]	2,002	2,123	1,885	1,894	1,925	1,920	2,197	2,167	1,919	1,621	1,993	1,785
Leaded yellow brass	1,492	1,422	1,412	1,206	1,112	1,195	1,089	1,214	971	845	1,013	983
Yellow and low brass[2]	895	908	919	935	1,006	1,088	1,034	1,003	742	1,515	789	803
Auto radiators	2,174	1,806	1,296	1,474	1,770	1,989	2,591	2,740	1,843	3,334	3,055	2,815
Bronzes	984	770	845	880	884	961	772	788	726	637	736	815
Nickel-copper alloys	244	264	264	270	176	241	281	307	288	327	284	305
Low-grade and residues	17,555	17,176	17,283	17,591	16,687	16,265	16,442	16,056	16,681	17,167	18,911	17,672
Other alloy scrap[3]	2,010	2,377	2,143	1,577	1,099	1,039	992	995	1,067	1,468	1,663	1,480
Total alloy scrap	27,356	26,846	26,047	25,827	24,659	24,698	25,398	25,270	24,237	26,914	28,444	26,658
Total scrap	56,577	48,913	47,364	48,397	48,713	46,826	49,846	50,652	44,793	49,445	50,078	46,355
Brass and wire-rod mills:												
Unalloyed scrap	12,189	11,220	11,424	12,983	14,185	13,995	14,978	15,780	15,904	14,661	13,735	11,767
Alloyed scrap	31,782	31,113	31,176	28,888	25,445	29,369	27,577	26,207	25,895	25,861	25,336	27,494
Total scrap[4]	43,971	42,333	42,600	41,871	39,630	43,364	42,555	41,987	41,799	40,522	39,071	39,261
Foundries and other manufacturers:[5]												
Unalloyed scrap	3,447	3,447	3,447	3,447	3,447	3,447	3,447	3,447	3,447	3,447	3,447	3,447
Alloyed scrap	6,778	6,778	6,778	6,778	6,778	6,778	6,778	6,778	6,778	6,778	6,778	6,778
Total scrap	10,225	10,225	10,225	10,225	10,225	10,225	10,225	10,225	10,225	10,225	10,225	10,225
All plants:												
Unalloyed scrap	44,857	36,733	36,189	39,001	41,687	39,570	42,873	44,610	39,908	40,640	38,817	34,912
Alloyed scrap	65,918	64,735	64,001	61,493	56,883	60,845	59,753	58,255	56,909	59,552	60,556	60,929
Total scrap[4]	110,775	101,468	100,190	100,494	98,570	100,415	102,626	102,865	96,817	100,192	99,373	95,841

[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 27

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
1989:					
Copper scrap[r]	[2]725,586	W	66,097	828,905	1,620,588
Refined copper[3]	461,022	1,698,351	[r]42,406	1,337	[r]2,203,116
Hardeners and master alloys	7,331	—	[r]3,661	—	[r]10,992
Brass ingots	—	—	[r]141,805	—	[r]141,805
Slab zinc	70,584	—	22,017	3,139	95,740
Miscellaneous	—	—	—	19	19
1990:					
Copper scrap	[2]754,386	W	75,654	777,833	1,607,873
Refined copper[3]	445,220	1,653,490	47,237	4,479	2,150,426
Hardeners and master alloys	906	—	3,269	—	4,175
Brass ingots	—	—	136,500	—	136,500
Slab zinc	73,728	—	27,401	3,103	104,232
Miscellaneous	—	—	—	179	179

[r]Revised. W Withheld to avoid disclosing company proprietary data; included with consumption of copper scrap at 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 30.

TABLE 28

APPARENT CONSUMPTION OF COPPER IN THE UNITED STATES

(Metric tons)

Period	Refined copper production	Copper in old scrap	Net refined imports	Stock change during period	Apparent consumption
1986[r]	1,073,981	479,213	489,532	-95,497	2,138,223
1987[r]	1,126,908	497,937	459,962	-111,733	2,196,540
1988[r]	1,406,020	518,179	273,346	-16,223	2,213,768
1989[r]	1,476,833	547,561	166,398	9,952	2,180,840
1990:					
January	137,360	46,232	4,244	-7,692	195,528
February	121,134	43,934	-4,455	-19,700	180,313
March	133,743	49,626	14,333	-7,162	204,864
April	125,599	46,059	17,731	4,729	184,660
May	138,845	49,051	15,734	9,891	193,739
June	129,696	48,159	11,839	3,351	186,343
July	131,790	41,791	-3,245	9,294	161,042
August	124,467	46,294	-2,157	-5,934	174,538
September	126,845	38,465	-993	-15,347	179,664
October	140,055	44,492	-3,121	-4,118	185,544
November	132,257	42,098	3,618	13,288	164,685
December	134,842	39,170	-3,021	14,018	156,973
Total[1]	1,576,633	535,372	50,508	-5,382	2,167,892

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

TABLE 29

FOUNDRIES AND MISCELLANEOUS MANUFACTURERS CONSUMPTION OF BRASS INGOT AND REFINED COPPER AND COPPER SCRAP IN THE UNITED STATES, BY GEOGRAPHIC DIVISION AND STATE

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
1986[r]	34,419	80,653	9,131	5,734	2,267	5,625	3,446	141,274	43,514	64,039
1987[r]	31,178	78,930	7,370	7,435	2,187	5,559	3,221	135,879	40,536	66,909
1988	33,336	89,024	8,669	6,660	1,959	7,593	3,929	151,169	46,412	60,706
1989[r]	34,391	85,746	7,820	6,598	1,654	5,594	3,661	145,466	41,469	64,068
1990:										
Atlantic:										
Middle: New Jersey, New York, Pennsylvania	5,459	8,479	821	744	189	473	142	16,306	8,055	8,339
South: Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	7,310	3,308	261	342	248	704	26	12,200	10,243	4,373
Central:										
East North: Illinois, Indiana, Michigan, Ohio, Wisconsin	11,584	39,060	3,345	2,511	1,050	1,995	2,611	62,156	13,833	38,017
South: Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	3,720	19,523	376	796	35	534	154	25,137	7,199	4,243
West North: Iowa, Kansas, Minnesota, Missouri, Nebraska	1,915	5,037	628	320	—	638	76	8,614	4,414	3,691
Mountain and Pacific:										
Arizona, California, Colorado, Idaho, Montana, Oregon, Utah, Washington, Wyoming	1,483	8,301	1,488	748	22	417	217	12,677	703	13,659
New England:										
Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island	462	827	529	212	306	302	42	2,679	1,669	169
Undistributed	—	—	—	—	—	—	—	—	32	329
Total[4]	31,933	84,536	7,448	5,672	1,849	5,062	3,269	139,769	46,150	72,820

[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 30

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	Total
1989:[r]						
Wire-rod mills	1,698,351	—	—	—	—	1,698,351
Brass mills	265,634	5,810	19,735	64,921	104,922	461,022
Chemical plants	W	314	—	—	623	937
Ingotmakers	W	—	W	—	1,337	1,337
Foundries	3,448	W	6,947	W	4,531	14,926
Miscellaneous[1]	14,142	W	7,728	W	4,673	26,543
Total	1,981,575	6,124	34,410	64,921	116,086	2,203,116
1990:						
Wire-rod mills	1,653,490	—	—	—	—	1,653,490
Brass mills	252,116	4,593	30,878	57,900	99,733	445,220
Chemical plants	W	W	—	—	1,086	1,086
Ingotmakers	W	—	W	—	4,479	4,479
Foundries	3,549	1,905	6,440	W	2,656	14,550
Miscellaneous[1]	13,245	111	13,184	W	5,061	31,601
Total	1,922,400	6,609	50,502	57,900	113,015	2,150,426

[r]Revised. 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 31

STOCKS OF COPPER IN THE UNITED STATES, END OF PERIOD

(Thousand metric tons)

Period	Blister and materials in process of refining[1]	Refined copper					
		Electrolytic refiners	Wire-rod mills	Brass mills	Other[2]	New York Commodity Exchange	Total[3]
1986	136	35	66	14	[r]24	84	[r]225
1987	150	29	28	15	23	17	[r]113
1988	121	16	29	17	[r]23	12	[r]97
1989	132	[r]24	32	12	[r]24	15	[r]107
1990:							
January	126	18	36	15	23	7	99
February	109	16	23	13	23	4	79
March	122	13	20	11	23	4	71
April	137	13	23	13	23	5	77
May	133	17	20	13	23	13	86
June	141	20	16	14	23	17	90
July	121	21	29	17	23	10	100
August	120	18	29	15	23	8	93
September	127	15	23	11	23	6	78
October	129	13	20	10	23	8	74
November	127	16	29	12	23	8	88
December	119	26	24	10	23	18	101

[r]Revised.
[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.
[3]Data may not add to totals shown because of independent rounding.

TABLE 32

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)
1989:							
January	118.00	118.00	103.50	80.50	r52.50	112.00	101.25
February	111.00	113.00	97.97	87.30	r57.25	116.00	104.75
March	128.50	119.50	108.32	97.33	57.50	116.00	106.90
April	130.50	115.50	110.93	87.35	57.95	116.00	107.75
May	115.00	118.00	100.16	84.50	59.00	118.27	115.02
June	106.50	104.00	91.18	75.91	59.00	117.83	115.25
July	105.00	94.50	88.63	72.00	59.00	117.50	113.95
August	114.50	101.00	99.78	73.83	59.65	117.63	112.95
September	122.00	119.00	105.50	82.00	62.00	123.09	116.75
October	127.00	116.50	106.64	82.86	62.00	120.50	116.75
November	113.50	106.50	97.25	80.70	62.00	119.70	115.50
December	100.00	99.00	88.05	77.70	60.78	119.50	115.25
Average	115.96	110.38	99.83	81.83	r59.05	117.84	111.84
1990:							
January	101.16	96.34	86.66	74.11	58.81	117.86	113.61
February	102.93	97.15	87.78	68.50	54.50	117.50	113.25
March	116.84	110.15	96.23	78.05	57.23	118.59	114.34
April	118.07	111.43	102.40	87.00	61.50	129.50	118.25
May	116.11	109.75	101.41	87.00	61.50	129.50	118.25
June	112.02	105.45	96.60	83.38	60.60	129.50	118.25
July	116.79	109.17	99.77	83.00	60.64	129.50	118.25
August	112.85	115.78	103.86	85.50	62.50	124.20	121.38
September	121.68	114.32	101.62	91.74	69.66	124.50	122.75
October	114.79	107.38	96.13	88.41	70.50	124.50	122.75
November	109.54	103.75	93.35	84.03	69.68	124.50	122.75
December	106.79	101.60	93.10	82.00	69.00	124.50	122.75
Average	112.46	106.86	96.58	82.73	63.01	124.51	118.88

rRevised.

Source: American Metal Market.

TABLE 33

AVERAGE MONTHLY PRICES FOR REFINED COPPER IN THE UNITED STATES AND THE LONDON METAL EXCHANGE

(Cents per pound)

Month	1989				1990			
	U.S. producers, delivered price		COMEX first position[3]	LME cash Grade A[4]	U.S. producers, delivered price		COMEX first position[3]	LME cash Grade A[4]
	Cathode[1]	Wirebar[2]			Cathode[1]	Wirebar[2]		
January	157.77	164.18	154.92	153.88	108.64	116.36	104.36	107.31
February	140.21	146.33	136.45	140.37	111.22	119.35	107.35	107.01
March	148.49	154.89	144.39	147.99	128.41	136.15	124.24	119.05
April	143.49	150.26	140.46	141.36	126.94	134.38	122.38	121.76
May	127.15	132.72	123.07	124.20	124.57	132.32	120.32	124.30
June	115.90	110.34	112.41	115.44	117.35	124.93	112.93	117.18
July	113.49	119.27	109.58	113.57	126.12	133.91	121.91	125.57
August	127.43	133.87	124.68	125.23	134.96	142.53	130.53	134.06
September	138.44	143.60	134.94	130.80	134.22	142.45	130.46	137.39
October	131.66	137.61	127.59	r129.74	130.18	138.28	126.41	124.39
November	118.11	123.68	113.96	117.50	119.76	127.76	115.75	117.25
December	109.22	115.60	r106.69	109.67	115.61	124.06	112.39	112.69
Average	130.95	136.03	r127.43	r128.91	123.16	131.04	119.09	121.02

rRevised.
[1]Listed as "U.S. producer cathode."
[2]Listed as "Electrolytic wirebar (Warrenton Refining Co.)."
[3]Listed as "COMEX high-grade first position."
[4]Based on average monthly rates of exchange.

Sources: Metals Week and American Metal Market.

TABLE 34

U.S. EXPORTS OF UNMANUFACTURED COPPER (COPPER CONTENT), BY COUNTRY

Country	Ore and concentrate		Matte, ash and precipitates		Refined		Unalloyed copper scrap		Blister and anodes		Total	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989[r]	266,831	$539,325	14,945	$35,363	130,189	$303,013	154,937	$244,197	5,475	$14,664	572,377	$1,136,562
1990:												
Belgium	—	—	528	3,309	2,008	2,914	365	336	—	—	2,901	6,559
Brazil	14,220	29,456	—	—	72	148	768	1,872	4	9	15,064	31,485
Canada	18,272	28,521	26,422	26,479	2,028	6,407	50,486	69,624	3,486	8,782	100,694	139,813
China	17,725	40,229	([1])	3	3,549	8,853	7,796	3,438	—	—	29,070	52,523
Costa Rica	—	—	—	—	784	2,231	—	—	—	—	784	2,231
Finland	4,047	6,624	—	—	10	37	—	—	—	—	4,057	6,661
France	29	39	17	24	1,613	3,916	396	1,176	—	—	2,055	5,155
Germany, Federal Republic of	139	211	808	4,682	946	2,555	5,711	9,873	19	202	7,623	17,523
Hong Kong	11,098	5,226	—	—	1,435	4,056	909	605	690	1,223	14,132	11,110
Indonesia	—	—	—	—	1,894	4,716	35	87	8	29	1,937	4,832
Italy	147	103	—	—	717	1,954	980	1,710	47	73	1,891	3,840
Japan	170,009	243,989	912	2,144	103,166	270,913	17,803	40,533	802	1,652	292,692	559,231
Korea, Republic of	18,819	39,865	—	—	7,871	21,410	32,282	64,490	73	142	59,045	125,907
Mexico	2	4	1,477	2,292	5,637	15,316	8,881	19,916	198	340	16,195	37,868
Netherlands	—	—	641	1,246	3,369	7,926	719	1,019	11	18	4,740	10,209
Philippines	2,802	6,471	—	—	19	14	40	11	—	—	2,861	6,496
Singapore	5	3	17	26	1,426	3,558	58	64	115	171	1,621	3,822
Taiwan	59	74	—	—	66,162	176,298	10,575	9,849	811	1,770	77,607	187,991
Thailand	5	7	—	—	2,155	5,421	1	4	—	—	2,161	5,432
United Kingdom	513	577	621	624	988	2,454	878	1,048	—	—	3,000	4,703
Venezuela	—	—	—	—	4,732	12,301	35	28	2	3	4,769	12,332
Other	344	385	264	151	584	1,436	908	1,734	156	290	2,256	3,996
Total[2]	258,235	401,785	31,709	40,977	211,164	554,833	139,624	227,418	6,422	14,701	647,154	1,239,714

[r]Revised.
[1]Less than ½ unit.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 35

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)
1989[r]	20,595	$65,443	19,620	$67,476	18,642	$75,602	6,175	$37,765	5,952	$24,301
1990:										
Australia	16	96	8	121	23	231	30	353	319	939
Austria	—	—	490	1,616	(2)	3	(2)	13	10	32
Brazil	—	—	1,093	3,132	23	244	2	13	—	—
Canada	6,179	21,894	9,708	33,849	6,755	25,477	2,761	10,292	268	970
China	12	59	500	816	927	2,307	24	326	—	—
Colombia	48	231	228	695	60	205	13	79	8	32
Dominican Republic	15	52	1,101	2,764	178	1,026	54	238	13	37
France	91	284	48	496	17	226	50	1,518	124	355
Germany, Federal Republic of	62	137	128	1,001	49	434	147	2,832	174	2,471
Hong Kong	117	470	293	2,623	92	308	49	1,316	47	139
Israel	281	1,137	51	505	86	562	36	477	71	193
Italy	59	72	51	227	(2)	26	55	218	207	513
Jamaica	20	83	658	2,086	45	158	38	179	6	30
Japan	106	484	193	2,012	37	751	142	1,604	640	2,212
Korea, Republic of	103	1,065	54	360	7	222	57	495	1,188	3,696
Malaysia	382	1,455	131	687	4	19	—	—	63	96
Mexico	2,407	7,778	1,172	3,936	9,805	38,017	1,464	8,238	57	196
Netherlands	511	1,734	15	164	50	645	56	607	268	897
New Zealand	110	472	4	55	5	45	37	288	173	514
Philippines	436	1,379	2	24	111	363	65	277	146	443
Saudi Arabia	695	2,598	11	135	31	124	54	438	—	—
Singapore	200	633	71	418	19	236	75	980	362	1,136
South Africa, Republic of	1	14	10	43	3	71	13	174	100	270
Spain	989	3,749	36	107	—	—	12	175	62	194
Taiwan	532	2,028	2,258	12,745	533	1,555	135	1,225	62	184
Thailand	642	2,379	158	734	4	40	12	75	23	64
Trinidad and Tobago	7	35	563	1,657	19	82	146	541	4	13
United Kingdom	207	700	159	896	222	2,317	649	6,159	191	603
Venezuela	121	589	697	2,390	131	415	32	104	—	—
Other	1,649	6,546	515	1,997	392	2,303	957	6,442	736	1,767
Total	15,998	58,153	20,406	78,291	19,628	78,412	7,165	45,676	5,322	17,996

[1]Total exports of wire rod for 1990 were 2,814 tons, valued at $8,949,000.
[2]Less than ½ unit.
Source: Bureau of the Census.

TABLE 36

U.S. EXPORTS OF COPPER SCRAP, BY COUNTRY

Country	Unalloyed copper scrap				Copper-alloy scrap			
	1989		1990		1989[r]		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Belgium	3,621	$4,640	365	$336	5,866	$7,740	6,187	$7,058
Brazil	809	1,529	768	1,872	1,782	2,386	226	1,153
Canada	38,062	47,784	50,486	69,624	30,000	47,273	9,776	13,958
China	6,048	3,297	7,796	3,438	8,507	6,117	14,758	13,905
France	53	66	396	1,176	760	945	584	821
Germany, Federal Republic of	13,217	24,251	5,711	9,873	39,965	55,601	13,928	19,212
Hong Kong	1,126	893	909	605	1,434	1,352	3,349	2,848
India	1,092	1,658	394	637	25,554	32,526	32,869	45,562
Italy	254	355	980	1,710	4,931	5,896	12,596	18,181
Japan	20,331	45,476	17,803	40,533	18,650	40,877	28,729	65,522
Korea, Republic of	32,600	60,535	32,282	64,490	29,167	47,074	26,213	47,908
Mexico	7,837	18,616	8,881	19,916	14,807	27,489	12,058	21,346
Netherlands	3,428	6,605	719	1,019	3,036	4,564	3,902	5,226
Singapore	121	123	58	64	1,215	1,584	2,318	2,838
Spain	869	877	152	167	4,163	2,923	622	726
Sweden	—	—	—	—	2,104	3,746	3,432	8,116
Taiwan	23,136	23,726	10,575	9,849	14,272	18,022	8,745	11,515
United Kingdom	1,229	2,198	878	1,048	5,464	7,415	2,417	3,893
Other	[r]1,104	[r]1,568	473	1,060	845	991	2,057	2,935
Total	[r]154,937	[r]244,197	[1]139,624	[1]227,418	212,522	314,521	184,766	292,723

[r]Revised.
[1]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 37

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)
1989[r]	46,516	$51,311	2,810	$6,685	77,218	$242,106	300,110	$853,805	31,577	$87,919	458,231	$1,241,826
1990:												
Brazil	—	—	—	—	—	—	10,203	25,741	176	429	10,379	26,170
Canada	201	381	76	127	2	31	184,315	479,955	23,335	55,065	207,929	535,559
Chile	—	—	—	—	13,960	36,189	56,547	142,080	3,650	8,672	74,157	186,941
Costa Rica	—	—	—	—	—	—	—	—	528	1,049	528	1,049
Dominican Republic	—	—	—	—	—	—	—	—	408	1,053	408	1,053
Japan	—	—	—	—	3,496	17,151	(2)	23	72	139	3,568	17,313
Mexico	75,392	123,442	7,853	19,344	15,668	44,258	74	163	3,640	6,211	102,627	193,418
Netherlands	—	—	—	—	—	—	—	—	422	1,315	422	1,315
Norway	—	—	—	—	—	—	690	1,837	—	—	690	1,837
Panama	—	—	—	—	—	—	—	—	653	1,171	653	1,171
Peru	60	146	—	—	3,582	8,528	2,425	6,487	—	—	6,067	15,161
Portugal	15,840	7,069	(2)	310	—	—	990	1,418	—	—	16,830	8,797
South Africa, Republic of	—	—	—	—	—	—	754	2,025	—	—	754	2,025
Sweden	—	—	—	—	(2)	9	1,001	2,547	—	—	1,001	2,556
Venezuela	—	—	—	—	—	—	100	238	1,506	3,149	1,606	3,387
Zaire	—	—	—	—	7,405	18,517	3,148	8,347	—	—	10,553	26,864
Zambia	—	—	—	—	—	—	625	1,699	—	—	625	1,699
Other	—	—	33	21	163	555	802	2,214	1,514	2,722	2,512	5,512
Total[3]	91,493	131,038	7,961	19,802	44,278	125,238	261,672	674,774	35,904	80,976	441,308	1,031,828

[r]Revised.
[1]C.i.f value at U.S. port. Values for years prior to 1989 were customs values.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 38

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)
1989[r]	33,065	$149,226	50,571	$202,470	4,693	$20,108	8,506	$29,741	3,216	$8,329
1990:										
Australia	95	241	461	1,750	—	—	—	—	2,589	6,677
Brazil	26	95	1,636	5,049	—	—	—	—	—	—
Canada	3,586	12,899	8,071	29,808	153	499	3	67	—	—
Chile	653	2,110	5,466	15,952	—	—	16	48	—	—
Finland	105	786	3,773	15,357	493	2,683	—	—	—	—
France	1,475	6,407	34	284	22	271	22	122	—	—
Germany, Federal Republic of	453	3,376	4,792	20,166	171	1,752	14	159	11	63
Italy	1,099	4,678	159	516	22	123	35	472	—	—
Japan	7,401	32,324	8,855	51,566	209	1,805	190	1,321	45	294
Luxembourg	—	—	971	9,573	—	—	—	—	—	—
Mexico	5,749	19,483	301	1,127	10	122	1,501	6,671	673	1,296
Netherlands	1	4	218	947	78	395	—	—	—	—
Norway	—	—	—	—	—	—	—	—	191	497
Peru	—	—	1,005	2,840	594	1,565	6,262	16,025	—	—
Poland	—	—	54	139	217	650	76	255	—	—
Sweden	65	303	13,419	55,199	5	160	—	—	—	—
Taiwan	3	24	356	2,596	22	279	192	642	—	—
Turkey	—	—	—	—	136	599	173	752	—	—
United Kingdom	342	2,166	1,088	10,871	4	78	4	39	168	453
Venezuela	—	—	—	—	—	—	264	884	—	—
Other	70	279	873	3,609	205	1,033	16	163	121	39
Total	21,123	85,175	51,532	227,349	2,341	12,014	8,768	27,620	3,798	9,319

[r]Revised.

[1]Total imports of wire rod for 1990 were 73 tons, valued at $434,308.

[2]C.i.f. value at U.S. port. Values for years prior to 1989 were customs values.

Source: Bureau of the Census.

TABLE 39

U.S. IMPORTS FOR CONSUMPTION OF COPPER SCRAP, BY COUNTRY

Country	Unalloyed copper scrap		Copper alloy scrap		
	Quantity (metric tons)	Value[1] (thousands)	Gross weight (metric tons)	Copper content[2] (metric tons)	Value[1] (thousands)
1989[r]	31,577	$87,919	79,320	57,110	$151,265
1990:					
Canada	23,335	55,065	62,899	45,287	129,397
Chile	3,650	8,672	194	140	389
Colombia	—	—	2,417	1,740	3,707
Costa Rica	528	1,049	127	91	216
Dominican Republic	408	1,053	1,089	784	2,479
France	10	72	192	138	1,505
Germany, Federal Republic of	—	—	209	150	781
Guatemala	446	823	285	205	357
Malaysia	55	77	241	174	1,054
Mexico	3,640	6,211	22,263	16,029	37,100
Netherlands	422	1,315	14	10	19
Panama	653	1,171	665	479	1,206
Taiwan	—	—	208	150	763
Venezuela	1,506	3,149	4,459	3,210	8,585
Other	1,253	2,317	3,448	2,483	5,219
Total[3]	35,904	80,976	98,710	71,071	192,777

[e]Estimated. [r]Revised.

[1]C.i.f. value at U.S. port. Values prior to 1989 were customs values.

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

Source: Bureau of the Census.

TABLE 40

COPPER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
Albania[e]	17.6	17.8	15.0	16.0	16.0
Argentina	.3	.4	.5	.7	.5
Australia	248.4	232.7	238.3	296.0	[2]316.0
Bolivia	.3	([3])	.2	.3	.1
Botswana[4]	21.3	18.9	24.4	21.7	[2]20.6
Brazil	40.2	[r]40.3	44.8	44.4	45.8
Bulgaria[e]	[r]38.0	[r]44.0	[r]47.0	[r]48.0	48.0
Burma	[r]10.1	[r]10.6	4.7	5.1	5.1
Canada:					
By concentration or cementation[5]	697.9	790.2	753.5	699.8	774.4
Leaching (electrowon)	.7	3.9	5.0	4.7	5.2
Chile[6]	[r]1,398.8	1,412.9	1,472.0	1,628.3	[2]1,603.2
China[e]	185.0	250.0	375.0	375.0	375.0
Congo	.7	1.3	[e]1.0	[e]1.0	—
Cuba	3.3	3.5	3.0	[e]3.0	3.0
Cyprus[7]	.6	.1	.3	.7	.7
Czechoslovakia[e 8]	5.3	5.3	5.0	[2]4.9	4.6
Ecuador[e]	.1	.1	.1	.1	.1
Finland	26.0	20.4	20.2	14.5	12.6
France	.3	.3	.5	1.0	1.5
Germany, Federal Republic of:					
Eastern states[e]	11.0	11.0	10.0	[r]4.5	4.0
Western states[8]	.8	1.5	.7	.1	—
Honduras	[e]5.0	.6	.5	2.4	1.5
India	48.1	56.5	55.4	57.4	58.0
Indonesia[8]	95.8	102.1	121.5	144.0	[2]178.1
Iran[e]	50.0	40.0	51.0	[r]68.0	64.5
Japan	34.9	23.8	16.7	14.7	[2]13.0
Korea, North[e]	15.0	15.0	15.0	15.0	15.0
Korea, Republic of	.2	.2	([3])	([3])	.1
Malaysia	28.3	29.9	22.0	23.6	24.0
Mexico:					
By concentration or cementation	181.1	244.0	268.8	243.7	287.0
Leaching (electrowon)	8.0	9.7	11.4	10.3	11.0
Mongolia[e]	136.0	140.0	160.0	[r]135.0	145.0
Morocco	20.2	[r]16.5	15.4	16.0	16.0
Mozambique	.3	.2	.1	.1	([3])
Namibia	49.6	37.6	40.9	26.9	25.0
Nepal	([e 3])	([3])	([3])	([3])	([2 3])
Norway	21.9	22.0	15.9	16.5	19.7
Oman	18.2	18.1	17.1	[e]16.6	16.6
Papua New Guinea	178.2	217.7	218.6	204.0	[2]170.2
Peru:[6]					
By concentration or cementation	370.9	391.1	301.7	353.1	[2]317.7
Leaching (electrowon)	29.0	26.5	21.1	19.7	[2]16.3
Philippines	222.6	216.1	218.1	189.5	184.0
Poland	434.0	438.0	437.0	384.0	380.0
Portugal[6]	.2	1.1	5.2	103.7	163.0
Romania[e 8]	27.0	26.0	26.0	25.0	25.0
Saudi Arabia[e]	—	—	.3	.6	.6

See footnotes at end of table.

TABLE 40—Continued

COPPER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
South Africa, Republic of[8]	184.2	188.1	168.5	191.6	188.4
Spain	r51.1	r16.2	13.8	24.6	26.0
Sweden	87.4	85.0	74.4	69.5	74.7
Turkey[9]	21.2	r26.3	30.5	r e37.1	38.4
U.S.S.R.[e 8]	620.0	630.0	640.0	640.0	600.0
United Kingdom	.6	.8	.7	.5	.9
United States:[8]					
By concentration or cementation	1,018.8	1,082.5	1,191.7	1,185.6	[2]1,193.7
Leaching (electrowon)	125.4	161.1	228.0	[10]311.9	[2 10] 393.5
Yugoslavia[11]	138.5	130.5	103.5	103.0	103.0
Zaire:[8]					
By concentration or cementation	r208.6	208.1	185.7	183.1	120.0
Leaching (electrowon)	319.2	307.5	309.5	283.5	250.0
Zambia:[12]					
By concentration or cementation (smelted)	322.6	318.7	284.1	e295.0	295.0
Leaching (electrowon)	139.8	144.5	147.7	e150.0	150.0
Zimbabwe[8]	20.4	18.5	16.1	15.7	14.1
Total[13]	r7,939.0	r8,255.6	8,455.2	8,730.5	8,815.4

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Data represent copper content by analysis of concentrates produced except where otherwise noted. Table includes data available through June 28, 1991.

[2]Reported figure.

[3]Less than 50 tons.

[4]Copper content of pelletized nickel-copper matte produced in smelter.

[5]Anode copper recovered in Canada from domestic concentrates plus exports of payable copper in concentrates and matte.

[6]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 Chile and Portugal.

[7]Copper content of cement copper. Includes copper content of pyrite for 1989-90.

[8]Recoverable content.

[9]Includes copper content of pyrite.

[10]Includes electrowon from concentrates roast-leached.

[11]Copper content by analysis of ore mined.

[12]Data are for fiscal years beginning Apr. 1 of year stated. Zambian-mined copper reported recovered during smelting and electrowinning.

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

TABLE 41

COPPER: WORLD SMELTER PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country[2] and metal origin	1986	1987	1988	1989[p]	1990[e]
Albania, primary[e]	13.7	14.0	14.5	14.5	14.0
Australia:					
Primary	169.6	172.9	177.8	199.0	[3]192.0
Secondary	9.2	[e]8.5	10.5	10.0	10.0
Total	178.8	[e]181.4	188.3	209.0	202.0
Austria, secondary	25.5	29.1	34.5	39.1	41.0
Belgium:[e]					
Primary	.9	.1	.2	.2	.2
Secondary	105.0	92.1	93.2	93.4	94.0
Total	105.9	92.2	93.4	93.6	94.2
Brazil, primary	116.0	147.0	147.9	153.4	155.0
Bulgaria:[e]					
Primary	[r]50.0	[r]55.0	[r]55.0	[r]57.0	55.0
Secondary	3.0	[r]3.0	[r]3.0	[r]2.0	1.0
Total	[r]53.0	[r]58.0	[r]58.0	[r]59.0	56.0
Canada:					
Primary	472.7	[r]491.1	528.7	[e]509.0	[3]510.0
Secondary[e]	12.0	14.0	14.0	16.0	16.0
Total[e]	484.7	[r]505.1	542.7	525.0	526.0
Chile, primary[3]	1,123.9	1,106.9	1,189.4	1,226.6	1,300.0
China, primary[e]	225.0	300.0	400.0	450.0	450.0
Czechoslovakia:[e]					
Primary	5.3	5.3	5.0	5.0	4.6
Secondary	20.9	21.9	22.1	22.0	22.4
Total	26.2	27.2	27.1	27.0	27.0
Finland:					
Primary	84.5	77.4	79.0	79.5	90.2
Secondary[e]	12.0	12.0	12.0	12.0	12.0
Total[e]	96.5	89.4	91.0	91.5	102.2
France, secondary	6.1	7.0	8.5	[e]8.4	9.0
Germany, Federal Republic of:					
Eastern states, primary[e]	15.0	17.0	25.0	[r]25.0	20.0
Western states:					
Primary	161.9	165.0	171.5	180.0	180.0
Secondary	76.7	42.7	50.0	75.9	75.9
Total	238.6	207.7	221.5	255.9	255.9
Hungary, secondary[e]	.1	.1	.1	.1	.1
India, primary	39.1	32.9	44.3	42.5	45.0
Iran:[e 4]					
Primary	47.5	38.0	49.4	72.2	76.3
Secondary	2.5	2.0	2.6	3.8	4.0
Total	50.0	40.0	52.0	76.0	80.3
Japan:					
Primary	827.7	871.0	854.6	882.3	[3]893.2
Secondary	134.4	109.0	139.4	123.2	136.9
Total	962.1	980.0	994.0	1,005.5	1,030.1

See footnotes at end of table.

TABLE 41—Continued

COPPER: WORLD SMELTER PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country[2] and metal origin	1986	1987	1988	1989[p]	1990[e]
Korea, North:[e]					
Primary	15.0	15.0	15.0	15.0	15.0
Secondary	3.0	3.0	3.0	3.0	3.0
Total	18.0	18.0	18.0	18.0	18.0
Korea, Republic of, primary	123.2	143.8	123.5	123.6	124.0
Mexico, primary	r73.7	r126.3	150.3	174.3	210.0
Namibia, primary	45.7	35.5	40.0	38.0	37.0
Norway, primary	35.2	29.7	31.7	35.0	[3]36.5
Oman, primary	14.7	15.7	16.8	e15.3	15.3
Peru, primary	327.2	323.0	246.9	e241.4	195.0
Philippines, primary	124.3	124.7	e159.2	105.0	110.0
Poland:[e]					
Primary	375.0	385.0	385.0	r380.0	380.0
Secondary	25.0	25.0	25.0	r20.0	20.0
Total	400.0	410.0	410.0	r400.0	400.0
Portugal:[e]					
Primary	3.0	2.0	2.5	.7	1.0
Secondary	r2.0	2.0	2.0	2.0	2.0
Total	r5.0	4.0	4.5	2.7	3.0
Romania:[e]					
Primary	32.0	30.0	28.0	42.0	35.0
Secondary	7.0	8.0	8.0	8.0	5.0
Total	39.0	38.0	36.0	50.0	40.0
South Africa, Republic of, primary[e]	192.0	192.0	180.0	190.0	185.0
Spain:					
Primary	100.0	r115.7	111.0	120.0	120.0
Secondary	35.2	r33.0	34.6	32.3	34.0
Total	135.2	r148.7	145.6	152.3	154.0
Sweden:					
Primary	83.4	92.9	93.7	87.1	[3]84.2
Secondary	19.1	12.7	22.2	24.6	[3]23.8
Total	102.5	105.6	115.9	111.7	108.0
Taiwan, primary	50.4	47.0	43.3	43.2	16.1
Turkey:					
Primary	35.2	19.1	e12.8	e20.9	19.7
Secondary	.3	e.1	e.1	e.2	.2
Total	35.5	r e19.2	12.9	21.1	19.9
U.S.S.R.:[e]					
Primary	770.0	r790.0	800.0	800.0	750.0
Secondary	145.0	147.0	150.0	150.0	130.0
Total	915.0	r937.0	950.0	950.0	880.0
United States:					
Primary[6]	908.1	972.1	1,043.0	1,120.4	[3]1,158.5
Secondary	287.8	276.6	331.6	359.1	[3]304.8
Total	1,195.9	1,248.7	1,374.6	1,479.5	[3]1,463.3

See footnotes at end of table.

TABLE 41—Continued

COPPER: WORLD SMELTER PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country[2] and metal origin	1986	1987	1988	1989[p]	1990[e]
Yugoslavia:					
Primary	196.4	103.4	106.5	108.0	110.0
Secondary	31.5	62.4	65.5	65.0	65.0
Total	227.9	165.8	172.0	173.0	175.0
Zaire, primary:					
Electrowon	319.2	307.5	307.0	292.8	[3]201.3
Other	178.9	179.9	[e]160.0	150.0	[3]138.1
Total	498.1	487.4	[r e]467.0	[r e]442.8	[3]339.4
Zambia, primary:[7]					
Electrowon	88.7	74.8	95.9	[e]100.0	100.0
Other	349.5	347.9	308.9	[e]325.0	325.0
Total	438.2	422.7	404.8	[e]425.0	425.0
Zimbabwe, primary[8]	20.4	18.8	16.1	15.7	16.2
Grand total[9]	[r]8,777.3	[r]8,896.6	9,251.2	9,509.7	9,378.4
Of which:					
Primary:					
Electrowon	407.9	382.3	402.8	392.8	301.3
Other	[r]7,406.0	[r]7,603.1	7,816.4	8,046.7	8,067.0
Secondary	[r]963.4	[r]911.2	1,031.9	1,070.1	1,010.1

[e]Estimated. [p]Preliminary. [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 28, 1991.

[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 ending Mar. 20 or beginning Mar. 21 of year stated. Only estimated production data are available. Secondary production is estimated to be about 5% of total.

[6]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: 1986—79,031 (revised); 1987—70,136 (revised); 1988—49,299 (revised); 1989—34,485; and 1990—19,817. Production from scrap prior to 1984 excludes data from secondary smelters processing only scrap.

[7]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 38).

[8]Refined figure; unrefined data not available. Includes production from low-grade electrowon cathodes produced in nickel processing.

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

TABLE 42

COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1986	1987	1988	1988[p]	1990[e]
Albania, primary[e]	11.7	12.0	13.0	13.0	13.0
Argentina, secondary	11.0	13.0	12.5	11.0	[2]11.9
Australia:					
Primary	164.0	178.9	191.2	230.0	[2]247.0
Secondary	21.1	28.8	26.7	25.0	27.0
Total[3]	185.1	207.8	217.9	255.0	274.0
Austria:					
Primary	7.1	3.9	3.6	7.2	8.0
Secondary	32.6	32.9	38.4	39.1	41.7
Total[3]	39.6	36.8	41.9	46.3	49.7
Belgium:[e 4]					
Primary	r308.0	r315.0	r300.0	r294.0	308.0
Secondary	r106.0	r92.0	r93.0	r103.0	102.0
Total	r414.0	r407.0	r393.0	r397.0	410.0
Brazil:					
Primary	116.0	147.0	147.9	153.4	155.0
Secondary	50.0	52.2	38.1	42.3	45.0
Total[3]	166.0	199.2	185.9	195.6	200.0
Bulgaria:[e]					
Primary	r38.0	r44.0	r45.0	r45.8	45.0
Secondary	r10.0	r10.0	r10.0	r10.0	10.0
Total	r48.0	r54.0	r55.0	[2]55.8	55.0
Canada:					
Primary	469.4	461.2	490.7	478.2	466.0
Secondary[e]	24.0	30.0	38.0	37.0	38.0
Total[e]	493.4	491.2	528.7	515.2	[2]504.0
Chile, primary	942.3	970.3	1,012.7	1,071.0	[2]1,191.6
China, primary and secondary[e]	400.0	400.0	510.0	r540.0	560.0
Czechoslovakia:					
Primary[e]	r10.3	r10.3	r10.0	r10.0	10.0
Secondary[e]	r15.9	r16.9	r17.1	r16.9	16.8
Total	26.2	27.2	27.1	26.9	26.8
Egypt, secondary[e]	2.7	2.5	2.5	2.6	2.6
Finland:					
Primary	59.2	54.5	47.9	49.7	56.9
Secondary[e]	5.0	5.0	6.0	6.0	8.0
Total[e]	64.2	59.5	53.9	55.7	64.9
France:					
Primary[e]	17.9	11.3	7.2	16.3	18.0
Secondary[e]	24.0	28.0	36.0	33.0	34.0
Total	41.9	39.3	43.2	e49.3	52.0
Germany, Federal Republic of:					
Eastern states:					
Primary	13.0	13.0	18.0	r e18.0	15.0
Secondary	60.0	61.0	62.0	e62.0	60.0
Total	73.0	74.0	80.0	80.0	75.0
Western states:					
Primary	r238.0	r195.1	192.2	257.2	260.2
Secondary	r183.9	r204.7	234.2	218.0	216.0
Total[3]	r421.9	r399.8	426.4	475.2	[2]476.2

See footnotes at end of table.

TABLE 42—Continued

COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1986	1987	1988	1988[p]	1990[e]
Hungary, primary and secondary[e]	12.8	12.5	[2]19.2	19.0	18.0
India, primary:					
Electrolytic	[r]35.8	[r]30.0	38.9	41.0	35.5
Fire refined	1.1	.8	1.2	.8	1.0
Total	36.9	[r]30.8	40.1	41.8	36.5
Iran, primary[e 5]	[r]26.0	[r]25.0	32.0	40.0	47.8
Italy:					
Primary[e]	4.4	5.0	4.0	3.3	3.5
Secondary	61.0	60.0	71.4	[e]80.0	82.5
Total	65.4	65.0	75.4	83.3	86.0
Japan:					
Primary	827.7	871.0	854.6	882.3	[2]893.1
Secondary	115.4	109.4	100.5	107.3	[2]114.8
Total[3]	943.0	980.3	955.1	989.6	[2]1,008.0
Korea, North:[e]					
Primary	18.0	18.0	18.0	18.0	18.0
Secondary	4.0	4.0	4.0	4.0	4.0
Total	22.0	22.0	22.0	22.0	22.0
Korea, Republic of:					
Primary	157.8	154.6	168.3	178.7	183.0
Secondary	[e]7.2	3.3	.7	1.2	2.6
Total	[e]165.0	157.9	169.0	179.9	[2]185.6
Mexico:					
Primary:					
Electrowon	8.0	9.7	11.4	10.3	11.0
Other[e]	67.8	[r]104.9	[r]107.7	[r]113.8	115.0
Secondary[e]	13.7	[r]21.2	[r]21.8	[r]23.0	25.0
Total[3]	89.5	[r]135.8	140.8	147.0	151.0
Norway, primary[5]	30.5	29.4	31.7	35.0	[2]36.5
Oman, primary	14.5	15.5	16.5	15.1	15.0
Peru, primary	[r]226.7	[r]225.9	179.6	220.0	[2]181.5
Philippines, primary	134.5	132.1	132.2	132.2	130.0
Poland, primary[5]	388.0	390.0	401.0	390.0	[2]341.0
Portugal, primary[e 5]	5.3	5.3	[r]5.4	[r]6.0	6.0
Romania:[e]					
Primary	32.0	30.0	30.0	33.0	30.0
Secondary	11.0	12.0	12.0	12.0	10.0
Total	43.0	42.0	42.0	45.0	40.0
South Africa, Republic of, primary[5]	158.6	152.7	139.4	[e]145.7	145.0
Spain:					
Primary	130.6	100.4	108.8	[e]115.7	116.0
Secondary	24.5	51.0	50.0	[e]50.0	50.0
Total	155.1	151.4	158.8	[e]165.7	166.0
Sweden:					
Primary	72.8	79.9	68.3	70.0	71.0
Secondary	19.1	12.0	22.0	24.6	26.3
Total	91.9	91.9	90.3	94.6	97.3

See footnotes at end of table.

TABLE 42—Continued

COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1986	1987	1988	1988[p]	1990[e]
Taiwan:					
Primary	50.4	47.0	43.3	43.2	[2]16.1
Secondary[e]	8.0	10.0	10.0	10.0	10.0
Total[e]	58.4	57.0	53.3	53.2	26.1
Turkey, primary	75.1	75.6	90.0	101.0	101.0
U.S.S.R.:[e]					
Primary	830.0	840.0	850.0	850.0	800.0
Secondary	145.0	147.0	150.0	150.0	130.0
Total	975.0	987.0	1,000.0	1,000.0	930.0
United Kingdom:					
Primary	62.4	54.0	49.3	48.6	47.0
Secondary	63.2	68.3	74.7	70.4	75.0
Total	125.6	122.3	124.0	119.0	122.0
United States:					
Primary:					
Electrowon	125.4	161.3	228.0	311.9	[2]393.5
Other	948.6	965.6	1,178.0	1,164.9	[2]1,183.2
Secondary	405.9	414.7	446.0	480.0	[2]440.8
Total[3]	1,479.9	1,541.6	1,852.0	1,956.8	[2]2,017.4
Yugoslavia:					
Primary	99.2	98.8	105.6	[e]110.0	110.7
Secondary	.8	40.1	39.8	[e]41.0	40.7
Total	100.0	138.9	145.4	151.0	[2]151.4
Zaire, primary[6]	218.0	210.1	202.6	181.9	140.0
Zambia, primary:[7]					
Electrowon	51.1	69.6	51.8	45.4	50.0
Other	446.5	426.6	397.7	418.1	400.0
Total[3]	497.6	496.3	449.6	463.6	450.0
Zimbabwe:[8]					
Primary	20.4	18.8	16.1	15.7	16.0
Secondary[e]	4.9	4.2	11.4	8.3	8.4
Total[e]	25.3	23.0	27.5	24.0	24.4
Grand total[3]	[r]9,504.7	[r]9,710.8	10,198.6	10,612.1	10,642.1
Of which:					
Primary[3]	[r]7,661.9	[r]7,764.1	8,040.8	8,385.4	8,431.0
Secondary[3]	[r]1,429.9	[r]1,534.2	1,628.6	1,667.7	1,633.1
Primary and secondary, undifferentiated	412.8	412.5	529.2	559.0	578.0

[e]Estimated. [p]Preliminary. [r]Revised.

[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 28, 1991.

[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]Excludes leach cathode exported for reprocessing in Belgium.

[7]Data are for fiscal year beginning Apr. 1 of that stated. Electrowon covers only presumably high-grade cathodes reported as "finished product leach cathodes." Other, in addition to electrorefined cathodes, includes "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.

[8]May not include copper-nickel matte (copper content more than 6,000 tons per year) imported from Botswana for toll refining in 1986-89.

DIATOMITE

By Lawrence L. Davis

Mr. Davis, a physical scientist with 35 years of industry and U.S. Bureau of Mines experience, has been acting commodity specialist for diatomite since 1989. Domestic survey data were prepared by Blanche S. Hughes, mineral data assistant; the international data table was prepared by Audrey Wilkes, international data coordinator.

U.S. sales of processed diatomite increased 2% to 631,000 metric tons valued at $138 million. Seven companies processed diatomite at 11 plants in 5 States. California continued to be the leading State, followed by Nevada, Oregon, Washington, and Arizona. Major domestic producers were Manville Products Corp., with operations at Lompoc, CA; Grefco Inc., Dicalite Div., at Lompoc and Burney, CA, and Mina, NV; Eagle-Picher Minerals Inc. at Sparks and Lovelock, NV, and Vale, OR; and Witco Corp., Inorganic Specialties Div., at Quincy, WA. Other producers were Whitecliff Industries, Mammoth, AZ; CR Minerals Corp., Fernley, NV; and Oil-Dri Production Co., Christmas Valley, OR.

TABLE 1

DIATOMITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES

(Thousand metric tons and thousand dollars)

	1986	1987	1988	1989	1990
Domestic production (sales)	570	596	629	617	631
Total value of sales	$128,362	$134,239	$143,774	$136,754	$137,982

TABLE 2

DIATOMITE SOLD OR USED,[1] BY MAJOR USE

(Percent of U.S. production)

Use	1986	1987	1988	1989	1990
Fillers	17	16	17	15	14
Filtration	67	69	69	71	71
Insulation	3	2	2	3	4
Other[2]	13	13	12	11	11

[1] Includes exports.
[2] Includes absorbents, additives, and silicate admixtures.

DOMESTIC DATA COVERAGE

Apparent domestic consumption of processed diatomite increased slightly to 488,000 metric tons. The major use of diatomite was in filtration to separate suspended solids in liquids. In 1990, domestic and export sales of filter-grade diatomite were 451,000 tons, slightly more than in 1989. Sales of diatomite as a filler, the second largest use, were about 90,000 tons, virtually the same as for 1989.

The average unit value of sales for processed diatomite was $219 per ton, slightly less than in 1989. U.S. exports of processed diatomite were 144,000 tons, about 5% more than in 1989. The average unit value was $293 per ton compared with $302 per ton in 1989. Diatomite was exported to 72 countries. The following countries combined received 50% of the total exported: Canada, 20,600 tons; Japan, 16,300 tons; the Federal Republic of Germany, 13,200 tons; France, 11,100 tons; and the United Kingdom, 10,500 tons. U.S. exports represented 23% of domestic production. Imports of diatomite were 689 tons, of which 94% was supplied by Mexico.

OUTLOOK

World production was estimated to be 1,838 billion tons in 1990. The United States remained the world's leading producer, followed by Romania, the U.S.S.R, and France. These four countries accounted for 75% of world production.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Diatomite. Ch. in Minerals Yearbook, annual.

Diatomite. Ch. in Mineral Commodity Summaries, annual.

Diatomite. Ch. in Bulletin 675, Mineral Facts and Problems, 1985 ed.

Other Sources

Engineering and Mining Journal.

Industrial Minerals (London).

Mining Engineering.

Mining Journal.

TABLE 3

AVERAGE ANNUAL VALUE PER METRIC TON[1] OF DIATOMITE, BY MAJOR USE

Use	1988	1989	1990
Fillers	$243.49	$233.68	$237.06
Filtration	244.34	237.61	233.68
Insulation	121.12	107.61	112.67
Other[2]	140.16	132.89	130.23
Weighted average	228.56	221.58	218.65

[1] Based on unrounded data.
[2] Includes absorbents, additives, and silicate admixtures.

TABLE 4

U.S. EXPORTS OF DIATOMITE

(Thousand metric tons and thousand dollars)

Year	Quantity	Value[1]
1987	126	33,075
1988	147	39,374
1989	137	41,290
1990	144	42,329

[1] U.S. Customs.

TABLE 5

DIATOMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1986	1987	1988	1989	1990[e]
Algeria[e]	[2]4	4	4	4	4
Argentina	14	5	7	[e]7	7
Australia	9	10	11	[e]11	10
Brazil (marketable)	[r]12	16	[r]14	[r]16	15
Canada[e]	4	4	4	4	4
Chile	3	3	3	3	3
Costa Rica	—	—	5	[e]5	5
Denmark:[3]					
Diatomite[e]	6	6	6	6	1
Moler[e]	[2]73	66	66	[r]70	60
France[e]	260	250	250	250	250
Germany, Federal Republic of:					
Western states	49	47	[r]47	[r e]47	47
Iceland	23	[r]23	25	[r e]26	25
Italy[e]	27	[r]27	28	[r]25	25
Kenya	1	1	1	1	1
Korea, Republic of	55	65	72	[r]75	75
Mexico	36	35	[r]37	[r]45	55
Peru	9	21	15	[e]15	16
Portugal	2	[r]3	2	[r]3	3
Romania[e]	300	280	280	260	250
South Africa, Republic of	2	(4)	(4)	(4)	(4)
Spain[e]	[2]128	100	100	100	100
Thailand	(4)	(4)	(4)	[r]1	1
Turkey	[r e]6	[r]5	[r](5)	[r](5)	—
U.S.S.R.[e]	250	255	260	260	250
United Kingdom	[e](4)	(4)	(4)	(4)	(4)
United States[6]	570	596	629	617	[2]631
Total	[r]1,843	1,822	[r]1,866	[r]1,851	1,838

[e] Estimated. [r] Revised.
[1] Table includes data available through Apr. 10, 1991.
[2] Reported figure.
[3] Data represent sales.
[4] Less than 1/2 unit.
[5] Revised to zero.
[6] Sold or used by producers.

FELDSPAR, NEPHELINE SYENITE, AND APLITE

By Michael J. Potter

Mr. Potter, a physical scientist with 24 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for feldspar since 1976. Domestic survey data were prepared by Linder Roberts, mineral data assistant; and international data table was prepared by Virginia Woodson, international data coordinator.

Feldspars are major components in most igneous rocks and constitute a large part of at least the outer layers of the Earth and its moon. Feldspar, usually of the potash or soda type or in mixtures of the two, finds its principal end uses in the manufacture of glass and ceramics. Feldspar acts as a flux and lowers the melting temperature of a ceramic mixture. In glassmaking, feldspar provides a source of alumina, which enhances the workability of the product and increases its chemical stability.

Feldspar consumption in glass containers and pottery remained flat during the first half of 1990 and decreased in the second half of the year. Feldspar use in glass containers has been affected by mergers and consolidation of glass manufacturers, increased use of recycled glass (cullet), and competition from imported nepheline syenite. Fewer housing starts in 1990 resulted in reduced feldspar demand in whiteware such as plumbing fixtures and tile.

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 feldspar that are consistent with international usage, will henceforth report data in kilograms and metric tons unless otherwise noted.

DOMESTIC DATA COVERAGE

Domestic production data for feldspar are developed by the U.S. Bureau of Mines by means of a voluntary survey. Of the 13 active operations, 9 operations responded, representing 69% of the total canvassed. These nine respondents reported a production of 474,000 tons or about 75% of the total domestic production shown in table 1. The estimated production of nonrespondents, 158,000 tons, was derived from past years' production levels and trends.

BACKGROUND

Definitions, Grades, and Specifications

Feldspar is the general term used to designate a group of closely related minerals, especially abundant in igneous rocks and consisting essentially of aluminum silicates in combination with varying proportions of potassium, sodium, and calcium. The principal feldspar types are orthoclase or microcline, both $K_2O \cdot Al_2O_3 \cdot 6SiO_2$, and anorthite, $CaO \cdot Al_2O_3 \cdot 2SiO_2$. Specimens of feldspar closely approaching these ideal compositions are seldom encountered in nature, however, and nearly all potash feldspars contain significant proportions of soda feldspar. Albite, or soda feldspar, and anorthite are the theoretical end members of a continuous compositional series known as the plagioclase feldspars, none of which is ordinarily without at least a minor admixture of potash. Commercially speaking, "potash spar" is feldspar containing 10% or more K_2O; "soda spar" contains 7% or more Na_2O.

Perthite is the name given to material consisting of orthoclase or microcline and containing crystals that are intergrown with crystals of albite. Most of the feldspar of commerce can be classified most correctly as perthite.

Alaskite is a relatively coarse-grained, granite-like feldspar ore that occurs in the Spruce Pine district of North Carolina. The principal mineral ingredients of this ore are approximately 45% plagioclase, 25% quartz, 20% microcline, and 10% muscovite mica. Minor amounts of other minerals are also present.[1] Beneficiated feldspar from alaskite is a major portion of total U.S. feldspar output.

Feldspar for glass manufacturing, ordinarily ground to 20 to 40 mesh, usually contains 4% to 6% K_2O, 5% to 7% Na_2O, and approximately 19% Al_2O_3. Material for this purpose may be sold as a feldspar concentrate low in free quartz or in the form of a mixture containing feldspar and quartz with harmful impurities removed. In glass-grade feldspar, the iron content, expressed as Fe_2O_3, is approximately 0.08% for high-quality clear glass. Typically, 70 to 90 kilograms of ground feldspar is used to produce 1 ton of container glass.

Feldspar with a high potash-to-soda ratio is often preferred for pottery making, and spar for this purpose is usually ground to minus 200 mesh. Potash spar ground to 120 or 140 mesh is usually specified for use in porcelain enamel, and even traces of such impurities as garnet, hornblende, tourmaline, and biotite mica ordinarily are not tolerated. Both potash and soda feldspars, ground to minus 200 mesh, are used in glazing.

Pottery-grade feldspar for whiteware and similar ceramic products may range from 5% to 14% in K_2O content and usually is ground to 200 mesh or finer. Limitations on iron content may be even more stringent than for glass grade; Fe_2O_3 content may be 0.07%. Feldspar for use in filler applications, such as for foam rubber products, may be similar to pottery spar in fineness of grind and

chemical composition, although more free quartz is often accepted; sometimes material for this purpose may be held to particle-size specifications expressed in micrometers.

Geology-Resources

Feldspar, one of the most abundant minerals in the Earth's crust, is found in significant amounts in some sedimentary strata and in nearly all igneous formations. Workable deposits of feldspar are probably widely distributed throughout most of the world, and the total quantity of the mineral potentially available is very large.

It has been estimated that feldspar constitutes 60% of all crystalline igneous rocks. Granted sufficient demand and economic incentive, the mineral could be extracted from the world's granite, a source that is extremely large.

Data are not available on the quantity of feldspar in either domestic or foreign deposits. However, U.S. reserves are estimated to be quite large in the Spruce Pine district of North Carolina alone.

Feldspar concentrations of potential economic interest exist in many pegmatites, granites, and other granitic rocks and as accumulations of certain residual sands on ocean beaches or river banks.

Pegmatites are masses of coarsely crystalline rocks of igneous origin. Pegmatite bodies may range in size from small pods to extensive formations measuring hundreds or even thousands of feet. The principal feldspar ore bodies of pegmatitic type currently being exploited in the United States are in Connecticut, Georgia, North Carolina, and South Dakota. Potentially exploitable pegmatite bodies are known to exist in other areas.

The only feldspathic sand deposits now being mined in the United States are in California, Idaho, and Oklahoma. Other accumulations of feldspathic sands in the United States offer possibilities as future sources of feldspar supply.

Granites are widely distributed igneous rocks of plutonic origin. Granites are present as major components of whole mountain ranges, and the dimensions of granite bodies can often be stated in miles. The important constituent minerals in granites are much the same as those in pegmatites, although there are likely to be significant differences in the respective proportions. Because of economic and technologic considerations, commercial utilization of granite in the United States as a source of feldspar is not presently taking place.

Technology

Most feldspathic rocks can be quarried by open pit procedures. High-grade, selectively mined feldspar from pegmatites may be dry processed, passing consecutively through jaw crushers, rolls, and pebble mills before being subjected to high-intensity magnetic or electrostatic treatment to bring the iron content down to an acceptable level.

The customary procedure applied to most massive deposits, such as alaskite, begins with drilling, blasting, and drop-ball breaking at the quarry, followed by primary and secondary crushing and fine grinding in jaw crushers, cone crushers, and rod mills, respectively. The sequence typically continues with acid-circuit flotation in three stages, each stage preceded by desliming and conditioning. The first flotation step typically depends on an amine collector to float off and remove mica, and the second uses sulfonated oils to separate iron-bearing minerals, most notably garnet. The third step, flotation with another amine collector, leaves behind a residue that consists chiefly of quartz. Sometimes the third step is bypassed, leaving a feldspar-silica mixture, which can be used with little or no additional processing as furnace-feed ingredients in the manufacture of glass.

The flotation-cake feldspar or feldspar-silica mixture is dewatered in filters or drain bins and dried in rotary driers for use as glass-grade feldspar. Some material is further ground in pebble mills as pottery spar and for other uses.

Byproducts and Coproducts

Feldspar was obtained as a coproduct in 1990 from two companies mining and processing lithium ores and one company treating weathered pegmatite ore containing mica and kaolin. Coproduct recovery of mica and silica sand was reported by some feldspar processors.

Economic Factors

Feldspar is largely sold in bulk and moved by rail hopper cars. Transportation can comprise 50% or more of the total delivered cost. Some shipments are by truck. Most feldspar products are shipped less than 1,000 miles. An exception is premium-grade high-potash feldspar.

ANNUAL REVIEW

Feldspar

Legislation and Government Programs.—According to provisions of the Tax Reform Act of 1969, which continued in force throughout 1990, the depletion rate allowed on domestic and foreign feldspar production was 14%.

Production.—Feldspar or feldspar-silica sand was mined in seven States, led by North Carolina and followed, in descending order, by Connecticut, California (estimated), Georgia, Oklahoma, Idaho, and South Dakota. North Carolina accounted for 66% of the total. Eleven U.S. companies operating 13 beneficiating plants and 1 grinding plant produced feldspar or feldspar-silica mixtures for shipment to more than 31 States and foreign countries, including Canada and Mexico. Of the 11 companies, 3 produced potash feldspar, and the remainder produced soda and/or potash feldspar or feldspathic sand mixtures. North Carolina had six plants, California had two, and Connecticut, Georgia, Idaho, Oklahoma, and South Dakota each had one. The grinding plant was in South Carolina.

The U.S. Bureau of Mines uses a criterion of 8% minimum K_2O content in collecting data for potash feldspar.

In late 1990, the two feldspar mines and processing plant in Spruce Pine, NC, owned by Indusmin Inc., were sold to Hecla Mining Co. The new name of the operation was KT Feldspar Corp.

Consumption and Uses.—Of the total feldspar sold or used in the United States, 56% went into glassmaking, including container glass and glass fiber, and 44% was used in pottery and other applications. Fewer housing starts in 1990 resulted in decreased feldspar usage in plumbing fixtures and tile compared with that of the previous year.

Processed feldspar is added to glassmaking formulas for its alumina and alkali contents. Alumina enhances the workability of molten glass and improves the finished product by giving it better chemical stability. The increased workability facilitates the operation of automatic machines for shaping jars and bottles. Greater chemical stability broadens the usefulness of the containers. Feldspar is used in ceramic mixtures, such as those for the making of vitreous

TABLE 1

SALIENT FELDSPAR AND NEPHELINE SYENITE STATISTICS

		1986	1987	1988	1989	1990
United States:						
Feldspar:						
Produced[1]	metric tons	665,000	655,000	650,000	655,000	630,000
Value	thousands	$26,100	$26,100	$26,400	$28,000	$27,400
Exports	metric tons	10,886	8,740	12,439	9,329	24,795
Value	thousands	$1,024	$691	$769	$829	$2,167
Imports for consumption	metric tons	1,135	4,384	6,193	12,003	11,318
Value	thousands	$542	$477	$659	$873	$723
Nepheline syenite:						
Imports for consumption	metric tons	271,072	280,034	281,086	303,000	276,000
Value	thousands	$11,280	$11,401	$11,233	$12,273	$12,200
Consumption, apparent[2] (feldspar plus nepheline syenite)	thousand metric tons	928	929	924	961	895
World: Production (feldspar)	do.	r4,115	r4,410	r4,899	r5,176	e5,023

eEstimated. pPreliminary. rRevised.
[1]Includes hand-cobbed feldspar, flotation-concentrate feldspar, and feldspar in feldspar-silica mixtures; includes potash feldspar (8% K_2O or higher).
[2]Production plus imports minus exports.

TABLE 2

FELDSPAR[1] PRODUCED IN THE UNITED STATES

(Thousand metric tons and thousand dollars)

Year	Hand-cobbed		Flotation concentrate		Feldspar-silica mixtures [2]		Total [3]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1986	12	W	474	19,855	181	W	665	26,100
1987	10	W	446	17,800	199	W	655	26,100
1988	13	W	452	18,657	185	W	650	26,400
1989	11	W	425	16,915	219	W	655	28,000
1990	W	W	437	15,815	W	W	630	27,400

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Includes potash feldspar (8% K_2O or higher).
[2]Feldspar content.
[3]Data may not add to totals shown because of independent rounding.

china and porcelain enamels, principally as a flux. It fuses at a temperature below the melting point of most of the other ingredients. It also performs as a vitreous binder to cement particles of various crystalline substances present in ceramic mixtures. Feldspar serves advantageously in abrasives and scouring soaps. It forms a mild abrasive but is soft enough to avoid injury to the article being cleaned. Feldspar is also used as a filler in paint, foam rubber, and plastics.

The quantity of potash feldspar sold or used in 1990 was 60,600 tons with a value of $5.8 million.

Whiteware is a significant end use of feldspar. In 1989, sanitaryware sales were 44% of total whiteware sales; floor and wall tile were 33%.[2] The mix for sanitaryware bodies is about 50% clay (ball clay and kaolin), 25% silica, and 25% feldspar or nepheline syenite. A typical glaze may contain about 30% feldspar and smaller proportions of several other ingredients.[3]

***World Review.*—Capacity.**—The data in table 10 are rated capacity for mines and refineries as of December 31, 1990. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Because actual capacity data were not available, recent peak production during the past 5 years for the United States

TABLE 3

PRODUCERS OF FELDSPAR AND FELDSPATHIC MATERIALS IN 1990

Company	Plant location	Product
APAC Arkansas Inc.	Muskogee, OK	Feldspar-silica mixture.
CISCO	Corona, CA	Do.
Cyprus Foote Mineral Co.	Kings Mountain, NC	Do.
The Feldspar Corp.	Middletown, CT	Soda-potash feldspar.
Do.	Monticello, GA	Potash feldspar.
Do.	Spruce Pine, NC	Soda-potash feldspar.
Do.	Montpelier, VA	Aplite.
Indusmin Inc.	Spruce Pine, NC	Soda-potash feldspar.
KMG Minerals, Inc.	Kings Mountain, NC	Potash feldspar.
Lithium Corp. of America	Bessemer City, NC	Feldspar-silica mixture.
Pacer Corp.	Custer, SD	Potash feldspar.
Spartan Minerals Corp.	Pacolet, SC	Feldspar-silica mixture.
Unimin Corp.	Emmett, ID	Do.
Do.	Spruce Pine, NC	Soda-potash feldspar.
U.S. Silica Co.	Oceanside, CA	Feldspar-silica mixture.

TABLE 4

FELDSPAR[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons and thousand dollars)

Use	1989		1990	
	Quantity	Value	Quantity	Value
Hand-cobbed:				
Pottery	5	W	W	W
Other	5	W	W	W
Total[2]	9	W	W	W
Flotation concentrate:				
Glass	166	7,009	162	7,270
Pottery	261	15,717	234	14,178
Total[2]	426	22,726	395	21,448
Feldspar-silica mixtures:[3]				
Glass	183	10,716	175	10,617
Pottery	23	W	W	W
Total[2]	206	W	W	W
Total:[2]				
Glass[4]	348	17,725	337	17,887
Pottery	289	W	W	W
Other[5]	5	W	W	W
Total	640	35,900	600	34,100

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Includes potash feldspar (8% K_2O or higher).
[2]Data may not add to totals shown because of independent rounding.
[3]Feldspar content.
[4]Includes container glass and glass fiber.
[5]Includes enamel, filler, etc., and unknown.

and foreign countries was considered to be equal to rated capacity.

Australia.—The domestic market of 10,000 tons per year was largely in the ceramic and welding rod manufacturing industries. The market was mainly on the eastern coast in Victoria and New South Wales.

The Mukinbudin pegmatite deposit owned by Commercial Minerals Ltd. was one of two major Australian feldspar operations. The mainly quartz-microcline (potash) feldspar deposit is near the town of Mukinbudin, which is 330 kilometers east of Perth, the capital of Western Australia. The quartz was crushed and screened as a decorative stone for the local building industry. The feldspar was crushed and shipped to clients or mills for further processing. Chemical analysis of the material was 11.5% K_2O, 2.6% Na_2O, and 0.1% Fe_2O_3. Both lump ore and milled feldspar were exported from the port city of Perth to Southeast Asia. Iron contents of 0.08% were achieved by processing selected high-grade ore; in 1990, a magnetic separation plant was being installed to produce feldspar with 0.04% Fe_2O_3 for use in glazes.

The country's second major deposit was the Pippingarra pegmatites, also owned by Commercial Minerals, 30 kilometers from Port Hedland on the northwest coast. The massive microcline feldspar deposit also contained muscovite mica, which was processed and sold for oil well drilling and other uses. An extensive drilling program was planned for early 1990 to delineate ore reserves. This deposit is well situated to serve the Southeast Asia market area.

Potash feldspar is not widely available in Asia, and a significant market for high-quality material exists in Japan, Korea, and Taiwan. The ceramic tile industry of Taiwan was reported to be the third largest in the world after Italy and Spain. Another outlet for potash feldspar in Southeast Asia was in welding rod manufacture for the heavy construction industry. The potash spar is able to improve the surface finish of the weld. Other end uses were in the television tube and neon tube glass industries.[4]

Nepheline Syenite

Nepheline syenite was produced by Indusmin Ltd., a division of Falconbridge Ltd., from two operations at Blue

TABLE 5

DESTINATION OF SHIPMENTS OF FELDSPAR[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Metric tons)

State	1986	1987	[2]1988	[3]1989	[4]1990
Alabama	18,200	W	W	W	W
California[e]	45,400	45,400	45,400	68,000	61,900
Florida	18,100	12,900	W	W	W
Georgia	82,200	78,500	84,500	74,400	66,800
Illinois	25,300	26,000	26,900	24,900	24,000
Indiana	W	W	27,300	25,400	23,800
Kentucky	15,300	W	15,400	14,700	12,700
Louisiana	12,800	13,500	12,600	10,900	9,100
Maryland	6,400	5,800	6,500	7,600	7,200
Mississippi	W	W	12,000	10,400	W
Missouri	5,500	4,700	4,400	W	4,100
North Carolina	18,800	36,700	21,500	18,100	15,700
Ohio	61,900	58,400	58,700	52,300	46,600
Pennsylvania	30,500	33,000	26,500	34,800	29,800
Texas	40,800	39,900	W	W	W
West Virginia	22,100	18,000	17,000	16,800	15,500
Other[5]	262,500	277,600	301,600	285,600	281,900
Total[6]	666,000	650,000	660,000	644,000	599,000

[e]Estimated. W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Includes potash feldspar (8% K_2O or higher).
[2]An estimated 68% of these data were obtained by survey forms; the remaining 32% were estimated.
[3]Because of a lack of actual data, an estimated 65% of these data were obtained from projections of previous years' data.
[4]Because of a lack of actual data, an estimated 67% of these data were obtained from projections of previous years' data.
[5]Includes Arkansas, Colorado, Connecticut, Kansas, Michigan, Minnesota, Oklahoma, Rhode Island, Tennessee, Virginia, States indicated by symbol W, and unspecified States. Also includes exports to Canada, Mexico, and other foreign countries.
[6]Data may not add to totals shown because of independent rounding.

TABLE 6

DESTINATION OF SHIPMENTS OF POTASH FELDSPAR[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Metric tons)

State	1986	1987	1988	1989	1990
Illinois, Indiana, Wisconsin	5,000	W	W	W	W
Maryland, New York, West Virginia	23,200	W	W	W	26,700
Ohio	W	W	W	W	W
Pennsylvania	W	W	W	W	W
Texas	300	W	W	W	W
West Virginia	3,200	W	W	W	W
Other[2]	35,500	W	W	W	W
Total	67,200	W	85,700	73,000	60,600

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]K_2O content of 8% or higher.
[2]Includes Alabama, Arkansas, California, Colorado, Connecticut, Florida, Georgia, Kansas, Kentucky, Louisiana, Michigan, Massachusetts, Minnesota, Missouri, New Jersey, North Carolina, South Carolina, Tennessee, Virginia, States indicated by symbol W, and other unspecified States. May also include countries.

Mountain and Nephton, Ontario, Canada. Output in 1989, the latest year for which information was available, was estimated to be more than 660,000 tons. End uses included glass, whiteware, and as a filler and extender in paint, plastic, adhesives, and rubber.[5] In late 1990, Unimin Corp. of New Canaan, CT, acquired the Indusmin nepheline syenite operations. The new name of the company was to be Unimin Canada Ltd.[6]

In Norway, nepheline syenite was produced at the Elkem Nefelin A/S, underground mining operation on the arctic island of Stjernøy. Output was 287,000 tons in 1988, the latest year for which data were available. Sales were largely to markets in Western Europe.[7]

Prices for Canadian nepheline syenite listed in Industrial Minerals (London), December 1990, were approximately $24 to $31 per ton for glass grade, 30 mesh, bulk, carlots-trucklots, depending on iron content; $74 per ton for ceramic grade, 200 mesh, bagged, 10-ton lots; and $87 to $100 per ton for filler-extender grade, bagged.

Aplite

Aplite is a feldspar mineral that has more than one geological definition. However, aplite from the one active U.S. operation contains lime-soda feldspar. Aplite, usually unsuitable for use in ceramics, has been used in the manufacture of glass when it is sufficiently low in iron.

Aplite of glassmaking quality was produced in the United States by The Feldspar Corp. near Montpelier, Hanover County, VA.

Domestic output was approximately the same as in 1989. The data are company proprietary and cannot be released for publication. Aplite traditionally has a somewhat lower price than feldspar. Industrial Minerals (London), December 1990, gave a value of $25.75 per ton for glass grade, bulk, 100% plus 200 mesh, f.o.b. Montpelier, VA.

With an annual production of 500,000 tons to 560,000 tons in recent years, Japan has been the world's largest producer of aplite. Italy is the world's largest producer of feldspathic materials, including feldspar and aplite; published figures did not give the relative breakdown of the two minerals.

TABLE 7

PRICES FOR FELDSPAR

(Dollar per metric ton, f.o.b. plant, bulk

Producing States	1989	1990
Ceramic grade:		
Middleton, CT, minus 200 mesh	74.41	74.41
Monticello, GA, 200 mesh, high potash	90.94	90.94
Spruce Pine, NC, 170 to 250 mesh	55.12	55.12
Glass grade:		
Middleton, CT, 96% plus 200 mesh	50.16	50.16
Monticello, GA, 92% plus 200 mesh, high potash	71.38	71.38
Spruce Pine, NC, 97.8% plus 200 mesh	35.83	36.93

Source: Industrial Minerals (London), No. 267, Dec. 1989, p. 74, and No. 279, Dec. 1990, p. 78.

TABLE 8

U.S. EXPORTS OF FELDSPAR, BY COUNTRY

Country	1989		1990	
	Metric tons	Value	Metric tons	Value
Canada	2,011	$146,955	2,558	$273,133
Dominican Republic	293	22,433	326	71,869
Germany, Federal Republic of	—	—	1,878	142,491
Italy	888	74,680	1,796	242,398
Mexico	2,043	172,329	1,536	236,668
Netherlands	—	—	14,075	829,743
Taiwan	1,090	154,261	238	72,316
United Kingdom	—	—	710	75,255
Venezuela	748	59,898	238	9,262
Other	2,256	198,440	769	213,647
Total	9,329	828,996	24,795	2,166,782

Source: Bureau of the Census.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF FELDSPAR, BY COUNTRY

Country	1989		1990	
	Metric tons	Value[1]	Metric tons	Value[1]
Germany, Federal Republic of	29	$8,241	69	$22,142
Mexico	11,974	864,407	11,249	700,638
Total	12,003	872,648	11,318	722,780

[1]Customs value.

Source: Bureau of the Census.

TABLE 10

WORLD FELDSPAR ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990

(Thousand metric tons)

	Rated capacity[1]
North America:	
Mexico	130
United States	665
Total	795
South America:	
Brazil	121
Venezuela	100
Other	142
Total	363
Europe:	
Finland	56
France	360
Germany, Federal Republic of	315
Italy	1,368
Norway	90
Poland	57
Portugal	66
Romania[e]	86
Spain	196
Sweden	40
U.S.S.R.[e]	330
Yugoslavia	50
Other	16
Total	3,030
Africa:	
South Africa, Republic of	82
Other	36
Total	118
Asia and Oceania:	
India	58
Japan	58
Korea, Republic of	242
Thailand	520
Turkey	100
Other	67
Total	1,045
World total[2]	5,350

[e]Estimated.

[1]Includes capacities of operating plants as well as plants on stand-by basis.

[2]Data do not add to total shown because of independent rounding.

TABLE 11

FELDSPAR: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989	1990[e]
Argentina	24,087	29,282	39,469	23,688	24,000
Australia	10,006	11,499	15,877	r e15,000	16,000
Austria	2,850	4,692	8,222	7,251	7,300
Brazil[3]	120,572	118,608	109,534	e120,000	120,000
Burma	2,861	1,916	2,626	e2,500	2,500
Chile	2,275	705	4,569	r8,173	8,000
Colombia	35,722	33,760	37,136	r40,850	40,000
Ecuador	2,298	1,558	r5,000	r22,576	8,000
Egypt	19,287	15,963	6,131	r27,731	27,000
Finland	47,049	51,632	r56,200	54,581	55,000
France	216,000	274,000	r322,000	r360,000	300,000
Germany, Federal Republic of:	247,498	310,447	308,776	r e310,000	315,000
Guatemala	5,446	7,669	e7,200	e7,000	7,000
Hong Kong	35,208	22,853	r11,050	r5,152	4,000
India	r48,264	49,663	r57,656	r56,690	58,000
Iran[e]	32,000	32,000	32,000	32,000	32,000
Italy	r1,237,058	1,188,700	1,367,776	r1,350,733	1,300,000
Japan[4]	32,063	33,754	29,465	43,137	58,300
Kenya	—	—	—	r1,112	1,000
Korea, Republic of	130,895	180,269	241,511	r232,607	230,000
Mexico	85,019	106,490	r83,170	r121,988	130,000
Morocco[e]	1,000	1,000	1,000	1,000	1,000
Mozambique[e]	100	—	—	—	—
Nigeria	2,418	485	190	945	900
Norway[e 5]	6 87,257	r90,000	r90,000	r90,000	90,000
Pakistan	11,575	6,675	9,026	r7,703	8,000
Peru	19,467	64,749	e20,000	e20,000	20,000
Philippines	6,661	11,996	9,199	e6,000	8,000
Poland	57,200	55,000	e50,000	e50,000	50,000
Portugal	33,740	40,729	r51,903	r65,854	60,000
Romania[e]	86,000	82,000	82,000	75,000	70,000
South Africa, Republic of	52,762	66,513	81,889	r56,220	6 56,124
Spain[7]	135,526	161,631	r195,668	r e155,000	150,000
Sri Lanka	7,270	7,442	6,345	6,656	6,800
Sweden	35,160	34,226	r e36,000	e40,000	40,000
Taiwan	26,290	28,116	19,101	r9,806	7,380
Thailand	115,163	168,881	293,678	r515,206	520,000
Turkey	12,180	30,336	r82,225	r90,751	100,000
U.S.S.R.[e]	330,000	330,000	330,000	330,000	300,000
United Kingdom (china stone)	7,304	5,692	6,267	6,470	6,500
United States	r665,000	r655,000	650,000	655,000	6 630,000
Uruguay	r1,632	r3,016	r2,787	r2,680	3,000
Venezuela	34,900	43,546	96,500	r97,000	100,000
Yugoslavia	47,909	44,912	35,615	r49,000	50,000

See footnotes at end of table.

TABLE 11—Continued

FELDSPAR: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Zambia	214	45	120	20	50
Zimbabwe	2,026	2,962	3,730	2,697	2,500
Total	[r]4,115,212	[r]4,410,412	4,898,611	5,175,777	5,023,354

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through Apr. 19, 1991.

[2]In addition to the countries listed, Czechoslovakia, Madagascar, and Namibia produce feldspar, but output is not officially reported, and available general information is inadequate for the formulation of reliable estimates of output levels.

[3]Series excludes production of leucite and sodalite; data consist only of that material reported by Brazil under the heading of "Feldspar." Data represent the sum of (1) run-of-mine production for direct sale, and (2) salable beneficiated product; total run-of-mine feldspar production was as follows, in metric tons: 1986—105,042; 1987—98,828; 1988—140,041; 1989—140,000 (revised, estimated); and 1990—140,000 (estimated).

[4]In addition, the following quantities of aplite concentrate were produced in metric tons: 1986—457,375; 1987—466,429; 1988—526,285; 1989—562,823; and 1990—517,000 (estimated).

[5]Excludes nepheline syenite.

[6]Reported figure.

[7]Includes pegmatite.

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF NEPHELINE SYENITE

Year	Crude		Ground	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1988	2,615	$111	278,471	$11,122
1989[1]	—	—	303,000	12,273
1990[1]	—	—	276,000	12,200

[1]Crude and ground combined for 1989 and 1990.

Source: Bureau of the Census.

OUTLOOK

U.S. feldspathic consumption has remained fairly constant for the past several years. Competition from imported nepheline syenite, as well as increased use of recycled glass (cullet) and lightweighting of glass containers, have impacted on the demand for feldspathic materials in glass manufacturing. Glass containers should at least maintain their market share in the near future in a field that includes metal cans and plastic containers.

Fewer housing starts in recent years have resulted in static feldspar demand in whiteware such as plumbing fixtures and tile and in glass fiber insulation for housing. Feldspar outlook in 1991 will be affected, in part, by the level of construction activity and remodeling.

[1]Rogers, C. P., Jr., and J. P. Neal. Feldspars. Ch. in Industrial Minerals and Rocks, rev. by K. H. Teague. AIME, New York, 5th ed., 1983, p. 711.

[2]Ceramic Industry. Giants in Whiteware. V. 135, No. 2, Aug. 1990, p. 36.

[3]Burger, J. The U.S. Sanitaryware Industry. Ind. Miner. (London), No. 277, Oct. 1990, p. 54.

[4]Toye, C. Quality Feldspars From Western Australia Going International. Paper from 9th "Industrial Minerals" International Congress, ed. by J. B. Griffiths (Proc. Conf. Sydney, Australia, 1990, Mar. 25-28, 1990). Metal Bulletin PLC, 1990, pp. 47-52.

[5]Taylor, G. H. Nepheline Syenite. Am. Ceram. Soc. Bull., v. 69, No. 5, May 1990, p. 873.

[6]Ceramic Industry. Unimin Acquires Silica Plants. V. 135, No. 5, Nov. 1990, p. 16.

[7]Neilsen, K. Norway, Small in Size—Large in Nonmetallic Minerals. Paper from Second World Congress on Non-metallic Minerals, Beijing, China, Oct. 17-21, 1989, pp. 453, 455-456.

OTHER SOURCES OF INFORMATION

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Other Sources

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FERROALLOYS

By Clark R. Neuharth

Mr. Neuharth, a physical scientist with 8 years U.S. Bureau of Mines experience, has been a commodity specialist since 1986, covering silicon initially and ferroalloys currently. Domestic survey data were prepared by Jo-Ann Sterling, Robin Johnson, and Elizabeth Voyatzis, mineral data assistants, and Mr. Neuharth; the international data tables were prepared by William Zajac, Chief, Section, International Data.

Ferroalloys and related materials are essential to the production of many metals and alloys, including aluminum, iron, and steel. The domestic ferroalloys industry has been in a state of decline since its peak production years in the early-1970's because of decreased demand and competition from low-priced imports. Since that time, many U.S. producers have gone out of business, leaving the domestic ferroalloy industry a lean but surviving element of the country's industrial base.

Overall domestic usage of ferroalloys and related materials was little changed compared with that of 1989 because the steel industry, the major consumer of ferroalloys, produced at a rate just slightly higher than that of the previous year. Domestic shipments of ferroalloy were slightly lower than those of 1989, while overall ferroalloy imports were somewhat higher.

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 ferroalloys that are consistent with international usage, will henceforth report data in kilograms and metric tons unless otherwise noted.

DOMESTIC DATA COVERAGE

Domestic production data for ferroalloys are developed by the U.S. Bureau of Mines by means of monthly and annual voluntary domestic surveys. Typical of these surveys are the three separate monthly surveys for chromium alloys and metal, manganese alloys and metal, and silicon alloys and metal, and the annual survey for ferroalloys. Of the 38 operations to which a survey was sent, 36 responded, representing an estimated 95% of the total production and/or shipments shown in table 4.

BACKGROUND

Ferroalloys impart distinctive qualities to steel and cast iron and serve important functions during iron and steel production cycles. The principal ferroalloys are those of chromium, manganese, and silicon. Manganese, used to neutralize the harmful effect of sulfur and as an alloying element, is essential to the production of virtually all steels and is also important to the production of cast iron. Chromium adds corrosion resistance to stainless steels. Silicon is used primarily for the deoxidation of steel and as an alloying element in cast iron. Boron, cobalt, columbium, copper, molybdenum, nickel, phosphorus, titanium, tungsten, vanadium, zirconium, and the rare earths are among the other elements contributing to the character of the various alloy steels and cast irons. Most of these elements are normally added to the molten metal as a ferroalloy. This report considers the ferroalloy industry as a whole and its role as a supplier of ferroalloys to the iron and steel industries.

Definitions, Grades, and Specifications

Ferroalloy is defined by the American Society for Metals and the U.S. Bureau of Mines as "an alloy of iron that contains a sufficient amount of one or more other chemical elements to be useful as an agent for introducing these elements into molten metal, usually steel." However, in practice, the term is used loosely to include addition agents and master alloys, sometimes containing very little or no iron, employed to introduce reactive elements to numerous alloy systems, and various other materials; for example, calcium-silicon, nickel-boron, and chromium, manganese, and silicon metal.

The bulk ferroalloys are produced in a variety of grades distinguished by (1) carbon level, (2) silicon level, (3) or aluminum level. Thus, ferromanganese is classified into three carbon ranges (high-, medium-, and low-carbon). Generally, ferrosilicon is classified by broad silicon ranges, but it is further classified by aluminum and calcium contents. Altogether, there are scores of different specifications applying to the ferroalloys used in the manufacture of steel and cast iron. Perhaps the most varied assortment of alloys is associated with silicon. These include silicon metal, with varying amounts of iron; five ranges of silicon in ferrosilicon; and magnesium ferrosilicon alloys and other inoculant-type alloys involving controlled additions of barium, calcium, zirconium, and rare-earth elements, some with magnesium, in alloys where silicon is the dominant element. The majority of

the specialized alloys involving another element or two elements in addition to silicon are utilized by the iron casting industry. In the United States, the most complete set of accepted ferroalloy specifications are those of the American Society for Testing and Materials.

Industry Structure

The ferroalloy industry is closely associated with the iron and steel industries, its largest customers. Domestically, 29 companies produced ferroalloy materials and/or silicon metal in 1990, although 4 of those produced only ferrophosphorus as a byproduct of elemental phosphorus production. The U.S. industry can be divided into three sectors according to the alloys produced, with only a few companies operating in more than one sector.

The first sector produces the tonnage or bulk ferroalloys of manganese, chromium, and silicon, and their respective metals. Except for manganese metal, chromium metal, and some specialty alloys, these products are made in submerged-arc electric furnaces, and to a limited extent, the companies can switch their production among these products according to market conditions. Since 1977, there has been no blast furnace production of ferromanganese in the United States, and currently no ferroalloys are produced domestically within a steel plant. One primary aluminum company operates a captive plant to produce silicon metal for alloying aluminum. Authors and publishers usually include silicon metal among the ferroalloys because its production process (i.e., electric furnace) is very similar to that of most ferroalloys.

The second sector of the industry comprises companies producing the remaining ferroalloys other than ferrophosphorus. These companies generally produce low-tonnage materials with relatively high unit values, sometimes referred to as "specialty ferroalloys," such as ferroboron, nickel-boron, ferrocolumbium, ferromolybdenum, ferronickel, ferrotitanium, and ferrovanadium.

The third sector of the industry produces ferrophosphorus as a byproduct of elemental phosphorus production.

Most countries with well-established steel industries also produce ferroalloys, but a definite shift in the location of ferroalloy production has occurred in more recent years toward countries with relatively low energy costs. These include Brazil, Norway, and Venezuela, as well as countries possessing substantial quantities of high-grade ferroalloy ores such as India and the Republic of South Africa. Development of a large export potential in countries such as these has decreased economic viability of small-scale ferroalloy production in some areas, particularly where stringent pollution abatement requirements have been established and power costs are high. Japan's ferroalloy industry, not unlike that in the United States, has been in a state of decline in more recent years because of high power costs.

Resources

The reader is referred to the respective commodity annual reports for complete discussions of ore reserves and potential sources of ferroalloy raw materials. The U.S. ferroalloy industry is dependent on imports for most of its primary supply of chromium, cobalt, columbium, manganese, and nickel. The United States has large reserves of silica, molybdenum ores, and raw materials for ferroboron, ferrotitanium, and the rare-earth additives. It also produces a substantial percentage of its vanadium requirements from domestic raw materials.

Technology

High-carbon ferromanganese, spiegeleisen, and silvery pig iron (containing 10% to 20% silicon) are produced in several countries in the type of blast furnace used to produce pig iron. However, since 1977, U.S. production of alloys containing chromium, manganese, and silicon has been in electric arc furnaces exclusively. Most of these alloys are smelted in submerged arc furnaces (i.e., the electric arc is kept submerged within the charge of raw materials). Ores are smelted with carbon from coke, coal, or wood chips as reductant. The high temperature and added energy needed for the reaction are provided by the electric arc. Unlike the operation of electric furnaces in steelmaking, that of the submerged-arc furnace is continuous, with raw materials being fed from above and molten alloy and slag (if produced) being tapped through holes in the side of the furnace. For some grades, such as low-carbon ferromanganese and low-carbon ferrochromium, two or three processing steps are involved, and open-arc as well as submerged-arc furnaces are used.

Modern ferroalloy electric furnaces evolved from calcium carbide furnaces, which became important in the 1920's. Initially, ferroalloy plants had several furnaces of small size that provided flexibility in producing a limited volume of a variety of alloys. The trend has been toward fewer but larger furnaces, with transformer ratings now up to 100 megavolt-ampere (MVA), and with some new plants consisting of just one or two furnaces. The larger furnaces are designed more for specific alloy production, and the use of the furnace for other alloys may

TABLE 1

GOVERNMENT INVENTORY OF FERROALLOYS, DECEMBER 31, 1990

(Metric tons of alloy, unless otherwise stated)

Alloy	Stockpile grade	Nonstockpile grade	Total
Ferrochromium:			
High-carbon	627,985	629	628,614
Low-carbon	272,373	16,738	289,112
Ferrochromium-silicon	51,699	1,242	52,941
Ferrocolumbium (kilograms contained columbium)	271,435	150,820	422,255
Ferromanganese:			
High-carbon	787,927	—	787,927
Medium-carbon	26,374	—	26,374
Ferrotungsten (kilograms contained tungsten)	381,359	536,778	918,137
Silicomanganese	21,386	—	21,386

require physical modification. Modern furnaces are equipped with automated materials handling equipment to reduce labor requirements and with computerized control systems to maintain more efficient production.

Some ferroalloys are produced in the electric furnace by metallothermic reduction. The reductant may be aluminum or silicon (often as ferrosilicon). The reactions are generally self-sustaining, but heat may be added by an electric arc to keep the molten alloy liquid until the slag can be separated.

Economic Factors

Prices.—Demand for ferroalloys is determined by the level of activity in the iron and steel industries, and prices for ferroalloys tend to vary, sometimes widely, with changes in demand or supply. For example, in 1987 and 1988, bulk ferroalloy prices rose steadily and, in some cases, more than doubled as U.S. steel production and that of stainless grades headed toward their highest levels in nearly 10 years. In 1989, as steel production fell slightly, most bulk ferroalloy prices also fell.

TABLE 2

HISTORICAL FERROALLOYS PRICE TRENDS

(Weighted annual averages)

Year	FeMn[1]	FeCr[2]	FeSi[3]
1976	376.63	42.45	28.55
1977	327.20	36.25	28.55
1978	334.11	33.11	29.96
1979	440.14	43.03	41.70
1980	428.37	45.85	41.77
1981	410.97	46.37	40.01
1982	396.23	46.01	37.93
1983	328.21	36.71	36.67
1984	331.60	43.21	41.89
1985	330.21	43.71	35.71
1986	319.22	39.94	33.65
1987	341.80	43.89	36.78
1988	510.23	85.08	56.82
1989	619.64	75.67	48.96
1990	644.27	47.51	39.94

[1]Imported standard-grade ferromanganese—prices in dollars per long ton of alloy.
[2]Imported charge-grade ferrochromium—prices in cents per pound of contained chromium.
[3]Imported 75%-grade ferrosilicon—prices in cents per pound of contained silicon.

Costs.—Principal elements in the cost of ferroalloy 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 of these elements, and particularly the cost of energy, increased rapidly since 1970. In addition, new capital costs for pollution control equipment were added.

Energy costs are a dominant factor in the cost of producing ferroalloys in submerged-arc furnaces. Silicon alloys require the highest energy input, followed by chromium- and manganese-containing alloys. In the United States, energy costs account for up to 40% of the cost of silicon-containing ferroalloys. In addition, many national Governments are favoring less power-intensive industries by allocating power. Thus, countries with an adequate technology base, economy of large-scale operation, and ensured low energy costs will be favored to become larger factors in the ferroalloy industry. The United States will be in an intermediate energy cost position. However, energy costs and ore reserves continue to favor expansion in production of (1) chromium alloys in Albania, Greece, India, the Philippines, the Republic of South Africa, and Turkey; (2) manganese alloys in Brazil, Mexico, and the Republic of South Africa; and (3) silicon alloys in Australia, Brazil, and Norway. At the same time, such growth will tend to dampen growth in steel-producing countries such as the United States, Japan, and many Western European countries.

Tariffs.—Tariff schedules for ferroalloys and related metals can be found in the respective individual commodity annual reports.

Operating Factors

Environmental Requirements.—Air pollution is the principal environmental problem in the production of ferroalloys. Most developed countries, such as Japan, the United States, and those of Western Europe, have stringent environmental controls, requiring pollution control systems. Ferroalloy furnaces in the United States are generally equipped with baghouses; wet scrubbers and electrostatic precipitators are also in use. In some other countries, environmental controls are not always required by the Governments, but producers are equipping new furnaces with the most modern equipment commercially available to effect substantial removal of objectionable emissions.

Energy Requirements.—Bulk ferroalloys produced in submerged-arc electric furnaces are extremely power intensive, especially silicon metal and the silicon-containing alloys, which can require up to 12,000 kilowatt-hours of electric energy per ton[1] of silicon contained in the final product. Standard ferromanganese is the least power intensive of the major ferroalloys, requiring approximately 2,500 kilowatt-hours per ton of alloy produced.

To buy power at low cost, many ferroalloy companies have long-term contracts with use-or-pay conditions that may restrict the companies' operational flexibility. Contracts that specify a high minimum charge limit the amount that costs can be reduced by cutting production during periods of weak demand. Under interruptible contracts, power can be cut off during power shortages.

ANNUAL REVIEW

Legislation and Government Programs

In November, the President signed into law Amendments to the Clean Air Act of 1977. It was expected that the new amendments would have both a direct and indirect impact on the domestic ferroalloys industry. A potential direct impact will be determined by new toxic emissions regulation. The Environmental Protection Agency placed all ferroalloy producers on a list of possible sources of toxic emissions subject to regulation. Indirectly, the industry could be impacted by the acid rain portions of the new law. New standards for the reduction of SO_2 emissions would almost certainly raise prices for electrical power, a major cost component in ferroalloy and silicon metal production.

The South Carolina Research Authority (SCRA), a public corporation created by the State's government to promote high-technology industries, completed phase I of a government-sponsored research project aimed at utilizing plasma-arc smelting technology for the production of ferrochromium. In 1989, SCRA received $3.5 million in seed funding from the Defense Logistics Agency (DLA) for phase I. Macalloy Corp., Arthur D. Little Inc., Clemson University, and the Massachusetts Institute of Technology were the other principals involved in the project. Macalloy provided matching funds for phase I. In 1990, a pilot-scale (2,000-kW)

furnace, capable of producing about 1,000 pounds of ferrochromium per hour, was built at Macalloy's smelting facility in Charleston, SC. After successful test firings of the furnace, several production campaigns were run by SCRA and Macalloy. The official results of these test runs are to be reported to DLA in early 1991; sources associated with the project have reported that the initial results were quite favorable. Also in 1991, phase II of the project, which is to involve the planning, development, and construction of a much larger prototype furnace, is to continue under the auspices of DLA. A $10 million grant was awarded to SCRA for phase II of the project, and as with phase I, matching funds will be provided by Macalloy.

Under contracts awarded in 1989, DLA continued the 7-year-old Ferroalloy Upgrading Program for chromium and manganese materials in the National Defense Stockpile (NDS). Macalloy Corp.'s contract called for the conversion of 126,053 short tons of chromite to high-carbon ferrochromium in 1990 and an additional 126,341 short tons in 1991 at a cost of approximately $30 million per year. A total of 51,742 short tons of high-carbon ferrochromium was added to the NDS inventory in 1990. The current contract also includes an option for the conversion of a total of 264,791 short tons of chromite in 1992 and 1993. Elkem Metals was under contract to convert 132,861 short tons of manganese ore to high-carbon ferromanganese in 1990 and 132,244 short tons in 1991, at a total cost of approximately $82 million. A total of 56,383 short tons of high-carbon ferromanganese was added to the NDS inventory in 1990. Elkem's manganese contract also included third- and fourth-year options under which an additional 264,791 short tons of manganese ore would be converted to high-carbon ferromanganese. A third DLA contract, also awarded to Elkem in 1989, calling for the conversion of stockpiled low-carbon ferrochromium to vacuum melting-grade electrolytic chromium metal, was completed. The conversion yielded 1,150 short tons of chromium metal at a cost of $7.2 million. According to DLA officials, a similar contract was awarded in 1990 for the conversion of stockpiled low-carbon ferrochromium to 860 short tons of vacuum melting-grade electrolytic chromium metal in 1991 at an approximate cost of $7 million.

Strategic Considerations

Ferroalloys and silicon metal are essential in the production of iron, steel, aluminum, and silicon-base chemicals, making their continued availability a matter of strategic importance. The domestic ferroalloys industry has been in a state of decline since its peak years in the mid-1970's owing to competition from low-priced imports. Since that time, most of the producers of chromium- and manganese-containing alloys have quit producing those materials or gone out of business altogether.

Issues

The U.S. dependence on foreign sources for most ferroalloy materials has risen steadily over the past two decades. Net import reliance for chromium-, manganese-, and silicon-containing materials was estimated to be 79%, 100%, and 30%, respectively, in 1990. Commercially, the United States is 100% dependent on foreign sources for chromium ore (chromite) and manganese ore used to make ferroalloys containing those elements; however, some of these ores and their respective alloys, along with materials containing columbium and tungsten, are held in the NDS. Supplies of raw materials necessary to produce silicon-containing ferroalloys and metal are readily available domestically, but the capacity to produce these materials has declined in recent years.

In August, a group of domestic silicon producers petitioned the Department of Commerce (DOC) and the International Trade Commission (ITC) for relief from allegedly dumped silicon metal imports from Argentina, Brazil, and China. Brazil also was alleged to have unfairly subsidized its silicon metal industry. The domestic producers involved in the actions taken against Brazil were American Alloys Inc., Globe Metallurgical Inc., Silicon Metaltech Inc. (SMI), and Simetco. These companies, as well as SKW Alloys Inc. and Elkem Metals Co., filed antidumping actions against Argentina and China. In October, the ITC announced their initial findings: that there was reasonable indication of injury caused to the domestic silicon industry by the dumping of imports from the three countries. The DOC later made a preliminary determination that Brazil was not providing countervailable subsidies to its silicon metal industry. The following trade actions were scheduled to be made in 1991: a final DOC decision in the countervailable subsidy investigation of Brazil; preliminary and final DOC determinations on the alleged dumping of silicon metal by Argentina, Brazil, and China; and final ITC determinations on injury to domestic silicon producers by imports from Argentina, Brazil, and China.

Production

U.S. ferroalloy shipments in 1990 were 860,433 tons valued at $871 million. The production and shipments of silicon-containing ferroalloys and silicon metal combined comprised the largest portion of the domestic industry based on tonnage and value. These materials were produced by 9 companies at 13 locations. Overall domestic production decreased 4% compared with that of 1989, with major producers cutting back production because of oversupply and low price levels. Applied Industrial Minerals Corp. (AIMCOR), Bridgeport, AL; American Alloys, New Haven, WV; SKW, Calvert City, KY; Elkem Metals, Alloy, WV, and Ashtabula, OH; Globe Metallurgical, Beverly, OH; and Simetco, Montgomery, AL, all idled capacity at some point during the year for major maintenance or because of market conditions.

Elkem Metals, Marietta, OH, was the only producer of ferromanganese and silicomanganese. Macalloy Corp. (Charleston, SC) continued to produce high- carbon ferrochromium. Ferronickel production continued at Glenbrook Nickel Co., Riddle, OR.

The Ferroalloys Association reported that its member companies consumed approximately 4.9 billion kilowatt-hours of electricity in 1990 compared with 5.3 billion kilowatthours the previous year.

Early in the year, Northwest Alloys Inc., a subsidiary of Aluminum Co. of America, closed its 25,000-ton-per-year ferrosilicon operation in Addy, WA. The company, which uses ferrosilicon in the production of magnesium, entered a long-term agreement with Elkem Metals to meet its ferrosilicon needs.

Strategic Minerals Cor. (Stratcor), Danbury, CT, announced plans to acquire Metals and Minerals Inc., a manganese sales subsidiary of Samancor Ltd. (Republic of South Africa), in 1991 to expand its sales line, which had consisted of vanadium-, tungsten-, and chromium-containing materials. With the acquisition, Stratcor plans to market ferromanganese, silicomanganese, and manganese ore.

TABLE 3

PRODUCERS OF FERROALLOYS IN THE UNITED STATES IN 1990

Producer	Plant location	Products[1]	Type of furnace
FERROALLOYS (except ferrophosphorus)			
Affiliated Metals and Minerals Inc.[2]	New Castle, PA	FeMo, FeV	Metallothermic.
AMAX Inc., Climax Molybdenum Co. Div.	Langeloth, PA	FeMo	Do.
American Alloys, Inc.	New Haven, WV	FeSi, Si	Electric.
Applied Industrial Minerals Corp. (AIMCOR)	Bridgeport, AL Kimball, TN	FeSi, other[2] do.	Do. Do.
Bear Metallurgical Inc.[2]	Butler, PA	FeMo, FeV	Metallothermic.
Cabot Corp.	Revere, PA	FeCb	Do.
Cyprus Minerals Co.	Sahuarita, AZ	FeMo	Do.
Dow Corning Corp.	Springfield, OR	Si	Electric.
Elkem A/S, Elkem Metals Co.	Alloy, WV Ashtabula, OH Marietta, OH Niagara Falls, NY	Cr, FeB, FeCr, FeMn, FeSi, Mn, Si, SiMn, other[2]	Electric and electrolytic.
Galt Alloys Inc.	Canton, OH	FeTi, FeAl	
Globe Metallurgical Inc.	Beverly, OH Selma, AL	FeSi, Si	Electric.
HTP Co.	Sharon, PA	FeTi	Metallothermic.
Keokuk Ferro-Sil Inc.	Keokuk, IA	FeSi, silvery pig iron	Electric.
Kerr-McGee Chemical Corp.	Hamilton (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[3]	Electric and metallothermic.
Reading Alloys Inc.	Robesonia, PA	FeCb, FeV	Metallothermic.
Reynolds Metals Co.	Sheffield, AL	Si	Electric.
Satra Concentratres	Steubenville, OH	FeCr	Slag conversion.
Silicon Metaltech Inc.	Wenatchee, WA	FeSi, Si	Electric.
Simetco	Montgomery, AL	Si	Do.
SKW Alloys Inc.	Calvert City, KY Niagara Falls, NY	FeCrSi, SiMn, FeSi, S	Do. Do.
Strategic Minerals Corp. (STRATCOR), U.S. Vanadium Corp.	do.	FeV, FeW	Do.
Teledyne Inc., Teledyne Wah Chang, Albany Div.	Albany, OR	FeCb	Metallothermic.
Union Oil Co. of California, Molycorp Inc.	Washington, PA	FeB, FeMo	Electric and metallothermic.
Universal Consolidated Co., Nickel Mountain Resources.	Riddle, OR	FeNi, FeSi	Electric.
FERROPHOSPHORUS			
FMC Corp., Industrial Chemical Div.	Pocatello, ID	FeP	Do.
Monsanto Co., Monsanto Industrial Chemicals Co.	Soda Springs, ID	do.	Do.
Occidental Petroleum Corp.	Columbia, TN	do.	Do.
Rhone Poulenc Basic Chemical Co.	Butte, MT Mount Pleasant, TN	do. do.	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; Si, silicon metal; SiMn, silicomanganese.
[2]The same equipment was used at both of these facilities.
[3]Includes specialty silicon alloys, zirconium alloys, and miscellaneous ferroalloys.

On June 15, SMI filed for protection under Chapter 11 of the Bankruptcy Law. SMI was reported to have had negative cash flow problems for several months in late 1989 and early 1990, and attributed its problems to a depressed silicon market and unfairly traded silicon metal imports (see Issues). SMI continued to produce silicon and was hoping to emerge from protection within 6 to 12 months.

AIMCOR completed construction of a new blending facility to produce desulfurizers and slag conditioners for the steel industry. Production commenced in July. The new facility was located next to the company's olivine processing plant in Aurora, IN. AIMCOR's ferrosilicon production facility in Kimball, TN, remained closed.

During the third quarter, Glenbrook Nickel was reported to have reached full

capacity, 1 million pounds of nickel contained in ferronickel per month. The operation reopened in 1989 after it had been closed by a previous owner, M.A. Hanna Co., in 1986. Glenbrook has been using stockpiled ore, which accumulated over 30 years while Hanna operated the smelter, and the company was expected to make a decision whether or not to reopen the Riddle Mine. The stockpiled ore was expected to last only about 3 years at current production levels. Ferrosilicon (50% grade), which is consumed in the ferronickel process, had been produced on-site initially, but Glenbrook stopped production, opting to buy its ferrosilicon on the open market.

In October, Reynolds Metals Co. permanently closed its silicon metal production facility in Sheffield, AL. The 8,500-ton-per-year silicon plant, the production of which was considered captive, was part of one of Reynolds' aluminum reduction facilities that was shut down a few years ago. The parent company reported it would fill its silicon requirements on the open market.

Affiliated Metals and Minerals Inc. emerged from Chapter 11 protection of the Bankruptcy Law and resumed ferroalloy tolling operations under the name Bear Metallurgical Inc. at a new site in Butler, PA. Affiliated had previously conducted ferroalloy tolling at its facility in New Castle, PA. Bear plans initially to toll-convert ferrovanadium and ferromolybdenum with equipment purchased from Affiliated. Bear also plans eventually to produce some of its own alloys and offer value added services such as crushing, briquetting, bagging, and other forms of packaging.

Elkem Metals neared completion of its new research facility in Pittsburgh, PA. The facility was to employ approximately 40 people and was built to replace the company's research center in Niagara Falls, NY. Company officials stated that the emphasis of the new facility and programs was more toward customer applications of ferroalloys rather than ferroalloys processing research.

Molycorp Inc. planned to reopen its Washington, PA, molybdenum roasting facility as a 50-50 joint venture with Kennecott Utah Copper Corp. in early 1991. Roasting of molybdenum concentrates at that site ceased in 1986 when Molycorp closed its molybdenum mining operation in Questa, NM. Under the joint venture, concentrates from Molycorp's Questa Mine, which reopened in 1989, and Kennecott's Bingham Canyon, UT, mine (about 10 million pounds of contained molybdenum per year each) will be blended as feed in the Washington facility's 20-million-pound-per-year roaster.

Chrome Corp. of America (CCA), a subsidiary of Boulder Gold NL (Australia), continued to study feasibility and to plan the development of a ferrochromium smelting operation in the Stillwater complex near Billings, MT. The new project planned to utilize the Coal Ore Direct Iron Reduction (CODIR) process for chromite developed by Krupp Industrietechnik (Federal Republic of Germany). Smelter feed for the operation initially could come from an existing 600,000-ton chromite stockpile at Columbus, MT; however, continued operation would require the reopening of existing chromite mines, which are estimated to have a life of about 20 years. Startup of the ferrochromium project was scheduled for 1993. At one point during the year, Phelps Dodge Mining Co. entered into a joint-exploration agreement with CCA covering both chromite and platinum-group metals in the Stillwater complex.

Consumption and Uses

Manganese is required in virtually all steels and most cast irons to counteract the harmful effects of sulfur. It also acts as a mild deoxidizer and is used for strengthening properties in engineering steels. Chromium provides corrosion resistance to stainless steels. Silicon, as ferrosilicon, is the primary deoxidizer used in the production of iron and steel. Silicon metal is used as an alloying agent in aluminum products and as a raw material in the production of silicon-base chemicals.

The iron and steel industry consumes most of the ferroalloys produced; however, other alloy systems, although relatively small in volume, represent substantial and growing markets with respect to value. Some examples are (1) silicon for alloying aluminum, principally the casting varieties; (2) nickel and cobalt-base alloys; and (3) titanium alloys.

Overall domestic usage of ferroalloys and related materials was little changed compared with that of 1989. The steel industry, the major consumer of bulk ferroalloys (i.e., those containing chromium, manganese, or silicon), in general was quite strong, with overall production of raw steel remaining steady throughout most of the year but trending downward at yearend, resulting in a total slightly above that of 1989. Shipments of castings from the ferrous foundry industry, also a large consumer of silicon- and manganese- containing ferroalloys, continued a 2-year decline. Production of stainless steel increased roughly 6% compared with that of the previous year, pushing demand for chromium-containing ferroalloys slightly higher. Aluminum-and silicon-base chemical production totals were slightly higher than those of 1989, increasing overall demand for silicon metal. Demand was mixed for other ferroalloy materials, those containing boron, columbium, molybdenum, nickel, titanium,

TABLE 4

U.S. FERROALLOY PRODUCTION[1] AND SHIPMENTS[2]

(Metric tons, gross weight, unless otherwise specified)

	1990			
	Net production	Net shipments		Stocks December 31
		Quantity	Value (thousands)	
Ferrosilicon[3]	433,726	412,625	$274,450	108,437
Silicon metal	140,792	133,460	180,093	13,746
Other[4]	254,157	260,555	408,219	24,353
Ferrophosphorus	46,018	53,793	7,988	17,122
Total[5]	874,693	860,433	870,750	163,658

[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, ferroboron and other complex boron additive alloys and chromium metal, ferrocolumbium, all manganese-containing ferroalloys and manganese metal, ferromolybdenum, ferronickel, ferrotitanium, ferrovandium, and silvery pig iron.

TABLE 5

REPORTED U.S. CONSUMPTION OF FERROALLOYS AS ADDITIVES IN 1990, BY END USE[1]

(Metric tons of alloys unless otherwise specified)

End use	FeMn	SiMn	FeSi	FeTi	FeP	FeB
Steel:						
Carbon	[2]311,322	67,241	[2]73,828	1,530	6,980	572
Stainless and heat-resisting	[2]15,420	4,642	[2]129,361	2,469	5	24
Other alloy	[2]69,659	[2]21,756	[2]73,542	157	1,108	261
Tool	279	([3])	[2]1,710	([3])	—	([3])
Unspecified	2,348	210	13,180	18	—	1
Total steel[4]	399,029	93,849	291,621	4,175	8,093	858
Cast irons	12,644	1,571	[5]216,914	W	1,747	W
Superalloys	[5]163	—	[5]363	836	—	W
Alloys (excluding alloy steels and superalloys)	[5]18,141	W	[5]96,103	972	125	85
Miscellaneous and unspecified	6,178	2,510	95,634	49	—	33
Total[4]	436,155	97,931	700,635	6,031	9,965	976
Percent of 1989	104	103	124	99	99	136
Consumer stocks, December 31	[6]59,283	[6]7,555	19,896	766	1,264	184

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; FeP, ferrophosphorous; FeB ferroboron, including other boron materials.
[2]Part included with "Steel: Unspecified."
[3]Included with "Steel: Unspecified."
[4]Data may not add to total shown because of independent rounding.
[5]Part included with "Miscellaneous and unspecified."
[6]Includes some producer stocks.

TABLE 6

REPORTED U.S. CONSUMPTION OF FERROALLOYS AS ALLOYING ELEMENTS IN 1990, BY END USE[1]

(Metric tons of contained elements unless otherwise specified)

End use	FeCr	FeMo	FeW	FeV	FeCb	FeNi
Steel:						
Carbon	[2]4,773	108	—	994	930	—
Stainless and heat-resisting	171,957	200	64	38	361	16,810
Other alloy	[2]23,290	1,545	66	1,936	811	162
Tool	[2]2,219	226	342	421	([3])	—
Unspecified	([4])	([4])	([4])	([4])	13	—
Total steel[5]	202,239	2,079	472	3,388	2,115	16,973
Cast irons	[2]3,288	740	W	18	—	W
Superalloys	9,346	62	5	42	454	W
Alloys (excluding alloy steels and superalloys)	2,425	84	W	606	W	W
Miscellaneous and unspecified	6,473	73	10	43	16	382
Total[5]	223,770	3,039	488	4,098	2,585	17,354
Percent of 1989	104	108	110	88	94	171
Consumer stocks, Dec. 31	10,787	222	33	355	NA	991

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; 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 total shown because of independent rounding.

and vanadium. Demand for these materials was also related to the consuming industries listed above.

Markets and Prices

Published prices for most ferroalloys and related materials ended the calendar year on the downside owing to decreasing demand by consuming industries. The

price for imported ferromanganese containing 78% manganese ended the year up slightly and was much more stable than the price of most other ferroalloy materials. Yearly average price for imported ferromanganese was roughly 5% higher than that of 1989. The price for imported charge chrome (ferrochromium containing 50% to 55% chromium) fell throughout the year. The yearly average, 47.5 cents per pound of contained chromium, was down about 40% compared with that of the previous year. The yearly average price for imported 75% ferrosilicon, 39.9 cents per pound of contained silicon, was about 20% lower than that of 1989. The price for imported silicon metal ended 2 cents higher than the average for the year, 54.8 cents per pound, which was down 8% compared with that of 1989. Prices for molybdenum- and vanadium-containing ferroalloys were mixed and ended the year on downward trends.

Foreign Trade

The trade deficit for ferroalloys and related metals overall was 884 million, a 10% decrease compared with that of 1989. Exports of ferroalloys and related metals overall decreased 13% compared with that of 1989; however, the associated value of those materials increased 9%. Exports of related metals increased by 49%, which was primarily due to a 78% increase in silicon metal exports.

Imports for consumption of ferroalloys and related metals overall increased 8% compared with those of 1989; however, the value associated with those materials decreased 8%. The Republic of South Africa continued to be the main source of U.S. imports of those materials, accounting for 26% of the total. Of the imported chromium- and manganese-containing materials, the Republic of South Africa supplied 40% and 32% of the respective totals. Other major suppliers of imported chromium-containing materials were Turkey (11%), Yugoslavia (12%), and Zimbabwe (14%). The second leading supplier of manganese-containing materials was France (18%). Imports of ferrosilicon increased 34% compared with those of 1989. The principal sources of ferrosilicon imports were Brazil, 28%; the U.S.S.R., 17%; Canada, 16%; and Venezuela, 14%. Imports of silicon metal overall increased 54%. The principal sources of silicon metal were Brazil, 44%; China, 33%; and Canada, 12%. Complete breakouts by country for U.S. imports and exports of most ferroalloys and related materials can be found in the respective commodity annual reports.

World Review

Capacity.—The data in table 8 are rated capacities as of December 31, 1990, for major countries that produce ferroalloys containing chromium, manganese, and silicon, as well as silicon 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. Because not all countries or producers make production capacity information available, historical production and trade data have been used to estimate production capacity in some cases.

Albania.—In recent years, the country has encountered difficulties because of water and subsequent electrical power shortages. Lack of rainfall curbed food supplies, while power shortages affected the production of chromite and ferrochromium, the country's most important mineral-metal commodities. Power shortages also delayed the startup of a new ferrochromium smelter at the Elbasan steel and metallurgical complex. Initial plans called for the facility to produce 38,000 tons per year of high-carbon ferrochromium.[2]

Argentina.—Silarsa, a joint venture between Axel Johnson Metals (30%) and Stein Ferroalloys (70%), started a new 6,500-ton-per-year silicon metal furnace at Mendoza in September. The plant was running at about 85% of capacity and all of the output was expected to be exported to Europe, Japan, and the United States. Construction of a second furnace of equal capacity was planned for 1991.[3]

Australia.—SIMCOA Pty. deferred indefinitely the expansion of its 30,000-ton-per-year silicon metal operation at Kemerton in Western Australia. Initial plans for the operation, which was commissioned by Barrack Mines Ltd. in 1989, included four 18-megawatt electric furnaces. Only two have been built and operated. Output, which had reached full capacity, was being exported to Asia, Europe, and North America.[4]

Bhutan.—Marubeni Corp. (Japan) announced its plans to form a joint venture with Bhutanese partners, Tashi

TABLE 7

FERROALLOY PRICES IN 1990

	High	Low	Average[1]
Standard-grade ferromanganese[2]	$660.00	$620.00	$644.27
Medium-carbon ferromanganese[3]	60.50	55.50	57.44
Silicomanganese[4]	28.75	25.25	26.88
Charge-grade ferrochromium[3]	55.50	45.00	47.51
High-carbon ferrochromium[3]	54.50	42.75	47.10
Low-carbon ferrochromium[3]	123.00	90.00	106.89
50%-grade ferrosilicon[3]	45.00	37.50	42.44
75%-grade ferrosilicon[3]	43.50	36.00	39.94
Silicon metal[4]	58.00	50.50	54.84
Ferromolybdenum[5]	4.10	3.60	3.85
Molybdenum oxide[5]	3.30	2.52	2.85
Ferrovanadium[5]	22.50	12.75	15.97

[1]Annual weighted average.
[2]Dollars per long ton.
[3]Cents per pound of contained element.
[4]Dollars per pound of contained element.
[5]Dollars per kilogram of contained element.

Commercial Corp. and Bhutan's Ministry of Trade and Industry, to build a 15,000-ton-per-year ferrosilicon plant at Pasakha, close to Bhutan's southern border with India. The site was chosen because of its proximity to a new hydroelectric plant. The operation was to be called Bhutan Ferroalloys Ltd. and was scheduled for commissioning at the end of 1992.[5]

Brazil.—According to Anuario da Industria Brasileira de Ferroligas (ABRAFE), overall ferroalloy production decreased 9% compared with that of 1989 because of a significant decrease, 27%, in the production of steel, the major consumer of ferroalloy materials; continually escalating production costs, primarily electrical power; and the country's new economic policies. The decrease in production marked the first since the country started its rapid expansion in ferroalloys production and advance into world markets during the 1980's. A number of producers shut down capacity. However, despite the decrease in overall production, a new record level for exports of ferroalloy materials, more than 560,000 tons or 60% of production, was achieved, and some expansion plans continued.

Camargo Correa Metais S/A (CCM) shut down two of its four 18,000-kilovolt-ampere, 16,000-ton-per-year silicon metal furnaces at its new facility in Tucurui, Para State, because of weak market conditions. The state-of the-art plant, which came on-line with two furnaces in 1988 and two more in 1989, had been producing at full capacity until midyear.[6] Other capacity shutdowns included that of one silicon metal furnace at Rima Electrometallurgia in Minas Gerais, Cia. Paulista de Ferroligas' ferrosilicon furnaces in Caxambu, and two of Ferbasa's ferrochromium furnaces in Pojuca.[7] Late in the year, Rima Electrometallurgia filed for protection under the country's bankruptcy law.[8]

Cia. Ferroligas do Amapá commissioned a 12-MVA furnace to produce 22,000-tons-per-year high-carbon ferromanganese at Porto de Santana. The furnace was originally intended for ferrochromium production, but the company felt market conditions favored production of ferromanganese. Most of the furnace's production is expected to be exported to the United States.[9]

Cia. Brasileira de Metalurgia e Mineracao (CBMM) planned to start construction of a new 23,000-ton-per-year ferrocolumbium production facility at Araxa. The facility was scheduled to begin production in 2 years at which time CBMM would cease production at its existing plant.[10]

China.—Annual production of ferroalloys and silicon metal has increased significantly over the past few years, and producers continued to advance their participation in world ferroalloy markets. However, future availability of electrical power for the country's growing industries was questionable, and because world market prices for ferroalloys remained depressed and the Chinese Government placed ferroalloys second in importance to aluminum, it was expected that the country might face ferroalloy and silicon metal production cuts in the future.[11]

EC.—In July the EEC imposed a 198-ECU/metric ton tariff on imports of silicon metal from China. The action was taken on complaints from silicon metal producers in the Federal Republic of Germany, France, Italy, and Spain that imports of Chinese silicon metal rose from 0% to 8% of the EC total in 4 years (1985-89).[12]

Late in the year, European silicon metal producers also filed a dumping action against silicon metal producers in Brazil. As with the material from China, silicon metal imports from Brazil into the EC had risen significantly over the past 5 years.[13]

TABLE 8

U.S. EXPORTS OF FERROALLOYS AND FERROALLOY METALS IN 1990

Alloy	Quantity (metric tons)	Content (metric tons)	Value (thousands)
Ferroalloys:			
Ferrochromium with greater than 4% carbon	5,795	3,477	$5,728
Ferrochromium with less than 4% carbon	2,521	1,517	3,782
Ferrochromium-silicon	802	333	1,028
Ferrocolumbium	838	(1)	5,500
Ferromanganese with greater than 2% carbon	3,708	2,928	2,588
Ferromanganese, other	3,579	2,594	3,977
Silicomanganese	1,791	1,164	1,666
Ferromolybdenum	300	182	2,372
Ferronickel	2,292	1,725	5,358
Ferrophosphorus	5,981	(1)	2,344
Ferrosilicon (greater than 55% silicon)	16,039	9,833	15,392
Ferrosilicon, other	34,040	16,962	28,600
Ferrovanadium	334	209	5,480
Ferrozirconium	88	(1)	74
Ferrotungsten and ferrosilicon-tungsten	31	15	98
Ferroalloys, n.e.c.	3,893	(1)	5,229
Total ferroalloys[2]	82,032	XX	89,217
Metals:			
Chromium	338	(1)	3,447
Manganese	6,144	(1)	14,043
Silicon			
(less than 99% silicon)	4,818	4,655	7,214
(99% to 99.99% silicon)	3,103	3,077	3,837
(greater than 99.99% silicon)	1,059	(1)	81,170
Total ferroalloy metals[2]	15,462	XX	109,711
Grand total[2]	97,494	XX	198,928

XX Not applicable.
[1]Not recorded.
[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 FERROALLOYS AND FERROALLOY METALS IN 1990

Alloy	Gross weight (metric tons)	Content (metric tons)	Value (thousands)
Chromium alloys:			
Ferrochromium containing 4% or more carbon	344,882	198,175	$174,911
Ferrochromium containing less than 4%, but greater than 3% carbon	24,952	13,696	13,230
Ferrochromium containing less than 3% carbon	46,059	30,485	58,299
Ferrochromium-silicon	3,801	1,459	2,616
Total chromium alloys[1]	419,694	243,815	249,055
Manganese alloys:			
Ferromanganese containing more than 4% carbon	305,664	236,708	162,987
Ferromanganese containing more than 2% to 4% carbon	101	80	44
Ferromanganese containing more than 1% to 2% carbon	62,501	50,917	55,225
Ferromanganese containing 1% or less carbon	11,561	10,171	16,073
Silicomanganese	224,473	147,520	117,847
Total manganese alloys[1]	604,300	445,396	352,176
Silicon alloys:			
Less than 55% silicon containing more than 2% magnesium	4,415	1,191	3,987
less than 55% silicon, n.e.c.	70,920	31,733	25,038
55% to 80% silicon, containing more than 3% calcium	22,099	13,802	27,893
55% to 80% silicon, n.e.c.	141,450	104,786	78,017
Greater than 90% silicon	100	94	59
Total silicon alloys[1]	238,983	151,605	134,993
Other ferroalloys:			
Ferrocerium and other cerium alloys	185	(2)	1,686
Ferromolybdenum	1,401	871	6,990
Ferronickel	41,767	14,273	116,484
Ferroniobium (columbium)	2,919	(2)	24,685
Ferrophosphorous	237	(2)	526
Ferrotitanium and ferrosilicon titanium	1,960	(2)	9,202
Ferrotungsten and ferrosilicon tungsten	659	493	2,739
Ferrovanadium	305	244	3,720
Ferroalloys, n.e.c.	2,404	(2)	8,351
Total other ferroalloys[1]	51,837	XX	174,383
Total ferroalloys[1]	1,314,815	XX	910,607
Metals:			
Chromium	6,664	(2)	43,160
Manganese, Unwrought	9,492	(2)	14,407
Manganese, other	3,461	(2)	5,331
Silicon, less than 99% silicon	8,534	8,325	7,119
Silicon 99 to 99.99% silicon	57,139	56,617	53,982
Silicon, greater than 99.99% silicon	709	(2)	53,284
Total ferroalloy metals[1]	85,999	XX	177,284
Grand total[1]	1,400,814	XX	1,087,891

XX Not applicable.
[1]Data may not add to totals shown because of independent rounding.
[2]Not recorded.
Source: Bureau of the Census.

France.—Chromeurope S.A., a subsidiary of Ferroaleaciones Espanolas S.A. of Spain, started its second high-carbon ferrochromium furnace, a 16-MVA unit. The company began production at its new Dunkirk facility with a 12-MVA unit in 1988. The combined planned output of the two furnaces was to be 36,000 tons-per-year.[14]

Usinor Sacilor planned to build a 100,000-ton-per-year ferromanganese-silicomanganese production facility in Dunkirk. Completion of the project was expected by the end of 1991. Some of the manganese ore was to come from Brazil.

TABLE 10

WORLD PRODUCTION CAPACITY FOR BULK FERROALLOYS,[1] DECEMBER 31, 1990

(Thousand metric tons, gross weight)

Country	Capacity
Albania	65
Argentina	88
Australia	175
Belgium	91
Brazil	1,122
Bulgaria[2]	32
Canada	247
Chile	21
China[3]	1,837
Colombia	(4)
Czechoslovakia[2]	116
Egypt	60
Finland	200
France	619
Germany, Federal Republic:	
Eastern states	93
Western states	386
Greece	30
Hungary	(4)
Iceland	67
India	589
Italy	300
Japan	1,168
Korea, North[2]	68
Korea, Republic of	104
Mexico	302
Norway	1,320
Peru	(4)
Philippines	140
Poland[2]	213
Portugal	16
Romania[2]	167
South Africa, Republic of	2,375
Spain	283
Sweden	231
Switzerland	(4)
Taiwan	90
Turkey	172
U.S.S.R.	3,896
United Kingdom	115
United States	1,017
Uruguay	(4)
Venezuela	96
Yugoslavia	363
Zimbabwe	233
Other[4]	342
Total	18,850

[1]Consists of ferroalloys of chromium, manganese, and silicon and silicon metal.
[2]Excludes silicon materials, which are included with "Other."
[3]Included with "Other."
[4]Does not include blast furnace capacity.

The new plant would supply about one-half of the company's manganese needs for steelmaking. At yearend, Usinor had received the EC Commission's endorsement of a electricity supply contract with the EDF.[15]

Greece.—Hellenic Ferroalloys (HFA) was forced to decrease production of ferrochromium by an estimated 25% because of worker strikes, by both HFA workers and those of the Public Power Cor. (PPC), and an ongoing dispute with the PPC over nonpayment of HFA's bills.[16] Larco, a producer of ferronickel, also lost some production due to the PPC strikes, which reduced electricity to its smelter.[17]

India.—Perennial power shortages continued to cause problems for ferroalloy producers, especially in Andhra Pradesh; however, Ferro Alloys Corp. Ltd. (FACOR) helped alleviate this problem with the completion of a 30- megawatt captive powerplant at Garividi to supply its Shreeramnagar ferrochromium works in Barividi.[18]

State-owned OMC Alloys Inc. announced that it would suspend charge chrome production at the end of the year owing to rising production costs and poor market conditions.[19]

Kolmak Chemicals planned to construct a new 15,000-ton-per-year ferrochromium operation under the name Standard Chrome in Raigarh, Madhya Pradesh. Chrome ore was expected to come from mines in Orissa.[20]

Netherlands.—Aimcor Formed Products Production Corp., a subsidiary of AIMCOR (United States), started construction of a 200,000-ton-per-year silica briquetting plant in Rotterdam. The operation was to produce a carbon-silica material, trade-named Silgro, to be used as feed in ferrosilicon and silicon metal production in the United States and Europe.[21]

New Caledonia.—Eramet-SLN, a ferronickel producer, was plagued with problems at its Noumea smelter, including a strike, delayed startup of its new oxygen facility, and a transformer fire at the end of the year. The company lost an estimated 4,500 tons of production and twice declared *force majeure*.[22]

Norway.—Elkem A/S purchased the Norsk Ferrokrom Mo I Rana operation, a joint venture involving Norsk Jern Holding, the FESIL group, and Macalloy Corp. (United States), and formed a new company, Elkem Rana. Norsk Ferrokrom, which had started production in 1989, was Norway's first ferrochromium project and consisted of two furnaces with a total capacity of 100,000-tons-per-year. Only one of the furnaces has been operated, but Elkem had planned to start the second furnace, possibly in 1991.[23]

Elkem also purchased the remaining interest in Bjoelvefossen, a four-furnace ferrosilicon operation at Alvik in which Elkem was a 48% owner.[24] Later in the year, Elkem announced it would shut one of the furnaces at Alvik as well as one ferrosilicon furnace at both its Bremanger and Thamshavn plants due to market conditions. The shutdowns would amount to about 20,000 tons of material on an annual basis. The company also announced that it would close a second silicon metal furnace at Meraker, leaving only one furnace in operation. Another ferrosilicon producer, FESIL, announced that it would cut production by 20% at its Hafslund, Rana Metall, and Finnfjord facilities.

South Africa, Republic of.—Tubatse Ferrochrome (Pty.) Ltd., a subsidiary of Samancor, commissioned its fifth ferrochromium furnace, making that facility the second largest of its type in the world. The new furnace had an annual production capacity of 60,000 tons, bringing Tubatse's total production capacity to 300,000 tons per year.[25]

Purity Ferrochrome Pty. commissioned two new 33-MVA, 60,000-ton-per-year ferrochromium furnaces at its smelter near Rustenburg, Transvaal Province. The new operation was later taken over by another of the country's ferrochromium producers, Consolidated Metallurgical Industries (CMI). With the acquisition, CMI increased its total ferrochromium capacity to 325,000 tons per year.[26]

Middleburg Steel and Alloys (Pty.) Ltd. started a direct-current, transferred-arc plasma furnace for the production of ferrochromium; however, the company was forced to shut the furnace down after experiencing problems with the furnace's refractory lining. The new unit was designed to process chromium ore fines, which are less expensive than lumpy ore and readily available domestically. The furnace should produce up to 120,000

per year when fully operational and should use only one-quarter of the electrical energy used to produce ferrochromium in a conventional submerged-arc furnace.[27]

Two new manganese ferroalloy furnaces were commissioned during the year. The first was a 48-MVA silicomanganese unit at the Transalloys Div. of Highveld Steel & Vanadium Corp. Ltd., which raised the company's total manganese ferroalloy capacity to about 200,000 tons per year (175,000 tons per year silicomanganese and 20,000 tons per year medium-/low-carbon ferromanganese). The second was a 50,000-ton-per-year ferromanganese unit at the Cato Ridge plant of Feralloys Ltd., a subsidiary of AMMOSAL, which raised that company's total ferromanganese capacity to 130,000 tons per year.[28]

Saudi Arabia.—United Gulf Industries Corp. planned to build a 25,000- tons-per-year ferrosilicon production facility in Jubail. The company also suggested future interest in building a ferromanganese-silicomanganese smelter if a source of manganese ore could be secured.[29]

Spain.—Sociedad Espanola de Fundiciones Electricas planned to permanently close its ferroalloy plant near Bilboa and disassemble its two electric furnaces that had been shut down in late 1989 because of high electrical power costs. The company had produced ferromanganese and ferrosilicon for domestic use.[30]

Sweden.—Ferrochromium producer Swedechrome permanently closed its 80,000-ton-per-year charge chrome production facility at Malmo early in the year. The company stated a number of reasons for the plant's closure, including low ferrochromium prices and an unfavorable cost position due to the country's embargo of South African chrome ore and high electricity prices.

KemaNord permanently closed its 24,000-ton-per-year silicon metal production facility. The company claimed it could not compete with low-cost producers on the world market in times of depressed prices.[31]

Turkey.—Etibank General Management started a fourth high-carbon ferrochromium furnace at its Elazig plant. The 30-MVA furnace raised total ferrochromium capacity at the Elazig plant to 150,000 tons per year.[32]

A consortium of companies from the Republic of Korea, including Sunkyong Ltd., its subsidiary Yukong Ltd., and state-run Korean Mining Promotion Corp. formed a joint venture with Egemetal Medencilik with plans to construct a 40,000-ton-per-year ferrochromium smelter in northwestern Turkey. Completion of the project was scheduled for 1993. The consortium planned to take one-half of the output for use in the Republic of Korea.[33]

Yugoslavia.—Ferroalloy producer Dalmacija Dugi Rat placed two of its three furnaces on care and maintenance at the beginning of the fourth quarter owing to weak world market conditions. One of the two furnaces accounted for one-half of the company's 75,000 tons per year ferrochromium capacity, output of which is mostly exported. The second idled furnace, which is capable of producing 25,000-tons-per-year ferromanganese, had been producing ferromanganese and silicomanganese for both domestic use and export.[34]

TABLE 11

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1986	1987	1988	1989[p]	1990[e]
Albania: Electric furnace, ferrochromium[e]	46,000	46,000	46,000	47,000	47,000
Argentina: Electric furnace:					
Ferromanganese	19,782	21,407	19,737	25,545	[4]23,787
Silicomanganese	12,977	11,746	11,610	16,857	[4]21,536
Ferrosilicon	22,979	23,998	30,539	28,381	[4]17,509
Silicon metal[e]	5,000	10,000	10,000	10,000	10,000
Other	5,272	6,790	5,952	7,461	[4]7,124
Total[e]	66,010	73,941	77,838	88,244	79,956
Australia: Electric furnace:[5]					
Ferromanganese	61,000	51,000	58,000	[e]60,000	60,000
Silicomanganese	23,000	43,000	44,000	[e]45,000	45,000
Ferrosilicon	19,000	18,000	[e]18,000	[e]20,000	20,000
Silicon metal[e]	—	2,000	8,000	9,000	33,000
Total[e]	103,000	[r]114,000	[r]128,000	[r]134,000	158,000
Austria: Electric furnace, undistributed	12,000	[r]7,000	20,000	15,000	12,000
Belgium: Electric furnace, ferromanganese[e]	87,000	90,000	95,000	95,000	90,000
Brazil: Electric furnace:					
Ferromanganese	164,093	155,252	180,588	180,668	[4]170,504
Silicomanganese	177,568	188,022	193,490	208,262	[4]216,779
Ferrosilicon	217,715	231,159	267,538	286,994	[4]229,408

See footnotes at end of table.

TABLE 11—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1986	1987	1988	1989[p]	1990[e]
Brazil: Electric furnace:—Continued					
Silicon metal	37,077	39,982	79,287	116,779	[4]131,614
Ferrochromium	109,392	105,394	130,024	113,267	[4]83,753
Ferrochromium-silicon	9,512	8,079	9,177	8,938	[4]4,973
Ferronickel	34,296	35,496	33,930	34,997	[4]34,257
Other	61,767	60,454	79,090	81,901	[4]68,026
Total	811,420	823,838	973,124	1,031,806	[4]939,314
Bulgaria: Electric furnace:[e]					
Ferromanganese[6]	32,000	31,000	31,000	[r]30,000	30,000
Ferrosilicon	15,000	10,000	[r]15,000	[r]14,000	14,000
Other	1,000	1,000	1,000	1,000	1,000
Total	48,000	42,000	[r]47,000	[r]45,000	45,000
Canada: Electric furnace:					
Ferromanganese[6]	124,000	165,000	161,000	185,000	185,000
Ferrosilicon	83,329	95,191	90,266	88,370	90,000
Silicon metal	78,700	76,900	66,300	106,000	100,000
Total	286,029	337,091	317,566	379,370	375,000
Chile: Electric furnace:					
Ferromanganese	6,277	6,613	6,899	7,250	6,500
Silicomanganese	1,706	1,231	681	180	700
Ferrosilicon	3,732	4,258	5,686	6,370	5,500
Other	1,644	2,197	3,403	5,830	3,000
Total	13,359	14,299	16,669	19,630	15,700
China: Furnace type unspecified:[e 7]					
Ferromanganese	[r]466,400	[r]510,300	[r]495,000	[r]550,000	550,000
Ferrosilicon	[r]466,200	[r]591,200	[r]787,600	[r]900,000	900,000
Other	[r]664,400	[r]744,500	[r]801,400	[r]932,000	950,000
Total	[r]1,597,000	[r]1,846,000	[r]2,084,000	[r]2,382,000	2,400,000
Colombia: Electric furnace, ferronickel	45,500	46,389	41,672	41,454	[4]43,847
Czechoslovakia: Electric furnace:					
Ferromanganese[e 6]	[r]97,679	[r]96,952	[r]95,087	[r]100,159	94,660
Ferrosilicon	21,090	21,030	22,730	20,997	[4]20,474
Silicon metal[e]	5,000	5,000	5,000	5,000	5,000
Ferrochromium	28,231	29,018	29,183	[r]29,844	[4]31,866
Other[e 8]	8,000	9,000	10,000	[r]10,000	8,000
Total	160,000	161,000	162,000	166,000	160,000
Dominican Republic: Electric furnace, ferronickel	55,954	81,303	73,363	78,160	[4]71,753
Egypt: Electric furnace, ferrosilicon	7,221	7,702	7,806	[e]7,800	7,800
Finland: Electric furnace, ferrochromium	133,676	143,000	156,000	169,000	165,000
France:					
Blast furnace:					
Ferromanganese	273,602	295,821	323,945	346,295	[4]319,930
Electric furnace:					
Ferromanganese	21,800	23,200	22,000	18,000	18,000
Silicomanganese[9]	27,200	31,200	59,000	[e]59,000	32,000
Ferrosilicon	196,000	155,000	[e]196,000	190,000	180,000
Silicon metal[e]	70,000	70,000	70,000	[r]72,000	70,000
Ferrochromium[e 10]	1,000	1,000	[r]2,000	[r]2,000	2,000
Other[11]	[r]72,000	70,000	60,000	60,000	70,000
Total	[r]661,602	[r]646,221	732,945	[r e]747,295	691,930

See footnotes at end of table.

TABLE 11—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1986	1987	1988	1989[p]	1990[e]
Germany, Federal Republic of:					
Eastern states:					
Electric furnace:					
Ferromanganese[e 6]	68,000	r65,000	r67,000	r67,000	65,000
Ferrosilicon[e]	26,000	r24,000	r25,000	r25,000	24,000
Silicon metal[e]	3,400	r3,000	3,400	r3,000	3,000
Ferrochromium[e]	22,000	r21,000	r22,000	22,000	21,000
Other[e 8]	15,600	r14,000	r13,600	r13,000	12,000
Total	135,000	r127,000	131,000	130,000	125,000
Western states:					
Blast furnace:					
Ferromanganese[e]	187,000	156,000	209,000	r230,000	230,000
Ferrosilicon[e]	69,000	40,000	65,000	r75,000	70,000
Electric furnace:					
Ferromanganese[e 6]	35,000	25,000	35,000	r45,000	30,000
Ferrosilicon[e]	50,000	40,000	50,000	r55,000	40,000
Ferrochromium[e]	60,000	50,000	60,000	r65,000	50,000
Other[e 8]	61,000	57,000	62,000	r66,000	55,000
Total	462,000	368,000	481,000	536,000	475,000
Greece: Electric furnace:					
Ferrochromium	38,260	42,000	44,000	45,000	45,000
Ferronickel	39,700	35,400	50,500	61,900	50,000
Total	77,960	77,400	94,500	106,900	95,000
Hungary: Electric furnace:[e]					
Ferrosilicon	9,000	9,000	10,000	9,000	9,000
Silicon metal	2,000	2,000	2,000	2,000	2,000
Other	2,000	2,000	1,000	1,000	1,000
Total	13,000	13,000	13,000	12,000	12,000
Iceland: Electric furnace, ferrosilicon	66,787	r60,184	70,051	72,008	4 62,791
India: Electric furnace:					
Ferromanganese	r179,910	r173,259	138,331	149,139	160,000
Silicomanganese	24,782	r37,504	52,895	75,469	75,000
Ferrosilicon	50,096	r50,747	46,721	73,751	75,000
Silicon metal	642	r1,445	686	r e800	850
Ferrochromium	r84,096	r93,944	140,262	133,522	145,000
Ferrochromium-silicon	9,493	12,321	2,769	11,384	12,000
Other	617	529	445	386	400
Total	r349,636	r369,749	382,109	r e444,451	468,250
Indonesia: Electric furnace, ferronickel	22,554	8,354	26,852	26,058	4 25,025
Italy:					
Blast furnace ferroalloys:					
Spiegeleisen	1,151	491	251	—	—
Ferromanganese	48,002	19,469	27,169	26,738	4 30,842
Electric furnace:					
Ferromanganese	11,653	17,067	12,280	14,220	14,000
Silicomanganese	66,083	75,192	66,959	46,868	70,000
Ferrosilicon	62,799	47,075	51,131	65,171	65,000
Silicon metal	18,904	16,500	e18,000	e19,000	18,000
Ferrochromium	55,939	59,045	77,123	81,331	81,000
Other[e 12]	4 14,022	14,500	14,500	15,000	14,500
Total[e]	r 4 278,553	r249,339	r267,413	r268,328	293,342

See footnotes at end of table.

TABLE 11—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1986	1987	1988	1989[p]	1990[e]
Japan: Electric furnace:					
Ferromanganese	359,044	332,286	378,351	394,055	[4]452,434
Silicomanganese	148,429	91,896	106,970	122,192	[4]77,465
Ferrosilicon	107,236	73,706	73,767	74,936	[4]62,599
Ferrochromium[10]	280,548	263,988	295,406	324,371	[4]293,345
Ferronickel	200,311	203,143	242,276	275,341	[4]234,311
Other[13]	9,765	8,284	10,293	11,111	[4]12,078
Total	1,105,333	973,303	1,107,063	1,202,006	[4]1,132,232
Korea, North: Furnace type unspecified:[e 7]					
Ferromanganese[6]	70,000	70,000	70,000	70,000	70,000
Ferrosilicon	30,000	30,000	30,000	30,000	30,000
Other[8]	20,000	20,000	20,000	20,000	20,000
Total	120,000	120,000	120,000	120,000	120,000
Korea, Republic of: Electric furnace:					
Ferromanganese	53,721	58,044	75,924	85,329	[4]84,000
Ferrosilicon	30,939	12,646	8,909	4,582	[4]2,000
Other	66,499	90,382	89,966	101,818	[4]99,000
Total	151,159	161,072	174,799	191,729	[4]185,000
Mexico: Electric furnace:					
Ferromanganese	156,359	161,331	165,487	168,042	[4]186,328
Silicomanganese	60,532	80,123	80,223	98,852	[4]52,147
Ferrosilicon	17,650	18,060	16,553	9,474	[4]24,536
Ferrochromium	2,670	6,300	9,295	2,569	[4]275
Other	1,526	852	727	92	[4]250
Total	238,737	266,666	272,285	279,029	[4]263,536
New Caledonia: Electric furnace, ferronickel	130,500	115,600	146,300	142,500	[4]126,500
Norway: Electric furnace:					
Ferromanganese	204,728	191,992	361,345	220,591	[4]213,266
Silicomanganese	245,427	237,277	232,501	270,315	[4]228,310
Ferrosilicon	352,572	336,168	380,976	401,116	[4]397,520
Silicon metal	86,838	81,460	88,854	100,194	[4]76,601
Other[9]	16,162	21,540	[r e]14,000	[r e]14,000	14,000
Total	905,727	868,437	[r e]1,077,676	[r e]1,006,216	929,697
Peru: Electric furnace:					
Ferromanganese	286	1,942	996	[e]1,000	900
Ferrosilicon	453	420	625	[e]600	500
Total	739	2,362	1,621	[e]1,600	1,400
Philippines: Electric furnace:[e]					
Ferrosilicon	20,000	—	([14])	9,000	10,000
Ferrochromium	55,000	([14])	([14])	[r]19,500	22,000
Total	75,000	([14])	([14])	[r]28,500	32,000
Poland:					
Blast furnace:					
Spiegeleisen	1,700	2,500	1,078	906	[4]140
Ferromanganese	[r]95,500	95,300	91,117	90,267	[4]71,000
Electric furnace:					
Ferromanganese[6]	3,700	4,800	4,066	1,427	[4]5,400
Ferrosilicon	78,500	77,100	82,114	83,210	[4]88,600
Silicon metal[e]	10,500	10,000	10,000	10,000	10,000
Ferrochromium	36,200	35,900	36,316	28,222	[4]13,700
Other[e 8]	16,500	16,000	[r]66,000	[4]60,718	[4]33,100
Total[e]	[r]242,600	[r]241,600	[r]290,691	[r]274,750	221,940

See footnotes at end of table.

TABLE 11—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1986	1987	1988	1989[p]	1990[e]
Portugal: Electric furnace:[e]					
Ferromanganese[15]	20,000	[r]17,000	[r]10,000	[4]13,170	12,000
Silicomanganese[15]	10,000	[r]8,000	[r]5,000	—	—
Ferrosilicon	5,000	[r]2,000	—	—	—
Silicon metal	7,000	[r]3,000	[r]2,500	—	—
Other	17	—	—	—	—
Total	[4]42,017	[r]30,000	[r]17,500	[4]13,170	12,000
Romania: Electric furnace:[e]					
Ferromanganese	82,000	81,000	80,000	80,000	80,000
Silicomanganese	40,000	39,000	40,000	40,000	40,000
Ferrosilicon	51,000	50,000	50,000	50,000	50,000
Silicon metal	4,500	4,500	4,500	4,500	4,500
Ferrochromium	44,000	42,000	42,000	42,000	42,000
Total	221,500	216,500	216,500	216,500	216,500
South Africa, Republic of: Furnace type unspecified:[7]					
Ferromanganese	337,213	315,000	447,000	403,000	[4]404,000
Silicomanganese	303,418	314,000	267,000	267,000	[4]279,000
Ferrosilicon	83,256	83,000	116,000	119,000	[4]107,000
Silicon metal	34,954	34,000	39,000	36,000	[4]36,000
Ferrochromium	870,181	951,000	963,000	[r e]1,006,000	992,000
Ferrochromium-silicon	5,000	[r]14,000	11,000	[r e]30,000	30,000
Other[e 16]	1,000	1,000	1,000	1,000	1,000
Total[e]	1,635,022	[r]1,712,000	[r]1,844,000	[r]1,862,000	[4]1,849,000
Spain: Electric furnace:[e]					
Ferromanganese	[r]45,000	[r]50,000	[r]48,000	[r]50,000	52,220
Silicomanganese	[r]35,000	[r]35,000	[r]38,000	[r]40,000	38,440
Ferrosilicon	[r]35,000	[r]40,000	[r]36,000	[r]38,000	37,500
Silicon metal	[r]10,000	[r]11,800	[r]10,700	[r]11,500	9,000
Ferrochromium	[r]14,000	[r]16,000	[r]15,000	[r]16,000	15,100
Other	[r]3,000	5,000	5,000	5,000	5,000
Total	[r]142,000	[r]157,800	[r]152,700	[r]160,500	157,260
Sweden: Electric furnace:					
Ferrosilicon	19,969	19,949	20,622	19,303	20,000
Silicon metal[e]	20,000	20,000	[4]20,000	—	—
Ferrochromium	126,144	111,815	143,055	151,697	150,000
Ferrochromium-silicon	17,024	—	—	—	—
Total[e]	183,137	151,764	[4]183,677	[4]171,000	170,000
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	20,040	17,026	25,822	30,623	[4]43,631
Silicomanganese	20,932	18,944	30,745	26,510	[4]20,587
Ferrosilicon	14,007	4,058	19,601	19,277	[4]15,501
Total	54,979	40,028	76,168	76,410	[4]79,719
Turkey: Electric furnace:					
Ferrosilicon	[e]7,000	4,400	5,200	4,970	5,000
Ferrochromium	[e]50,000	52,530	54,030	59,715	60,000
Total	[e]57,000	56,930	59,230	64,685	65,000

See footnotes at end of table.

TABLE 11—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1986	1987	1988	1989[p]	1990[e]
U.S.S.R.:					
Blast furnace:					
Spiegeleisen	20,000	19,000	18,000	18,000	17,000
Ferromanganese	601,000	593,000	604,000	609,000	600,000
Ferrophosphorus	26,000	25,000	25,000	29,000	25,000
Electric furnace:[e 17]					
Ferromanganese	r436,800	r437,800	r453,500	r414,100	410,000
Silicomanganese	200,000	200,000	200,000	200,000	200,000
Ferrosilicon	r1,831,600	r1,867,400	r1,911,800	r1,872,600	1,860,000
Silicon metal	65,000	65,000	65,000	65,000	65,000
Ferrochromium	r798,400	r806,200	r925,400	r860,800	850,000
Ferrochromium-silicon	13,000	13,500	14,000	14,000	14,000
Ferronickel	90,000	90,000	90,000	90,000	90,000
Other[11]	150,000	150,000	160,000	160,000	160,000
Total[e]	r4,231,800	r4,266,900	r4,466,700	r4,332,500	4,291,000
United Kingdom:					
Blast furnace, ferromanganese	100,000	92,400	107,300	e100,000	100,000
Electric furnace, undistributed[e]	10,000	10,000	10,000	10,000	10,000
Total[e]	110,000	102,400	117,300	110,000	110,000
United States: Electric furnace:[18]					
Ferromanganese[19]	106,475	102,462	W	W	W
Ferrosilicon	307,936	324,097	449,328	475,256	4433,726
Silicon metal	112,394	135,559	149,094	136,531	4140,792
Ferrochromium[20]	95,624	106,716	W	W	W
Other[21]	118,166	68,822	347,668	318,663	4300,175
Total	740,595	737,656	946,090	930,450	4874,693
Uruguay: Electric furnace, ferrosilicon[e]	250	250	250	250	250
Venezuela: Electric furnace:					
Silicomanganese	28,573	28,000	33,760	e30,000	30,000
Ferrosilicon	50,743	52,188	51,363	e55,000	55,000
Total	79,316	80,188	85,123	e85,000	85,000
Yugoslavia: Electric furnace:					
Ferromanganese	40,051	38,041	45,078	33,869	40,000
Silicomanganese	41,330	42,528	46,804	52,737	45,000
Ferrosilicon	99,574	98,843	120,522	122,153	110,000
Silicon metal	31,312	31,915	25,830	15,897	20,000
Ferrochromium	68,604	56,276	93,349	90,429	80,000
Ferrochromium-silicon	7,513	6,240	3,688	3,815	2,000
Ferronickel	8,647	9,556	15,047	17,102	10,000
Calcium silicon	(13)	487	772	1,099	1,000
Other	6,715	7,584	10,678	10,100	10,000
Total	303,746	291,470	361,768	347,201	4318,000
Zimbabwe: Electric furnace:					
Ferromanganese	8,029	r8,500	e2,000	—	—
Ferrochromium	187,454	r186,947	224,000	173,000	170,000
Ferrochromium-silicon	52,298	r21,000	29,000	25,000	25,000
Total	247,781	r216,447	r e255,000	198,000	195,000
Grand total	r16,563,199	r16,567,183	18,422,349	18,861,500	18,299,435
Of which:					
Blast furnace:					
Spiegeleisen[22]	r22,851	r21,991	19,329	18,906	17,140
Ferromanganese[22 23]	r1,305,104	r1,251,990	1,362,531	1,402,300	1,351,772

See footnotes at end of table.

TABLE 11—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1986	1987	1988	1989[p]	1990[e]
Of which:—Continued					
Blast furnace:					
Ferrosilicon	69,000	40,000	65,000	75,000	70,000
Ferrophosphorus	26,000	25,000	25,000	29,000	25,000
Total blast furnace	r1,422,955	r1,338,981	1,471,860	1,525,206	1,463,912
Electric furnace:[7]					
Ferromanganese[24 25]	r2,444,427	r2,422,974	2,572,491	2,469,187	2,527,630
Silicomanganese[24]	r1,466,957	r1,482,663	1,509,638	1,599,242	1,471,964
Ferrosilicon	r4,462,633	r4,485,829	5,070,698	5,254,569	5,073,214
Silicon metal	r605,221	r626,061	680,151	725,201	737,357
Ferrochromium[26]	r3,207,419	r3,226,073	3,507,443	3,482,267	3,360,039
Ferrochromium-silicon	r113,840	r75,140	69,634	93,137	87,973
Ferronickel	r627,462	r625,241	719,940	767,512	685,693
Calcium-silicon	([13])	487	772	1,099	1,000
Other[27]	r1,316,672	r1,371,434	1,777,722	1,896,080	1,844,653
Undistributed	22,000	r17,000	30,000	25,000	22,000
Total electric furnace	r14,266,631	r14,332,902	15,938,489	16,313,294	15,811,523
Furnace type unspecified:					
Ferromanganese[7]	r873,613	r895,300	1,012,000	1,023,000	1,024,000

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

[1]Table includes data available through June 21, 1991.

[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." For countries for which one or more of the individual ferroalloys listed separately in this footnote have been inseparable from some other ferroalloys owing to the nation's reporting system, such deviations are indicted by individual footnotes. In instances where ferroalloy production has not been subdivided in sources, and where no basis is available for estimation of individual component ferroalloys, the entry has been reported as "Undistributed."

[4]Reported figure.

[5]Data for year ending Nov. 30 for 1986; calendar years thereafter.

[6]Includes silicomanganese.

[7]Although furnace type has not been specified for any ferroalloy production for China, North Korea, and the Republic of South Africa, all electric furnace (and metallothermic) output of these countries has been included under electric furnace (and metallothermic) output except for their production of ferromanganese, which is reported separately below.

[8]Includes ferrochromium-silicon and ferronickel, if any was produced.

[9]Includes silicospiegeleisen.

[10]Includes ferrochromium-silicon, if any was produced.

[11]Includes ferronickel, if any was produced.

[12]Series excludes calcium silicide.

[13]Includes calcium-silicon, ferrotungsten, ferromolybdenum, ferrovanadium, ferrocolumbium, and other ferroalloys.

[14]Revised to zero.

[15]Estimated figures based on reported exports and an allowance for domestic use.

[16]Ferrovanadium only; other minor ferroalloys may be produced, but no basis is available for estimation.

[17]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.

[18]U.S. production of ferronickel cannot be reported separately in order to conceal corporate proprietary information.

[19]U.S. output of ferromanganese includes silicomanganese and manganese metal.

[20]U.S. output of ferrochromium includes ferrochromium-silicon, chromium briquets, exothermic chromium additives, other miscellaneous chromium alloys, and chromium metal.

[21]Includes ferronickel.

[22]Spiegeleisen for the Western states of the Federal Republic of Germany is included with blast furnace ferromanganese.

[23]Includes silicospiegeleisen for France.

[24]Ferromanganese includes silicomanganese (if any was produced) for countries carrying footnote 6 on "Ferromanganese" data line.

[25]U.S. production under "Other" for 1988-90.

[26]Ferrochromium includes ferrochromium-silicon (if any was produced) for countries carrying footnote 8 on "Ferrochromium" data line.

[27]Includes ferronickel production for France, Norway, and the United States.

OUTLOOK

In recent years, a shift of production from major ferroalloy-consuming countries to countries that possess significant ore reserves and low-cost electric power has occurred. For example, a number of expansions and new operations have been underway in chromite-producing countries (e.g., Finland, the Philippines, Republic of South Africa, Turkey, and Zimbabwe). Some of the projects came online in 1989 and 1990, increasing world ferrochromium capacity by more than 10% to 15%. Further ferrochromium capacity expansion, another 10% to 15%, is expected over the next several years. It is expected that this trend will continue in the future, not only for chromium-containing ferroalloys, but for those of man-

ganese and silicon as well, as more traditional producers of ferroalloys (i.e., countries with well-established steel industries such as the United States and Japan) continue to decrease ferroalloy production capacity.

In most cases, consumption of chromium, columbium, manganese, molybdenum, nickel, silicon, vanadium, and the rare-earths as ferroalloys relates either directly or indirectly to the production of iron and steel. Demand forecasts for steel and the major ferroalloy elements are given in the individual commodity annual reports.

[1]Unless otherwise specified, the unit of weight in the report is the metric ton of 1,000 kilograms.
[2]Metal Bulletin (London). No. 7530, Nov. 5, 1990, p. 13.
[3]———. No. 7529, Nov. 1, 1990, p. 9.
[4]Metals Week. V. 61, No. 36, Sept. 10, 1990, p. 1.
[5]Metal Bulletin (London). No. 7509, Aug. 20, 1990, p. 11.
[6]Metals Week. V. 61, No. 35, Sept. 3, 1990, p. 1.
[7]Metal Bulletin (London). No. 7499, July 16, 1990, p. 15.
[8]Metals Week. V. 61, No. 51, Dec. 24, 1990, p. 6.
[9]American Metal Market. V. 98, No. 212, Oct. 30, 1990, p. 16.
[10]Metal Bulletin (London). No. 7475, Apr. 19, 1990, p. 26.
[11]———. No. 7489, June 11, 1990, p. 27.
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[12]Metals Week. V. 61, No. 31, Aug. 6, 1990, p. 2.
[13]———. V. 61, No. 48, Dec. 3, 1990, p. 6.
[14]Metal Bulletin (London). No. 7496, July 5, 1990, p. 11.
[15]Metals Week. V. 61, No. 6, Feb. 5, 1990.
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[16]Metals Week. V. 61, No. 39, Oct. 1, 1990, p. 10.
[17]———. V. 61, No. 40, Oct. 8, 1990, p. 6.
[18]Metal Bulletin (London). No. 7508, Aug. 16, 1990, p. 11.
[19]———. No. 7539, Dec. 6, 1990, p. 11.
[20]———. No. 7523, Oct. 11, 1990, p. 11.
[21]American Metal Market. V. 98, No. 78, Apr. 20, 1990, p. 4.
[22]Page 1 of work cited in footnote 12.
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[23]Metal Bulletin (London). No. 7494, June 28, 1990, p. 13.
[24]Metals Week. V. 61, No. 1, Jan. 1, 1990, p. 1.
[25]Metal Bulletin (London). No. 7471, Apr. 2, 1990, p. 13.
[26]———. No. 7513, Sept. 6, 1990, p. 13.
[27]———. No. 7532, Nov. 12, 1990, p. 13.
[28]Metal Bulletin. Monthly (London). Aug. 1990, pp. 8-13.
[29]Metal Bulletin (London). No. 7519, Sept. 27, 1990, p. 11.
[30]———. No. 7468, Mar. 22, 1990, p. 11.
[31]———. No. 7515, Sept. 13, 1990, p. 33.
[32]———. Work cited in footnote 20.
[33]———. No. 7461, Feb. 26, 1990, p. 19.
[34]———. No. 7514, Sept. 10, 1990, p. 29.
———. No. 7528, Oct. 29, 1990, p. 31.

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FLUORSPAR

By M. Michael Miller

Mr. Miller, a physical scientist with 13 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 Gail D. Mason, mineral data assistant; and international data tables were prepared by Harold Willis, international data assistant.

In the United States, one major producer and two small producers supplied about 11% of the Nation's fluorspar requirements. Supplementing fluorspar as a domestic source of fluorine was byproduct fluosilicic acid production from some phosphoric acid producers. Imports of fluorspar, which continued to supply most of the U.S. requirements, decreased by about 23% compared with those of 1989. Hydrofluoric acid (HF) imports were about 10% lower than reported in the previous year.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for fluorspar were developed by the U.S. Bureau of Mines from voluntary surveys of U.S. operations. Surveys were conducted to obtain fluorspar mine production and shipments and fluosilicic acid production. Of the five fluorspar mining operations to which a survey request was sent, three responded, representing more than 95% of domestic shipments. Shipments for the two nonrespondents was estimated using data from contacts within the industry. Production statistics in table 1 are withheld to protect company proprietary data. Of the seven fluosilicic acid producers surveyed, seven responded, representing 100% of the quantity reported. The consumption survey was sent to approximately 93 operations quarterly and to 40 additional operations annually. Of the operations surveyed quarterly, 60% responded. Of the operations surveyed on an annual basis, 68% responded. Together, quarterly and annual responses represented 96% of the apparent consumption data shown in table 1.

BACKGROUND

Definitions, Grades, and Specifications

Technically, pure fluorspar, or the mineral fluorite, contains 51.1% calcium and 48.9% fluorine. Natural fluorite is commonly associated with other minerals such as quartz, barite, calcite, galena, siderite, celestite, sphalerite, chalcopyrite, other sulfides, and phosphates. It occurs in well-formed isometric crystals, in massive and earthy forms, and as crusts or globular aggregates with radial fibrous

TABLE 1

SALIENT FLUORSPAR STATISTICS[1]

		1986	1987	1988	1989	1990
United States:						
Production:						
Finished (shipments)[e]	metric tons	70,800	63,500	63,500	66,000	63,500
Value f.o.b. mine	thousands	W	W	W	W	W
Exports	metric tons	14,710	2,595	3,136	5,134	14,921
Value	thousands	$1,634	$308	$346	$694	$1,891
Imports for consumption	metric tons	501,478	531,530	689,139	655,590	513,921
Value[2]	thousands	$41,436	$43,935	$62,748	r$79,897	$65,938
Consumption (reported)	metric tons	525,112	542,830	r651,055	641,882	564,545
Consumption (apparent)[3]	do.	518,264	643,659	723,804	r693,121	586,856
Stocks, Dec. 31:						
Domestic mines:						
Finished	do.	W	W	W	W	W
Consumer	do.	81,531	30,310	56,012	79,347	54,991
World: Production	do.	r4,849,710	r4,816,572	r5,206,605	r5,585,712	e5,106,632

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Does not include fluosilicic acid (H_2SiF_6) or imports of hydrofluoric acid (HF) and cryolite.
[2]C.i.f. U.S. port.
[3]U.S. primary and secondary production plus imports, minus exports, plus adjustments for Government and industry stock changes.

texture. In crystalline form, it can be colorless or may exhibit a wide range of colors, including yellow, blue, purple, green, rose, red, bluish and purplish black, and brown. It has a hardness of 4 on the Mohs' scale, a specific gravity ranging from 3.01 to 3.60, and a melting point of 1,378° C.

Three principal grades of fluorspar are available commercially: acid, ceramic, and metallurgical. Although the specifications for individual grades are generally well defined, some variation is permitted to satisfy the requirements of individual consumers.

In the United States, acid-grade fluorspar (acidspar) contains at least 97% CaF_2. Some manufacturers of hydrofluoric acid in the United States and Europe can use 96% CaF_2 or slightly lower if the remaining impurities are acceptable. User specifications may impose limits on silica, calcium carbonate, sulfide or free sulfur, calcite, beryllium, arsenic, lead, phosphates, and other constituents. Moisture content of the dried material is preferably 0.1% or less. Particle size and distribution are sometimes specified for proper control of the rate of chemical reaction and stack losses. Very few reserves in the world can be used to produce acid-grade fluorspar without flotation processing.

Ceramic-grade fluorspar is generally marketed as No. 1 ceramic, containing 95% to 96% CaF_2, and No. 2 ceramic, containing 85% to 90% CaF_2. An intermediate grade of about 93% to 94% CaF_2 is also available. Specifications on impurities vary, but may allow a maximum of 2.5% to 3.0% silica, 1.0% to 1.5% calcite, 0.12% ferric oxide, and trace quantities of lead and zinc. Shipments of ceramic-spar are usually tailored to the specific need of individual consumers.

Metallurgical-grade fluorspar (metspar) contains a minimum of 60% effective CaF_2. In the United States, metspar is usually quoted in terms of effective CaF_2 units, obtained by subtracting 2.5 times the silica content of the ore from its total CaF_2 content. The term "metspar" is usually used to refer to material with a maximum CaF_2 content of 85%, but sometimes is used for material as high as 96%, which includes what is technically ceramic grade. Other countries may require a minimum of 80% CaF_2, which allows larger quantities of silica, usually a maximum of 15%, and other contaminants. Metspar is often traded as a lump or gravel that must pass a 25- to 37.5-millimeter screen (1 to 1 1/2 inch) and contain less than 15% of material passing a 1.6-millimeter screen (1/16 inch).

In the domestic steel industry, various shapes and sizes of briquets or pellets are being used. Generally made to consumer specifications, briquets contain varying quantities of fluorspar mixed with binders, fillers, and fluxing agents. Typically made on roll presses and ranging in size from that of a peach seed to a 5-centimeter square, briquets contain 25% to 90% 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.

Identified world fluorspar resources are approximately 365 million metric tons of contained fluorspar. As might be expected, the countries with the highest production have the largest fluorspar reserves, although their production ranking does not necessarily mirror their reserve ranking. World resources of equivalent fluorspar from phosphate rock are approximately 325 million metric tons, which includes about 32 million metric tons from domestic phosphate rock.

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 then moves underground.

Narrow vein mining is often done by shrinkage stoping and open stoping where strong walls occur, while stratiform or

TABLE 2

WORLD FLUORSPAR RESERVES AND RESERVE BASE[1]

(Thousand metric tons contained CaF_2, 100% equivalent)

Country	Reserves[2]	Reserve base[3]
North America:		
Canada	2,000	5,000
Mexico	19,000	23,000
United States	W	10,000
Total	21,000	38,000
Europe:		
France	10,000	14,000
Italy	6,000	7,000
Spain	6,000	8,000
U.S.S.R.[e]	62,000	94,000
United Kingdom	2,000	3,000
Total	86,000	126,000
Africa:		
Kenya	2,000	3,000
Namibia	3,000	5,000
South Africa, Republic of	30,000	36,000
Total	35,000	44,000
Asia:		
China[e]	27,000	46,000
Mongolia[e]	50,000	59,000
Thailand	1,000	2,000
Total	78,000	107,000
Other countries	19,000	25,000
World total	239,000	340,000

[e]Estimated. W Withheld to avoid disclosing company proprietary data.
[1]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 annual, U.S. Bureau of Mines, Mineral Commodity Summaries.
[2]Recoverable CaF_2 at the demonstrated level (measured plus indicated).
[3]The reserve base includes demonstrated resources, reported in terms of 100% CaF_2, that are currently economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

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 also used prior to flotation to remove clay or manganese oxides (wad).

Ceramic and acid grades of fluorspar are produced by multistage froth flotation. Ore from the mine is crushed and ground to proper size; care is taken not to over grind and cause fluorspar to be lost in the slimes. If lead and zinc sulfides are present, they are preferentially floated off with xanthate collector. After this process is completed, all the easy floating fluorspar is removed in a quick pass through a flotation circuit and sent on to the cleaner circuit. The tailings are discarded. The middling product is reground to separate the more finely interlocked grains of fluorspar and gangue and passed through one or more cleaner circuits. The final products generally comprise an acid-grade concentrate and, in some cases, one or more concentrates of lower grade, which are sold as ceramic grade, or pelletized and sold as metallurgical grade. Fatty acids are used as collectors for the fluorspar. Quebracho or tannin is used to depress calcite and dolomite; sodium silicate is used to depress iron oxides and silica; and chromates, starch, and dextrin are used to depress barite. Cyanide is used to depress any remaining sulfides. Lime, caustic, or soda ash can be used for acidity control. Flotation temperatures range from ambient to 80° C.

ANNUAL REVIEW

Legislation and Government Programs

At yearend, the National Defense Stockpile fluorspar inventory was unchanged from yearend 1989. New goals were finalized in 1990 of 900,000 short dry tons (about 816,000 metric tons) for acid grade and 310,000 short dry tons (about 281,000 metric tons) for metallurgical grade.

The Defense Logistics Agency, Defense National Stockpile Center, announced the offering for sale of a portion of the 15,000 short dry tons (13,608 metric tons) of metallurgical-grade fluorspar authorized

for disposal during fiscal years 1990 and 1991. Sale was authorized of 5,000 short dry tons (4,536 metric tons) for fiscal year 1990 and 10,000 short dry tons (9,072 metric tons) for fiscal year 1991. No bids were received during calendar year 1990. Additional offerings were scheduled for May, July, and September 1991. The material offered is stockpiled near Gallup, NM. It is of nonstockpile grade and has an effective calcium fluoride content of 59%.

Depletion allowances against Federal taxes of 22% and 14%, respectively, remained in effect for domestic and foreign production by U.S. companies.

On November 28, 1990, the Illinois Wilderness Act of 1990 was signed into Federal law. The law designated seven tracts in the Shawnee National Forest in southern Illinois as wilderness and, therefore, components of the National Wilderness Preservation System. The 7 tracts total about 10,630 hectares (26,266 acres). The boundaries of the Shawnee National Forest encompass a substantial portion of the Illinois-Kentucky fluorspar district, including the operations of Ozark-Mahoning Co. The law designated 2 additional tracts totaling about 1,119 hectares (2,764 acres) as special management areas. Within these two areas, prospecting for fluorspar and associated minerals may be allowed for a period of not more than 8 years from the enactment date. If fluorspar and associated minerals are found on these lands, mining may be allowed for a 20-year period from the date of enactment. If no prospecting or mining takes place during the allotted time periods, these special management areas will be designated as wilderness and become components of the National Wilderness Preservation System.[3]

On November 15, 1990, the Clean Air Act Amendments of 1990 were enacted into law. Title VI covered stratospheric ozone protection. Chemicals damaging to stratospheric ozone were listed as class I and class II substances. Class I substances were separated into five groups, which include the following three groups containing fluorine: group I—chlorofluorocarbons (CFC's) 11, 12, and 113-115; group II—halons 1211, 1301, and 2402; and group III—CFC's 13, 111, 112, and 211-217. Class II substances consisted of hydrochlorofluorocarbons (HCFC's).

Production phaseout schedules were established for all class I substances limiting production to a percentage of that produced by the individual in the designated baseline year. The baseline year for groups I and II was 1986, and for group III it was 1989. Notwithstanding the scheduled termination of production, limited production and consumption of CFC 114 and the halons may be authorized for national security, aviation safety, fire suppression, and explosion prevention, if it is determined that no safe and effective substitute has been found.

TABLE 3

CFC PRODUCTION PHASEOUT

Year	Production limit[1]
1991	85%
1992	80%
1993	75%
1994	65%
1995	50%
1996	40%
1997	15%
1998	15%
1999	15%
2000	—

[1]Percentage of baseline year 1986 or 1989.

Although a specific phaseout schedule has not been established for class II substances, the law does state that as of January 1, 2015, production of all class II substances are limited to a percentage of that produced by the individual in an as yet to be selected baseline year. Effective January 1, 2030, it shall be unlawful for any person to produce any class II substance. The Environmental Protection Agency has until December 31, 1999, to promulgate regulations phasing out production and restricting the use of class II substances.

The phaseout schedules for both class I and class II substances can be accelerated if new scientific evidence warrants it, the availability of substitutes makes it practical, or the Montreal Protocol on Substances that Deplete the Ozone Layer is modified to include a phaseout schedule more accelerated than the one under this law.[4]

Issues

HF is used as a catalyst to convert low-molecular-weight byproduct hydrocarbons into larger hydrocarbons, such as 2,2,4-trimethylpentane. The resulting compound is called alkylate, and the process is called petroleum alkylation. Alkylate is a prime blending compound for high-octane gasoline.

The use of HF acid for petroleum alkylation and CFC refrigerant production in populated areas has come under intense scrutiny. Accidental releases of HF during transport have heightened the public's awareness of the potential danger from a major accident. The perceived danger from an accidental release of HF acid resulted in an out-of-court settlement between Torrance, CA, and Mobil Oil to end Mobil's use of HF at their refinery in Torrance by 1997. In a similar issue, the Southern Coast Air Quality Management District, the air regulatory panel for the four county Los Angeles area, voted on April 4, 1991, to ban HF use by refiners by the end of 1997 and by refrigerant manufacturers by the end of 1998. Interim controls are scheduled to go into effect January 1, 1992. The ban will take effect unless an additive is developed to prevent the formation of toxic vapor clouds. Four petroleum refineries and one refrigerant plant were impacted by the decision.[5]

The California bans have impacted primarily the petroleum refining industry. HF is used in about one-half of U.S. refineries. The alternative to HF in the alkylation process is sulfuric acid. The American Petroleum Institute estimated that, based on the average cost of a typical alkylation unit, it would cost about $4 billion to replace all existing HF alkylation units with sulfuric acid units. Switching from an HF process to a sulfuric acid process would most likely require construction of new alkylation units. Because most of the equipment used in the two processes is not interchangeable, conversion of an existing unit would require shutting down the unit for several months and special chemical cleaning of the few pieces of reusable equipment. Also, the space required for the new equipment would be difficult to find on the existing alkylation unit site. For these reasons, most refiners would decide to construct new alkylation units elsewhere in the refinery rather than convert the existing unit.[6]

If a ban or severe restrictions on usage were to spread throughout the United States, it would have a major economic impact on other industries that depend on HF as a feedstock or as a necessary

processing chemical. These would include the fluorochemical, aluminum, stainless steel, and uranium chemical industries.

Production

Illinois remained the leading producing State, accounting for about 95% of all 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 Atochem North America Inc., operated three mines and a flotation plant in Pope and Hardin Counties, IL. Ozark-Mahoning also dried imported fluorspar to supplement its production. Seaforth Mineral & Ore Co. Inc. dried imported fluorspar at its facilities at Cave-In-Rock, IL, and East Liverpool, OH, for sale primarily to consumers in the ceramic industry. H. & H. Equipment and Engineering Co. produced and shipped metallurgical-grade fluorspar from its mine in Juab County, UT. J. Irving Crowell, Jr., & Son shipped a small amount of metallurgical-grade fluorspar from its Crowell-Daisy Mine in Nye County, NV.

Ozark-Mahoning reestablished production from the former Inverness Mining Co. Minerva #1 Mine. Overall, Ozark-Mahoning's production was evenly divided between the Minerva #1, Annabell Lee, and Denton Mines.

Seven plants processing phosphate rock for the production of phosphoric acid sold a reported 46,754 metric tons of byproduct fluosilicic acid at a value of about $5,855,000. This was equal to 82,287 metric tons of 92% fluorspar equivalent.

Reported and estimated production of fluorspar briquets for use in steel furnaces totaled about 108,000 metric tons valued at $10,700,000. Fluorspar briquets were produced by two plants owned by Cametco Inc., one plant owned by National Briquetting Co., one plant owned by Oglebay Norton Co., and one plant owned by Mercier Corp. The Mercier plant went out of business in 1990. Oglebay Norton also dried, packaged, and shipped imported ceramic- and acid-grade fluorspar.

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.

Reported domestic consumption by the HF industry decreased by about 18%. Reported consumption by the steel industry increased by about 5%, although the increase may have been simply the result of more accurate reporting. According to the American Iron and Steel Institute, domestic production of raw steel in 1990 remained essentially unchanged from 1989 levels.

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 glass fibers, aluminum, cement, and brick, and was also used in the melt shop by the foundry industry.

Three companies reported fluorspar consumption for the production of HF. The U.S. Department of Commerce, Bureau of the Census, reported that, based on their monthly survey, anhydrous, technical, and aqueous HF, 100% basis, "produced and withdrawn from the system," was an estimated 136,000 metric tons for 1990 compared with the 1989 quantity of about 177,000 metric 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. According to preliminary data from the U.S. International Trade Commission, production of trichlorofluoromethane (CFC-11) decreased by 30% to 61,277 metric tons, dichlorodifluoromethane (CFC-12) decreased by about 47% to 94,586 metric tons, and chlorodifluoromethane (HCFC-22) decreased by about 6% to 138,830 metric tons, compared with 1989 figures.

As a consequence of the passage of the Clean Air Act Amendments, CFC-11 and CFC-12 production will be phased out during the next 10 years and may be phased out even sooner as discussed previously. Because HCFC-22 is not a fully halogenated CFC and has a much lower ozone-depletion potential, it was classified as a class II substance and will be phased out at a later date. The chemical industry continued to pursue research into replacement compounds for the CFC's and HCFC's that are to be phased out. Construction continued on commercial plants to manufacture some of the most promising replacements. The CFC producers are developing substitutes called hydrochlorofluorocarbons (HCFC's) that have ozone-depletion potentials of about 5% that of CFC-11, CFC-12, and CFC-113, which in total account for more than 90% of CFC consumption. Other substitutes, called hydrofluorocarbons (HFC's), have no ozone-depletion potential because they contain no chlorine atoms. The most likely candidates to replace controlled CFC's are HCFC-22, for use in home air-conditioning and plastic foams; HCFC-123, a potential substitute for CFC-11 in plastic foams and refrigeration; HFC-134a, a potential substitute for CFC-12 in refrigeration and auto air conditioners; and HCFC-141b, a potential substitute for CFC-11 in plastic foams. In addition, some of the replacements will be mixtures of these compounds and other HCFC's and HFC's. Only HCFC-22 is currently in commercial use. Inhalation and toxicity tests continued on the various replacements.

The manufacture of synthetic cryolite and aluminum fluoride for use in aluminum reduction cells was a major use of HF. In the Hall-Héroult process, alumina is dissolved in a bath of molten cryolite, aluminum fluoride, and fluorspar to allow electrolytic recovery of aluminum. An estimated 20 to 30 kilograms of fluorine was consumed for each metric ton of aluminum produced. Aluminum fluoride was used by the ceramic industry for some body and glaze mixtures and in the production of specialty refractory products. It was used in the manufacture of aluminum silicates and in the glass industry as a filler.

HF was consumed in the manufacture of uranium tetrafluoride that was used in the process of concentrating uranium isotope 235 for use as nuclear fuel and in fission explosives. It was also used in stainless steel pickling, petroleum alkylation, glass etching, oil and gas well treatment, and as a cleaner and etcher in the electronics industry. It was used as the feedstock in the manufacture of a host of fluorine chemicals used in dielectrics, metallurgy, wood preservatives, herbicides, mouthwashes, decay-preventing dentifrices, plastics, and water fluoridation.

Fluosilicic acid was used primarily in

TABLE 4

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	
	1989	1990	1989	1990	1989	1990
Hydrofluoric acid (HF)	397,423	324,275	—	—	397,423	324,275
Iron and steel (foundries)	—	—	4,534	3,336	4,534	3,336
Open-hearth furnaces	W	—	24,528	19,993	24,528	19,993
Basic oxygen furnaces	—	—	74,356	83,142	74,356	83,142
Electric furnaces	1,635	2,013	32,778	36,786	34,413	38,799
Other[1]	W	W	W	W	106,628	[e]95,000
Total	W	W	W	W	641,882	564,545
Stocks, Dec. 31 (consumer)	47,703	20,652	8,309	34,339	79,347	54,991

[e]Estimated. W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Includes glass and fiberglass, enamel, welding rod coatings, primary aluminum, primary magnesium, other chemical products, other ceramic products, and other primary metals.

water fluoridation, either directly or after processing to sodium silicofluoride, and to make aluminum fluoride for the aluminum industry.

Stocks

Fluorspar consumer stocks decreased substantially from the previous year. Consumer stocks were 54,991 metric tons, down 31% from the level reported in 1989. Government stockpiles of fluorspar remained unchanged and contained a reported 891,957 short dry tons (809,171 metric tons) of acid grade and 294,045 short dry tons (266,753 metric tons) of metallurgical grade. The Government stockpiles also include 899 short dry tons (816 metric tons) of nonstockpile, acid-grade material and 116,777 short dry tons (105,938 metric tons) of nonstockpile, metallurgical-grade material. The Defense Logistics Agency attempted unsuccessfully to sell some of the latter in 1990.

Prices

According to prices published by Industrial Minerals (Metal Bulletin PLC), the price of domestic acid-grade fluorspar increased by about $5 per metric ton. Published foreign producer prices at yearend were essentially unchanged compared with 1989 prices. Although not published in 1990, prices for Chinese fluorspar were reported to be 20% to 30% below the published 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) and for synthetic cryolite was unchanged at $550 per short ton (about $606 per metric ton).

Foreign Trade

According to the Bureau of the Census, U.S. exports of fluorspar increased by 191% and had an average value of $127 per metric ton. More than 11,000 metric tons were exported to Canada, which received 76% of U.S. fluorspar exports.

Imports for consumption of fluorspar decreased by about 22%, with Mexico remaining the most important supplier, followed by, in descending order of the quantity imported, China, the Republic of South Africa, Canada, Morocco, and Kenya. The average unit value, in dollars per metric ton, was $135 for acid grade and about $102 for subacid grade.

U.S. import duties underwent major changes in 1990. Presidential Proclamation 6123 of April 26, 1990, made acid-grade fluorspar from Mexico eligible for preferential tariff treatment under the Generalized System of Preferences, pursuant to Title V of the Trade Act of 1974,

TABLE 5

PRICES OF DOMESTIC AND IMPORTED FLUORSPAR

(Dollars per metric ton)

	1989	1990
Domestic, f.o.b., Illinois district, bulk, acid-grade	185–191	190–195
Mexican, f.o.b., Tampico:		
Acid-grade, filtercake	130–135	135
Metallurgical-grade	90	90– 95
South African, f.o.b., Durban, acid-grade, dry basis	130–140	130–140

Source: Industrial Minerals (Metal Bulletin PLC), No. 268, Jan. 1990, p. 66 and No. 280, Jan. 1991, p. 66.

TABLE 6

U.S. EXPORTS OF FLUORSPAR, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Australia	208	$22,961	72	$12,662
Canada	4,317	546,944	11,354	1,385,153
Colombia	—	—	55	6,200
Dominican Republic	190	34,886	637	155,398
Ghana	57	14,670	—	—
India	28	37,600	—	—
Indonesia	43	4,706	—	—
Israel	—	—	254	27,983
Mexico	261	28,695	814	104,215
Taiwan	—	—	539	59,290
United Kingdom	—	—	545	60,099
Venezuela	30	3,900	651	79,666
Total	5,134	694,362	14,921	1,890,666

Source: Bureau of the Census.

as amended. Effective July 1, 1990, this material was exempted from duty upon entering the United States. The preferential tariff treatment applies as long as Mexico's share of the import market does not exceed 50% or $89.9 million.[7] Effective on August 20, 1990, the 13.5% ad valorem tariff on imports of all metallurgical-grade fluorspar was suspended through December 31, 1992. The suspension was provided for in Public Law 101-382, Customs and Trade Act of 1990, Title III, Part 1, Section 450F, signed into law August 20, 1990.[8]

Imports for consumption of HF decreased about 11% to a quantity equivalent to approximately 153,000 metric tons of fluorspar. Imports of synthetic and natural cryolite decreased 11% to a quantity equivalent to approximately 8,800 metric tons of fluorspar. Imports of aluminum fluoride decreased about 22% to a quantity equivalent to approximately 54,000 metric tons of fluorspar.

TABLE 7

U.S. IMPORTS OF FLUORSPAR, BY COUNTRY AND CUSTOMS DISTRICT

Country and customs district	1989		1990	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
CONTAINING MORE THAN 97% CALCIUM FLUORIDE (CaF_2)				
Brazil: Houston	—	—	5,433	$354
Canada:				
Houston	17,737	$2,152	6,360	753
New Orleans	20,975	3,067	15,777	2,433
Total	38,712	5,219	22,137	3,186
China:				
Houston	68,051	7,912	57,791	7,524
Laredo	6,402	736	—	—
New Orleans	84,853	10,492	67,397	8,920
Portland	—	—	2	6
Total	159,306	19,140	125,190	16,450
France:				
New York	18	7	54	51
Philadelphia	—	—	90	41
Total	18	7	144	92
Germany, Federal Republic of:				
Wilmington	1	11	6	12
Kenya: Houston	4,830	579	8,800	1,234
Mexico:				
Buffalo	—	—	949	106
El Paso	r64,658	r6,674	46,895	5,793

See footnotes at end of table.

TABLE 7—Continued

U.S. IMPORTS OF FLUORSPAR, BY COUNTRY AND CUSTOMS DISTRICT

Country and customs district	1989		1990	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
CONTAINING MORE THAN 97% CALCIUM FLUORIDE (CaF_2)—Continued				
Mexico—Continued				
Houston	34,115	3, 731	17,581	2,259
Laredo	64,165	7,799	63,306	8,386
New Orleans	20,853	2,585	13,531	1,609
Philadelphia	612	64	—	—
San Diego	—	—	702	79
Total	184,403	20,853	142,964	18,232
Morocco: New Orleans	38,145	5,430	10,950	e1,533
Namibia: Houston	—	—	4,229	422
South Africa, Republic of:				
Houston	10,382	1,453	—	—
New Orleans	106,909	15,914	86,660	13,516
Total	117,291	17,367	86,660	13,516
Spain: New Orleans	11,097	1,791	—	—
Grand total	553,803	70,397	406,513	55,031
CONTAINING NOT MORE THAN 97% CALCIUM FLUORIDE (CaF_2)				
Canada:				
Detroit	—	—	34	4
Seattle	160	23	—	—
Total	160	23	34	4
China: New Orleans	2,860	243	28,088	2,518
Mexico:				
Baltimore	12,616	1,331	5,699	641
Buffalo	—	—	325	30
Detroit	—	—	34	3
El Paso	r5,894	r385	17,153	1,171
Houston	72	4	—	—
Laredo	8,381	579	683	65
New Orleans	71,519	6,890	41,265	4,529
Philadelphia	—	—	5,757	541
Seattle	285	45	90	158
Total	98,767	r9,234	71,006	7,138
South Africa, Republic of: New Orleans	—	—	8,280	1,247
Grand total	101,787	r9,500	107,408	10,907

eEstimated. rRevised.
[1]C.i.f. value at U.S. port.

Source: Bureau of the Census.

An application was submitted to the Foreign Trade Zones Board, Department of Commerce, requesting a special-purpose subzone status for the alumina and aluminum fluoride manufacturing plant of the Aluminum Co. of America (Alcoa) in Calhoun County, TX, adjacent to the Point Comfort Customs point of entry. Zone procedures would exempt Alcoa from customs duty payments on foreign material used in its exports. On domestic sales, the company would be able to choose the finished product duty rate that applies to aluminum fluoride (duty free) rather than the rate on fluorspar ($2.07 per metric ton).[9]

World Review

World fluorspar consumption and production decreased compared with 1989 levels. In order of rank, China, Mongolia,

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF HYDROFLUORIC ACID (HF), BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Canada	33,858	$37,416	24,629	$29,284
Germany, Federal Republic of	74	172	47	123
Japan	1,202	1,651	1,016	1,567
Malawi	19	21	—	—
Mexico	82,804	77,588	75,362	77,513
Monaco	68	73	—	—
United Kingdom	877	998	738	861
Total	r118,902	r117,919	101,792	109,348

rRevised.
[1]C.i.f. value at U.S. port.

Source: Bureau of the Census.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF CRYOLITE, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Australia	—	—	435	$271
Canada	251	$1,759	835	634
China	—	—	128	101
Denmark	3,941	3,690	2,335	2,314
Germany, Federal Republic of	70	919	874	720
Iceland	—	—	559	631
Japan	—	—	2,090	2,062
Netherlands	45	561	11	16
Other	11	157	39	26
Total	[2]8,429	[2]7,647	7,306	6,775

[1]C.i.f. value at U.S. port.
[2]Total includes synthetic cryolite imports; data not available by country.

Source: Bureau of the Census.

Mexico, the U.S.S.R., and the Republic of South Africa were the major producers. The international fluorspar industry suffered the initial effects of major changes in traditional markets. Some smaller producers have closed or were in danger of closing because of shrinking markets and price pressures from Chinese suppliers.

Canada.—St. Lawrence Fluorspar Ltd., subsidiary of Minworth Group PLC, London, England, ceased production. Mine production was halted in the third quarter, and the company was put into receivership in January 1991. Pumping stopped in early April 1991, and the mine was allowed to flood. The company had been in production for less than 4 years. Initial production began in 1987 from the Tarefare vein open pit and the Blue Beach North underground mine. The operation produced mainly acid-grade fluorspar, with most being exported to the United States.

China.—Fluorspar exports from China continued at high levels, with reported exports of 1,094,000 metric tons in 1989. Based on reported export data and estimates of domestic consumption, it is estimated that China produced about 1.5 million metric tons in 1990. U.S. imports from China decreased by about 4% to 153,000 metric tons. China's largest export market remained Japan, although exports to Japan were down by 20% compared with those of 1989. China produces from 15 Provinces, has reserves reportedly in excess of 100 million metric tons, and routinely undercuts all other producers in price. Metallurgical-grade material at 90% CaF_2 was offered in Northern Europe at $90 per metric ton, c.i.f., and acid-grade material was offered at $100 to $105 per metric ton, c.i.f.

Zhejiang Province is one of the major fluorspar-producing Provinces in China. The major fluorspar area is the Wu Yi fluorspar district in central Zhejiang Province. The Dong Feng Fluorite Co., owner and operator of the principal mines and mill, is under the Ministry of Metallurgical Industry. The company operates 14 active mines producing about 600,000 metric tons of ore with an average ore to waste ratio of 1.3:1. They produce on average about 90,000 metric tons of metallurgical grade and 235,000 of acid grade per year.

Denmark.—After more than 130 years, Denmark's production of natural cryolite from the Ivigtut Mine in Greenland has ceased. Mine production ended some years ago, but Kryolitselskabet Oresund A/S, with the Danish State as co-shareholder since 1940, continued to process material stockpiled in Greenland and at its Strandboulevarden plant in Copenhagen. In late 1990, the last of the plant stockpile was worked out. Cryolite, sodium aluminum fluoride Na_3AlF_6, is necessary for the electrolytic recovery of aluminum.

Mexico.—Official production figures for Mexico as shown in table 11 were provided by Consejo de Recursos Minerales (the Mexican Council of Mineral Resources). The data tend to be about 10% below industry-supplied figures and do not present the data in a breakdown by grade normally used by the fluorspar industry. The Instituto Mexicano de Zinc, Plomo y Coproductos A.C., collects fluorspar data for the fluorspar industry. According to their numbers, Mexico produced 207,000 metric tons of metallurgical grade and 488,000 metric tons of acid grade in 1990. More than 60% of Mexico's production came from Cia.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM FLUORIDE, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Canada	8,477	$8,276	5,023	$5,259
China	1,460	1,063	2,035	1,654
France	2,700	3,715	2,495	3,094
Italy	—	—	1,010	2,454
Japan	8,006	7,939	5,303	6,162
Mexico	22,069	20,491	16,712	18,961
Norway	1,000	1,024	1,999	2,061
United Kingdom	408	185	522	230
Other	1,351	1,378	505	420
Total	45,471	44,071	35,604	40,295

[1]C.i.f. value at U.S. port.

Source: Bureau of the Census.

Minera Las Cuevas S.A. de C.V. and Fluorita de México S.A. Mexico exported in excess of 300,000 metric tons in 1990, of which more than 60% was shipped to North America.

In May 1990, Industrial Químicas de México S.A. de C.V., a wholly owned subsidiary of Rhne-Poulenc S.A., announced plans for construction of a new HF and xanthate plant in Coahuila, Mexico. The plant was to be completed by the end of 1992 and have a final HF capacity of 60,000 metric tons. Construction plans have now been suspended indefinitely because of changed economic conditions and reduced demand.

Current Research

The U.S. Bureau of Mines, through its basic research program, has investigated column flotation for recovery of high-grade fluorspar concentrate and byproduct

TABLE 11

FLUORSPAR: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989	1990[e]
Argentina	39,076	r54,975	r18,052	r23,317	20,000
Brazil (marketable):					
Acid grade	53,555	58,736	54,050	r56,973	55,000
Metallurgical grade	31,059	31,212	35,310	r38,558	35,000
Total	84,614	89,948	89,360	r95,531	90,000
Canada: Acid grade[e]	—	10,000	40,000	50,000	25,000
China:[e]					
Acid grade	450,000	550,000	950,000	1,200,000	1,200,000
Metallurgical grade	450,000	450,000	450,000	500,000	300,000
Total	900,000	1,000,000	1,400,000	1,700,000	1,500,000
Czechoslovakia[e]	95,000	95,000	95,000	95,000	95,000
Egypt	80	776	1,849	r1,721	1,700
France:					
Acid and ceramic grades	148,000	134,000	r153,000	r159,000	155,000
Metallurgical grade[e]	50,000	50,000	50,000	50,000	50,000
Total	198,000	184,000	re203,000	re209,000	205,000
Germany, Federal Republic of:					
Western states (marketable)	88,834	85,201	r77,710	re74,500	74,600
Eastern states[e]	100,000	90,000	90,000	90,000	70,000
Total[e]	188,834	175,201	167,710	164,500	144,600
Greece[e]	4150	200	200	200	150
India:					
Acid grade	7,633	8,259	r8,823	r10,300	10,400
Metallurgical grade	4,100	4,450	r6,772	r12,589	12,500
Total	11,733	12,709	r15,595	r22,889	22,900

See footnotes at end of table.

TABLE 11—Continued

FLUORSPAR: WORLD PRODUCTION, BY COUNTRY[1]

Country	1986	1987	1988	1989	1990[e]
Iran[5]	[r]7,352	[r]6,483	[r]26,350	[re]25,000	25,000
Italy:					
Acid grade	90,900	77,800	81,700	[r]66,600	67,000
Metallurgical grade	54,536	56,600	58,157	[r]59,679	60,000
Total	145,436	134,400	139,857	[r]126,279	127,000
Kenya: Acid grade	37,146	61,504	99,092	[r]95,181	95,000
Korea, North: Metallurgical grade[e]	40,000	40,000	40,000	40,000	40,000
Korea, Republic of: Metallurgical grade	243	[r]63	261	[r]856	900
Mexico:[6]					
Acid grade	423,614	[r]409,846	[r]338,000	[r]359,000	285,000
Ceramic grade	13,593	12,015	[r]27,000	[r]27,000	22,000
Metallurgical grade	263,152	306,633	[r]253,000	[r]225,000	201,000
Submetallurgical grade	66,463	95,398	[r]138,000	[r]168,000	126,000
Total	766,822	823,892	[r]756,000	[r]779,000	[4]634,000
Mongolia: Metallurgical grade[e]	790,000	800,000	800,000	[r]750,000	750,000
Morocco: Acid grade	83,000	78,000	100,500	[r]105,000	105,000
Namibia: Acid grade	—	—	[re]1,500	[re]15,000	30,000
Pakistan	4,353	[r]3,528	284	[r]4,741	4,700
Romania: Metallurgical grade[e]	20,000	18,000	18,000	16,000	15,000
South Africa, Republic of:					
Acid grade	293,368	[e]279,000	282,986	[re]310,000	262,000
Ceramic grade[e]	[4]7,703	7,000	8,000	[r]9,000	7,500
Metallurgical grade[e]	[4]32,814	30,606	37,435	[r]49,340	41,532
Total	333,885	316,606	328,421	368,340	[4]311,032
Spain:					
Acid grade	257,108	147,757	[r]137,140	[re]130,000	130,000
Metallurgical grade	25,352	23,859	[r]5,435	[re]5,000	5,000
Total	282,460	171,616	[r]142,575	[re]135,000	135,000
Sweden	265	220	225	[e]150	150
Thailand:					
Acid grade	11,500	—	—	—	—
Metallurgical grade	156,409	102,398	76,321	[r]98,375	100,000
Total	167,909	102,398	76,321	[r]98,375	100,000
Tunisia: Acid grade	36,828	32,653	[r]55,416	[r]53,575	53,000
Turkey: Metallurgical grade[e]	[r][4]1,604	10,000	[4]13,240	13,000	13,000
U.S.S.R.[e]	[4]410,500	410,500	[r]410,500	410,000	380,000
United Kingdom	133,420	120,400	103,797	[r]122,057	120,000
United States (shipments)[e]	71,000	63,500	63,500	66,000	63,500
Grand total	[r]4,849,710	[r]4,816,572	[r]5,206,605	[r]5,585,712	5,106,632

[e]Estimated. [r]Revised.

[1]Table includes data available through May 24, 1991.

[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 for 1986-87 were provided by the Instituto Mexicano de la Fluorita (now disestablished). Data for 1988-89 and total for 1990 are as reported by Consejo de Recursos Minerales.

concentrates from a marginal deposit in Nevada. A sample of about 4,500 kilograms was obtained from the Fish Creek fluorspar deposit in Eureka County, NV, grading about 14% CaF_2. The recovery process consisted of (1) grinding the ore, (2) fluorspar rougher and cleaner flotation, (3) desliming the rougher fluorspar flotation tailings, (4) mica flotation, and (5) silicate rougher flotation. Acid-grade fluorspar, mica, silica sand, and low-grade beryl concentrate were recovered. In addition to technical research, the Bureau conducted a cost evaluation on the use of column flotation to recover fluorspar only from the deposit.[10]

OUTLOOK

There are three major sectors of fluorspar demand: metallurgical-grade fluorspar and briquets by the steel industry; acid-grade fluorspar by the aluminum industry, primarily for production of aluminum fluoride; and acid-grade fluorspar by the chemical industry for production of feedstock HF.

Consumption of fluorspar by the steel industry is difficult to quantify. The problem is compounded by the large number of steel mills, the industry's often times indifferent response to consumption surveys, and the lack of accurate data on fluorspar briquets. Consumption of fluorspar by the steel industry has declined dramatically since the introduction of the basic-oxygen furnace and the gradual obsolescence of the open-hearth furnace. Some companies have reported that with certain new furnaces fluorspar use will be unnecessary. Domestically, steel production is expected to be down by 5% to 10% in 1991 owing to the economic recession. A recovery is expected by the end of the year, but many economists are predicting only a weak recovery. As such, it is estimated that overall consumption of metallurgical-grade fluorspar by the steel industry will be flat or continue to decrease during the next 3 to 5 years.

The aluminum industry consumes fluorine from different sources and in different forms. Although some 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 fluorspar, from HF, or from fluosilicic acid. A small amount of cryolite is imported for consumption, but most is recovered as a byproduct of waste fluorine recovery or, in the case of a new potline, by tapping an operating pot for molten electrolyte. This material, termed "molten crushed bath," is allowed to solidify and is then crushed for use in the startup of a new potline.

The domestic aluminum industry is currently operating at or above rated capacity. No expansion of capacity is anticipated in the next few years, and the consumption of fluorspar and fluorine chemicals by the aluminum industry is expected to remain at current levels during the next 3 to 5 years.

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 reminder is used in chemical intermediates, glass and metal processing, petroleum alkylation, stainless steel pickling, uranium chemical production, and other small uses. The initial effects of the CFC phaseout are being felt as was demonstrated by the 18% decrease in fluorspar consumption by the HF industry in 1990. It may be too early to judge whether the forecasts for large increases in HF consumption for production of replacement HCFC's and HFC's were far off the mark. Yet, the number and variety of not-in-kind replacements undergoing research or ready for development seem to be growing rapidly. Other forecasts have been more pessimistic from the start and anticipated that any gains in HF consumption for HCFC's and HFC's would be offset by overall decreases in CFC usage. In the short term, fluorspar consumption by the fluorocarbon industry is expected to be at much reduced levels from just a few years ago.

Some areas of HF consumption that are expected to grow are production of fluoropolymers, fluoroelastomers, and new fluorine-containing agricultural and pharmaceutical chemicals. The demand for fluoropolymers and fluoroelastomers could grow by 10% per year in the next 3 to 5 years. Industry estimates project the combined number of potential fluorine-containing drugs and agrochemicals at more than 500. Unfortunately, these markets only account for a small percentage of HF consumption, and it is highly unlikely these markets will be able to absorb the losses expected in the fluorocarbon sector.

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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]U.S. Congress. Illinois Wilderness Act of 1990. Public Law 101-633, Nov. 28, 1990, 104 Stat. 4577.

[4]U.S. Congress. Clean Air Act Amendments of 1990. Public Law 101-549, Nov. 15, 1990, 104 Stat. 2399.

[5]Sternberg, K. Use of Hydrofluoric Acid Comes Under the Gun in California. Chem. Week, v. 147, No. 17, 1990, p. 26.

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[7]Federal Register. Presidential Documents. To Modify Duty-Free Treatment Under the Generalized System of Preferences and for Other Purposes. V. 55, No. 84, May 1, 1990, pp. 18075-18084.

[8]U.S. Congress. Customs and Trade Act of 1990. Public Law 101-382. Aug. 20, 1990, 104 Stat. 629.

[9]Federal Register. Foreign-Trade Zones Board (Dep. Commerce). Foreign-Trade Zone 155—Calhoun-Victoria Counties, TX; Application for Subzone; Alcoa Alumina and Aluminum Fluoride Plant. V. 55, No. 35, Feb. 21, 1990, p. 6027.

[10]Peterson, M., L. Duchene, and M. Shirts. Column Flotation of Multiple Products From a Fluorite Ore. BuMines RI 9309, 1990, 22 pp.

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GALLIUM

By Deborah A. Kramer

Ms. Kramer is a physical scientist with the Branch of Industrial Minerals. She has covered gallium for 7 years. Domestic survey data were prepared by Eraina C. Dixon, mineral data assistant.

U.S. gallium consumption was slightly higher than that in 1989. Even though demand increased slightly, it has stagnated at about 10,000 kilograms per year for the last 4 years. Most gallium consumption continued to be in the form of gallium arsenide (GaAs) for optoelectronic devices and integrated circuits. As in the past, the United States and Japan accounted for most of the world gallium demand.

Owing to low metal prices and stagnant demand, companies in Australia, Norway, and the United States idled gallium recovery facilities during the year. By yearend, only 50% of the available gallium production capacity was operational. Research on new production technology and development of new devices continued however, as GaAs manufacturers attempted to decrease manufacturing costs and to produce devices that were superior to silicon-base components.

TABLE 1

SALIENT U.S. GALLIUM STATISTICS

(Kilograms unless otherwise specified)

	1986	1987	1988	1989	1990
Production[e]	[1]750	W	—	—	—
Imports for consumption	17,202	12,490	12,160	15,284	9,894
Consumption	16,043	10,729	10,741	9,667	9,860
Price per kilogram	$525	$525	$525	$525	$525

[e]Estimated. W Withheld to avoid disclosing company proprietary data.
[1]Reported figure.

DOMESTIC DATA COVERAGE

Gallium data are collected from two voluntary surveys of U.S. operations. In 1990, there were 31 responses to the "Consumption of Gallium" survey, representing 86% of the total canvassed. Significant quantities of gallium are used by universities and Government research facilities, which are not canvassed by the Bureau's survey; data in tables 1 and 2 representing gallium consumption were adjusted to reflect full industry coverage.

ANNUAL REVIEW

Legislation and Government Programs

On September 13, the Deputy Assistant Secretary for Export Administration determined that foreign availability existed for certain GaAs to controlled destinations such that current U.S. export controls were ineffective. Consequently, the Department of Commerce planned to publish regulations amending the national security export controls on certain forms of GaAs to controlled destinations. The forms of GaAs covered by the determination include doped, semi-insulating GaAs; conducting GaAs; and undoped, semi-insulating GaAs, except undoped, semi-insulating GaAs having all of the characteristics for use in monolithic microwave integrated circuit applications.[1]

Production

Hecla Mining Co. began production of germanium in February at its mine and plant near St. George, UT. After the germanium circuit was operational, the company also planned to begin recovering gallium, but because of declining metal prices, the company closed the operation in August without producing any gallium. At yearend, the plant remained closed, although Hecla hoped to restart the operation if prices improved.

Eagle-Picher Industries Inc. recovered and refined gallium from both imported and domestic sources at its operation in Quapaw, OK. Recapture Metals Inc., Blanding, UT, recovered gallium from scrap materials.

Consumption and Uses

Domestic consumption of gallium increased slightly from that in 1989, but over the past 4 years, it has stagnated around the 10,000-kilogram-per-year level. Except in military applications, GaAs-base integrated circuits still had limited uses in commercial products. Optoelectronic devices continue to account for much of the U.S. gallium consumption.

In May, Bertram Laboratories, a subsidiary of Chemetall GmbH, announced the purchase of Epitronics Corp., a subsidiary of Alcan Aluminium Ltd. With this purchase, Bertram Laboratories, which manufactures bare GaAs wafers, will extend its capacity to include epitaxial deposition, Epitronics' product specialty. Operations were expected to continue at the companies' plants in Arizona and New Jersey.

Vitesse Semiconductor Corp. reportedly agreed to provide its GaAs manufacturing technology to Thomson CSF of France in exchange for manufacturing capacity. Under the agreement, Thomson will have exclusive distribution rights for Vitesse's digital GaAs components in Western Europe, and Vitesse will have

access to Thomson's new manufacturing facility in Grenoble, France.

Vitesse also increased the integration of GaAs digital components by developing a new manufacturing technology. This technology makes possible the production of GaAs gate arrays that have 100,000 gates; the most complex GaAs gate array previously manufactured had 30,000 gates. The company claims that the new GaAs arrays would deliver the same performance as some silicon-base components at comparable prices and with a reduction in power consumption.[2]

Hewlett-Packard Co. announced the development of a bright yellow light-emitting diode (LED) that has a brightness about 10 times that of existing yellow LED's. The improved performance will enable yellow LED's to be used in applications including sunlight-viewable message panels and automotive exterior lighting. Existing applications for yellow LED's will require a lower current, which will reduce heat. Hewlett-Packard expects that the new LED's will be available by yearend 1991.

The Defense Advanced Research Projects Agency (DARPA) invested $4 million in Gazelle Microcircuits Inc., a maker of digital GaAs components. Unique about this investment was that DARPA would not have to give any return on its investment to the Government's general fund; it would be able to use the return to fund other projects. Another benefit was that DARPA would have greater control over foreign access to Gazelle's GaAs technology.

Markets and Prices

Published yearend prices for gallium and gallium oxide have not changed since 1986. Press reports indicated that the free market price for 99.99999%-pure gallium had dropped to $150 to $200 per kilogram by the third quarter. The average value of gallium imports into the United States was $328 per kilogram, a 13% decrease from that of 1989.

Foreign Trade

Gallium export data were combined with data for other materials by the Bureau of the Census and could not be separately identified. Some data were available on gallium exports through the Journal of Commerce Port Import/Export Reporting Service (PIERS), but this source provided data only on materials that are transported by ship. Because

TABLE 2

U.S. CONSUMPTION OF GALLIUM,[1] BY END USE

(Kilograms)

End use	1989	1990
Optoelectronic devices:		
Laser diodes and light-emitting diodes	3,383	5,251
Photodetectors and solar cells	2,768	703
Integrated circuits:		
Analog	564	1,317
Digital	1,520	372
Research and development	1,214	846
Specialty alloys	110	—
Other	108	1,371
Total	9,667	9,860

[1]Includes gallium metal and gallium compounds.

TABLE 3

STOCKS, RECEIPTS, AND CONSUMPTION OF GALLIUM,[1] BY GRADE

(Kilograms)

Purity	Beginning stocks	Receipts	Consumption	Ending stocks
1989:				
97.0% to 99.9%	16	117	110	23
99.99% to 99.999%	36	10	36	10
99.9999%	359	6,146	6,151	354
99.99999%	377	3,213	3,370	220
Total	788	9,486	9,667	607
1990:				
97.0% to 99.9%	23	—	14	9
99.99% to 99.999%	10	19	19	10
99.9999%	354	6,490	6,625	219
99.99999%	220	3,295	3,202	313
Total	607	9,804	9,860	551

[1]Consumers only.

TABLE 4

YEAREND GALLIUM PRICES

(Dollars per kilogram)

Gallium metal, 99.99999%-pure, 100-kilogram-lots	$525
Gallium metal, 99.99%-pure, 100-kilogram lots	435
Gallium metal, 99.9999%-pure, imported	$460- 490
Gallium oxide, 99.99%-pure	435
Gallium oxide, 99.99%-pure, imported	400- 420

Source: American Metal Market.

most gallium was shipped by air, it is likely that there were significantly more gallium-containing materials, particularly scrap, that were exported than were reported by PIERS. According to PIERS, 5,751 kilograms (gross weight) of gallium epitaxial material was shipped to France in 1990.

Beginning in 1991, the Bureau of the Census will separate GaAs wafers from silicon wafers under the Harmonized Tariff System. Two new categories will be instituted; one for doped GaAs wafers and one for undoped GaAs wafers.

World Review

Virgin gallium production in 1990 was estimated to be 40,000 kilograms, and Australia, the Federal Republic of Germany, and Japan were the largest producing countries. Lower demand and declining prices for gallium resulted in several companies mothballing gallium recovery circuits during the year.

Although available world gallium capacity data show that significant quantities of gallium can be produced, much of this capacity was not operational at yearend. Because of closures in Australia, Norway, and the United States, only 50% of the total world capacity was operational.

Australia.—Rhône-Poulenc S.A. reportedly stopped producing gallium at its plant in Pinjarra, Western Australia, in the third quarter because of declining demand. With the gallium inventory that built up at the plant, the company could continue supplying its customers' gallium requirements. The 50,000-kilogram-per-year plant had opened in April 1989 and was the largest gallium recovery plant in the world.

Canada.—Johnson Matthey Ltd. announced that it would close its Trail, British Columbia, facility on December 31 as a part of a restructuring of its electronic business. Production and sale of GaAs wafers was expected to undergo retrenchment, but research and development on polished GaAs wafers would be relocated from Trail to Crystar Research in Victoria. In addition, production of other materials, including high-purity cadmium and tellurium, would be relocated to the company's facility in Spokane, WA. Johnson Matthey had purchased the electronic business from Cominco Ltd. in late 1988.

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF GALLIUM, UNWROUGHT, WASTE AND SCRAP, BY COUNTRY

Country	1989		1990	
	Kilograms	Value	Kilograms	Value
Belgium	—	—	32	$3,200
China	—	—	437	73,411
France	8,266	$3,152,094	3,994	1,429,381
Germany, Federal Republic of	3,825	1,320,316	3,265	1,160,842
Hungary	—	—	310	59,425
Japan	126	122,815	339	195,309
Netherlands	39	8,225	—	—
Norway	—	—	1,000	215,000
Sweden	23	13,560	—	—
Switzerland	2,586	898,645	—	—
United Kingdom	419	149,051	517	113,334
Total	15,284	5,664,706	9,894	3,249,902

Source: Bureau of the Census.

India.—The Central Engineering and Environment Research Institute (CEERI) reportedly developed a process to recover gallium from alumina wastes. Scientists at CEERI said that the country had a potential to produce 6,000 kilograms of gallium annually by this process. The new process underwent trials at a pilot plant at National Aluminium Co. Ltd.'s alumina plant.

Japan.—In 1989, Japan's demand for high-purity gallium was reported to be 54,000 kilograms. Production was reported to be 6,000 kilograms, imports were slightly higher than 16,000 kilograms, and recovery from scrap was 32,000 kilograms. France, the Federal Republic of Germany, Hungary, and Switzerland were the sources of most of the imports, with lesser quantities supplied by China, Czechoslovakia, and the United States. About 46% of the gallium was used as GaAs and gallium phosphide crystal substrates, and the rest was used in epitaxial production of LED's and laser diodes.[3]

Dowa Kogyo, a subsidiary of Dowa Mining Co. Ltd., reportedly developed a new use for gallium in ski waxes. By developing a spray version of the new ski wax, the company has increased its market from professional skiers to include the public.

Norway.—Elkem A/S announced that it would mothball its 5,000-kilogram-per-year gallium recovery circuit at its aluminum plant in Bremanger by yearend. Low gallium prices were cited as the reason for the closure. Elkem's plant, which opened in 1987, produced 99.9%-pure gallium from aluminum smelter flue dusts generated at the company's aluminum plants in Tyssedal and Mosjen.

Current Research

Scientists at the Massachusetts Institute of Technology developed the first laser diode transmitter to pass requirements for intersatellite communications. Designed to send communications over a 23,000-mile distance between satellites, the GaAs laser transmitters were a part of the Laser Intersatellite Transmission Experiment, sponsored by the Air Force Space Technology Center. Increased security of laser transmissions compared to those of radio waves made the lasers attractive for satellite links.

Anadigics Inc. received an $8 million contract from British Satellite Broadcasting to develop a GaAs monolithic microwave integrated circuit for home television applications.

TRW Inc. announced that it produced a demonstration GaAs integrated circuit that combined both analog and digital function on the same chip. Because the technologies involved in manufacturing analog and digital components differ, previous attempts to combine the two on a single chip resulted in performance

TABLE 6

WORLD ANNUAL PRIMARY GALLIUM PRODUCTION CAPACITY,[1] DECEMBER 31, 1990

(Kilograms)

North America: United States[2]	12,000
Europe:	
Czechoslovakia	3,000
France	20,000
Germany, Federal Republic of	15,000
Hungary	4,000
Norway	5,000
Total	47,000
Asia:	
China	8,000
Japan	17,000
Total	25,000
Oceania: Australia	50,000
World total	134,000

[1]Includes capacity at operating plants as well as at plants on standby basis.
[2]All U.S. capacity is standby capacity as of Dec. 31, 1990.

tradeoffs in either one or the other of the components.

American Telegraph & Telephone Co.'s (AT&T) Bell Laboratories announced the development of the first digital optical processor. The experimental device is based on GaAs components called symmetric self electrooptic effect devices (S-SEED) that were developed at AT&T in 1986. In the processor, pairs of S-SEED act like transistors in ordinary computers, except that light is used to communicate between the transistors instead of electricity. Although the experimental device is about 4 square feet in size and operates at slower speeds than most personal computers, it represents a breakthrough in developing optical computers that have processing power potentially 1,000 times greater than existing computers.[4]

Researchers at the University of California-Santa Barbara developed an indium gallium aluminum arsenide (InGaAlAs) surface-emitting laser that requires about 0.001 ampere to operate, 30% to 40% less than previously reported levels. Lasers such as these could be used in integrated circuits to communicate with light rather than with electricity.[5]

As a first effort in producing laser diodes that could compete with gas lasers as a source of blue light, scientists at IBM Corp. generated a record 10% efficiency in converting electrical power into blue light by doubling the frequency of a gallium aluminum arsenide (GaAlAs) laser diode. Potential applications include optical storage, displays, undersea optical communications, and photochemistry. The 10% electrical efficiency is several hundred times that of blue gas lasers.[6]

To improve the characteristics of GaAs components produced by metal-organic chemical vapor deposition (MOCVD), two consortia—one in Europe and one in the United States—have been formed. The European Commission provided funding for a 3-year project to allow multiple wafers to be coated uniformly by MOCVD. Using novel equipment developed by one of the consortium members, project members plan to develop GaAs/GaAlAs, gallium indium arsenide (GaInAs), gallium indium aluminum phosphide (GaInAlP), and indium gallium arsenide phosphide (InGaAsP) heterostructures and products for applications such as guided optics, lasers, and microwave electronics for satellite broadcasting equipment. Members of the consortium are Philips BV (the Netherlands), Aixtron GmbH (the Federal Republic of Germany), and Telefonica and Technical University of Madrid (Spain). In the United States, the U.S. Army Electronics Technology and Devices Laboratory (EDTL) formed a cooperative research and development agreement with EMCORE, American Cyanamid Co., and Polytechnic University to investigate aspects of MOCVD technology. EDTL will be responsible for material characterization and device fabrication, EMCORE will perform the MOCVD thin-film growth, and American Cyanamid will provide the chemicals for MOCVD—tertiarybutylarsine and tertiarybutylphosphine. Polytechnic University provided research on the MOCVD process using these liquid replacements for arsine and phosphine, hazardous gases normally used for MOCVD growth.

Other researchers are investigating alternate sources for the arsenic and phosphorous used in MOCVD because of the hazards associated with these gases. At the State University of New York and the University of Illinois, acceptable semiconductor materials were produced at temperatures as low as 100° C using $(C_6F_5)_2GaAs(C_2H)_4$. In this compound, gallium and arsenic were bonded in a 1:1 ratio. Using a compound in which both the gallium and arsenic are present, rather than using two separate compounds, provided better control over the composition of the epitaxial layer.

Scientists at the National Aeronautics and Space Administration's (NASA) Jet Propulsion Laboratory reported the development of a new technique for epitaxial film deposition to reduce contamination when rectifying contacts are made. Normally, after an epitaxial layer is grown on a GaAs surface under a high vacuum, the gold used as a contact metal interdiffuses with the GaAs and forms an ohmic rather than a rectifying contact. Diffusion can be prevented by exposing the GaAs surface to air, but this may lead to contamination. In NASA's technique, an epitaxial film only two atomic layers thick was deposited on the GaAs surface. The film was thin enough not to constitute an electronic barrier, but thick enough to form a physical barrier to the interdiffusion of gold and GaAs.[7]

At the University of California—Santa Barbara, researchers developed a nonintrusive analytic technique for characterizing the top atomic layers of crystals grown on GaAs by molecular beam epitaxy. The technique, called reflection high-energy electron diffraction (RHEED), involved diffracting electrons of a crystal at an angle and observing the diffraction pattern on a phosphor screen. Diffraction of the electrons is dependent on the type and placement of atoms on the surface. By using RHEED, scientists hoped to reduce manufacturing costs and increase efficiency by optimizing crystal growth.

A new bipolar transistor that was claimed to be the world's fastest ballistic collection transistor was developed by Nippon Telegraph & Telephone Corp. The new transistor, fabricated from layers of GaAs and GaAlAs, was considered as a possible replacement for silicon in the development of high-speed transistors because it operated at five times the speed of a conventional silicon transistor. These GaAs devices could improve the performance of optical and radio communications systems and supercomputers.

By adapting GaAs solar cells, researchers at Varian Associates Inc. developed a component that can convert light from a fiber-optic cable into electrical power. Light transmitted through a fiber-optic cable is directed onto a GaAs solar cell that is divided into six sections. Each section

converts the light to electricity at 1 volt, but when connected in series, the sections add up to give 6 volts of electricity, which is enough voltage to power most integrated circuits. Electrical conversion rate of the GaAs solar cells were measured at 45% to 50%, about twice the efficiency of silicon solar cells. A component such as this has applications in the development of fly-by-light aircraft control systems, phased-array radar, bomb detonators in nuclear weapons, and sensors in harsh chemical environments.[8]

Continued research efforts led to the development of solar cells with new sunlight-to-electricity conversion efficiencies. Using a three-layer design, with a two-layer GaAlAs-GaAs cell on top of an InGaAs single cell, scientists at Varian Associates reported a 24.9% efficiency in deep-space conditions. This surpassed the previous record of 23.9% efficiency. At the Solar Energy Research Institute, a two-layer cell demonstrated a 31.8% efficiency. The two-layer cell, composed of an upper layer of indium phosphide and a lower layer of InGaAs, was being developed for use on U.S. Navy satellites. Most commercial land-based solar cells have an efficiency rating of about 12% to 16%.

Developments in GaAs production techniques, properties, and integration of GaAs components into commercial applications were highlighted in several articles in nontechnical journals.[9]

OUTLOOK

At the same time that advances are made in GaAs integrated circuit technology, similar advances are being made in silicon technology, resulting in continuing competition between GaAs and silicon in many applications. Primarily because of its cost, GaAs will continue to be used only in applications where the benefits of its properties outweigh the added cost. In most instances, these types of applications are for defense components, which have limited production.

GaAs components are caught in a vicious cycle. Until costs are reduced, the components will not be used in a significant number of commercial applications that would bring about a substantial increase in demand. But until more applications develop, reducing costs by increasing the scale of production is difficult. Because of costs and competition from other materials, U.S. gallium consumption probably will remain stagnant for the next few years.

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GEM STONES

By Gordon T. Austin

Mr. Austin, a physical scientist with more than 30 years industry and Government experience, has been the gem stones commodity specialist since 1986. Mr. William Field, mineral data assistant, prepared the domestic production survey data.

Production value of natural gem materials in the United States during 1990 was essentially unchanged at $52.9 million. The materials produced included faceting rough, lapidary rough, carving material, specimen material, natural and cultured freshwater pearls, mother of pearl, agatized coral, and coral.

The reported combined production value of synthetic and simulant materials was $20.5 million, about a 9% increase over that of 1989. Synthetic gems are laboratory grown and have essentially the same optical, physical, and chemical properties, and the same appearance as the natural gem that they represent. Synthetic gem materials 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 gem 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.

Wholesale and retail outlets, gem and mineral shops, gem and mineral show dealers, cutting factories, and jewelry manufacturers were the major purchasers of domestic gem materials.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines estimates of U.S. production were from the "Natural and Synthetic Gem Material Survey," a voluntary survey of U.S. operations, and from Bureau estimates of unreported production. Of the approximately 400 operations surveyed, 82% responded, accounting for about 95% of the total production, 92% of the natural production, and 100% of the synthetic and simulant production.

The 400 operations surveyed in 1990 were an increase of about 10% compared with the number of operations surveyed in 1989. The response rate was essentially the same as that of 1989. The Bureau estimated the production by nonresponding operations, by professional collectors, and by amateur or hobbyist collectors. The basis for these estimates were information from published data, conversations with gem and mineral dealers, analyses of gem and mineral shows and sales statistics, and from information informally supplied by collectors. In the formal voluntary survey and the informal surveys, the Bureau is totally dependent upon the cooperation of the producers, brokers, dealers, and collectors. Individuals and companies have been very cooperative and forthcoming with information. The Bureau is very appreciative of this cooperation.

BACKGROUND

The history of production and preparation of gem stones begins with the wearing of items for personal adornment in prehistoric times; this preceded even the wearing of clothes. Amber was mined in the Baltic countries for use as a gem material before 25,000 B.C. Later, the Phoenicians in their writings described their trade routes to the Baltic for amber and to areas in Asia and Africa for other gem materials. The voyages of Columbus brought increased interest in gem 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 has resulted in the development of one of the largest deposits in the world.

Commercial mining of gem materials has never been extensive in the United States. Although more than 60 gem minerals and materials have been produced commercially from domestic sources, most of the deposits are relatively small. In many instances, production rests in the hands of the numerous hobbyists and members of mineralogical and lapidary clubs. The Crater of Diamonds State Park near Murfreesboro, AR, is open to the public on a daily fee basis. Many gem-quality stones are found there 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 gem stones data. Customarily, diamond, ruby, sapphire, and emerald are considered the major gems.

The designation "gem stone" refers to a material appropriate for personal adornment. The most important qualities of gem stones 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. The perfection of polish enhances the luster of a stone. Visible imperfections impair the luster of transparent stones. However, defects, described as "jardens" or "inclusions,"

may enhance the beauty and value of natural rubies, sapphires, and other gem stones and may be used to identify the country of origin and even the mine. 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 1,500 mineral species, only about 100 possess all of the attributes required in gems. Silicates furnish the greatest number, including such minerals as beryl, topaz, tourmaline, and feldspar. Oxides such as corundum (ruby and sapphire) and quartz (amethyst, agate, etc.) comprise the second largest group. Sulfides, carbonates, and sulfates are of small importance; the phosphates yield only turquoise and variscite. An exception is pearl, essentially calcium carbonate, which is ranked high as a gem. Diamond, the best known gem stone, is an isometric crystalline form of the element carbon.

In general, gem materials 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 gem materials 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. Gem materials are cut into gem stones in three main styles; cabochons, baroque, and faceted.

Cabochons are cut in four operations: sawing, grinding, sanding, and polishing. Sawing, the initial step in cutting, is customarily done with a diamond saw to obtain a slab or slice of the desired size and thickness from the rough gem material. 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, silicon carbide, or aluminum oxide wheels or coated abrasive disks. In grinding, the hardness of the gem material determines the grit and hardness of the abrasive used. Multiple grinding steps starting with 80- to 100-mesh (grit) through 600-mesh abrasives are normally used. The scratches left by grinding are removed by progressively finer grinding and sanding. Disk or belt sanders use bonded to cloth abrasives, waterproof reinforced paper abrasives, or cloth charged with abrasive pastes. The final polish is obtained by using hard felt, wood, or leather laps, with various polishing agents such as fine diamond compound, tin oxide, tripoli, chromium oxide, cerium oxide, alumina, and rouge.

Polished irregular shapes are called baroque gems. An inexpensive method of polishing baroque gems consists of tumbling them in rubber-lined drums, using a grinding and polishing medium with or without water.

Facet cutting is employed ordinarily on transparent gem stones to increase brilliancy and appearance and is generally 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. The "round brilliant" cut, most commonly used in faceting, has 58 facets, 33 above the circle "girdle" and 25 below it, arranged in eightfold symmetry. The "round brilliant" and some other common cuts are illustrated in figure 1.

Industry Structure

An estimated 80% to 85% of gem and natural industrial diamond is marketed through the Central Selling Organization (CSO) by the Diamond Trading Co. Ltd. and the Industrial Distributors Ltd. The CSO sells uncut gem diamonds on behalf of De Beers and most other major producers at sights (approved bidder viewings) in London, England, in Lucerne, Switzerland, and Kimberley, Republic of South Africa.

The CSO has been extremely successful at maintaining the rough diamond market for about 50 years. In modern times there has never been a decrease in CSO's price of rough diamonds. Table 9 illustrates the timing and the amounts of the average CSO price increases for rough gem diamonds from 1949 until the present. The compounded affect of these increases is a price increase of about 1,800% over the approximately 41.5 years. Thus, a piece of rough that sold for $100 in August 1949, would sell for about $1,800 in April 1990.

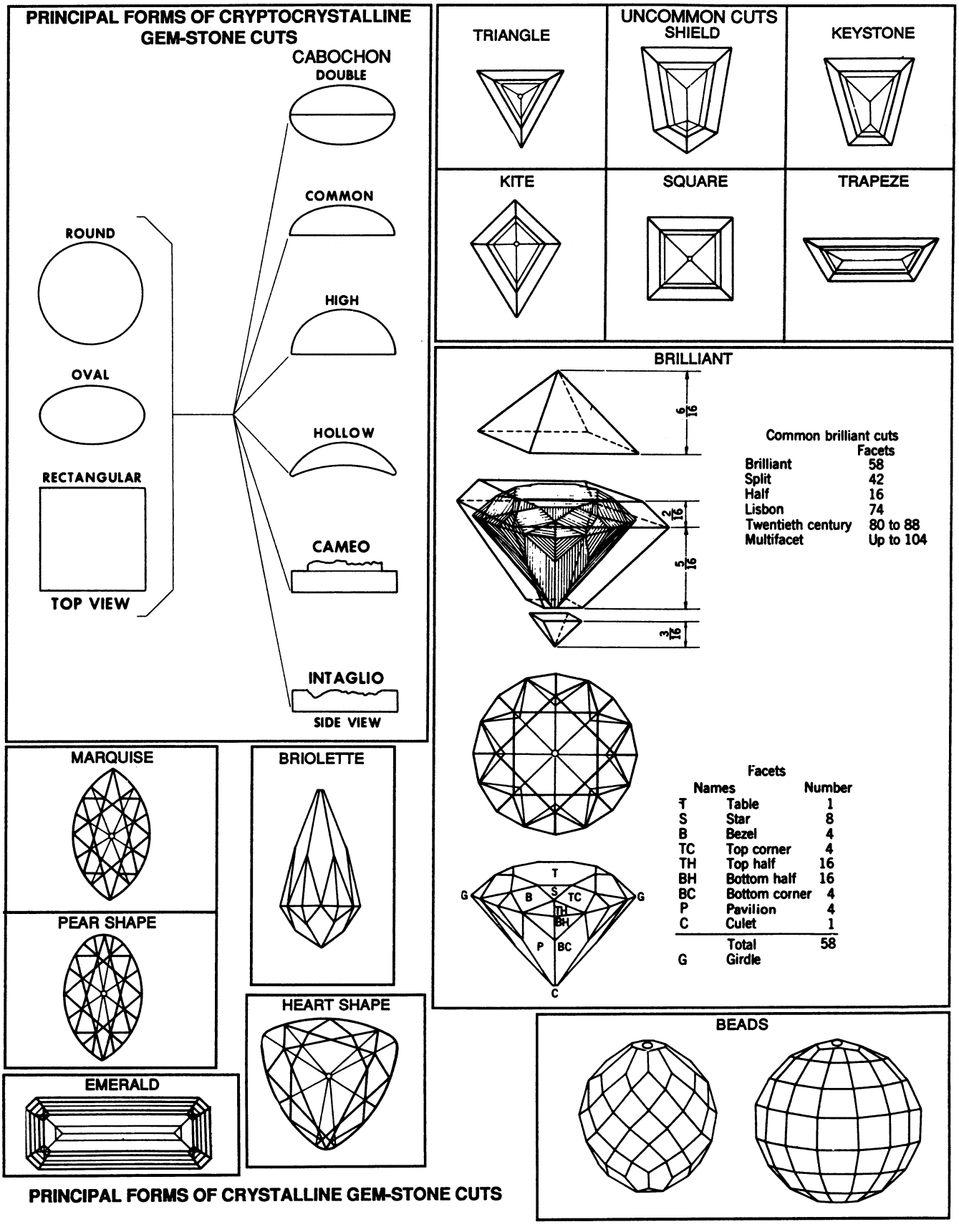
For more than 30 years, the major diamond cutting and polishing centers of the world were in Belgium and Israel, with a certain amount of the larger stones being cut in the United States. However, in the early 1980's, the development of a large cottage industry in India—today there is estimated to be more than 450,000 cutters—made a major impact on world diamond trade. Indian consumption of most of the world's small-gem, cheap-gem, and near-gem rough material in the manufacture of small stones resulted in annual cut-stone exports of almost $3 billion from April 1, 1988, to March 31, 1989. These small stones averaged less than one-fifth of a carat (0.20 carat). The availability of small inexpensive stones resulted in substantial changes in the design of jewelry. The utilization of small cut diamond stones (usually 0.07 to 0.14 carats each, called melee) to create a pavé effect (set close together to conceal the metal base) is but one example. Cutting and polishing of colored, synthetic, and simulant gem stones is centered in Thailand, India, Hong Kong, and Brazil, where cheap labor and favorable export laws ensure the lowest total costs for finished gems.

Geology-Resources

Gem materials occur in a large variety of igneous, metamorphic, and sedimentary rocks and mineral deposits, usually as a small fraction of the total deposit. The origins are as varied as the occurrences. Principal formation of gem materials is by precipitation from watery solutions, by crystallization from molten rock, and by metamorphic processes. Approximately one-third of gem minerals is composed of silicate minerals, about one-fifth of aluminasilicates, and nearly 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

FIGURE 1

PRINCIPAL FORMS OF CRYPTOCRYSTALLINE AND CRYSTALLINE GEM STONE CUTS



PRINCIPAL FORMS OF CRYSTALLINE GEM-STONE CUTS

in table 2.

The United States has no defined large resources of major gem materials. Emerald deposits are known in North Carolina, as are ruby and sapphire. Historically, sapphires have been mined in Montana, and commercial mining once again is underway. Numerous other domestic deposits of gem minerals 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 them.

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 gem materials are nearly all unevaluated. However, world gem diamond reserve is estimated to be about 300 million carats, including near-gem and cheap-gem qualities. Nearly all of the reserves are in Australia, Africa, and the U.S.S.R. (Siberia). The estimates for diamond reserves are of limited value because data needed for reliable estimates are not available from the producers. Reserve data on other gem materials are even less available than for diamond.

Technology

Synthetic Gems.—The first synthetic gem produced was ruby, and later, by various melt techniques, sapphire, spinel, rutile, strontium titanate, and cubic zirconia. The Verneuil flame-fusion process, developed in 1902, consists of growing a single crystal in a simple, downward-impinging oxyhydrogen blowpipe flame. In manufacturing synthetic gems, pure oxides of aluminum and titanium, and as needed, moderating and coloring oxides, are charged at the top of a small furnace and melted as they pass through an oxygen-hydrogen flame. The molten material is solidified on a fireclay peg as a carrot-shaped single crystal known as a boule, usually ½ to 1 inch in diameter, 2 to 4 inches long, and weighing 75 to 250 carats. After cooling, the boule is heat treated and tapped at one end to relieve the internal strain that causes the boule to split into two vertical halves. The halves are then cut and polished into gems. Other melt techniques used are the Czochralski pulled-growth method for ruby, sapphire, spinel, yttrium-aluminum-garnet (YAG), gadolinium-gallium-garnet (GGG), and alexandrite; the Bridgman solidification method for sapphire; and skull melting for cubic zirconia and sapphire.

Solution techniques for manufacturing synthetic gems include flux methods for emerald, ruby, sapphire, spinel, YAG, GGG, and alexandrite; hydrothermal methods for emerald, quartz, and the colored varieties of quartz such as smoky, yellow, citrine, and amethyst; and the high temperature ultra-high-pressure presses used in the manufacture of synthetic diamond in which a molten metal is used as the solvent.

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. However, the Verneuil, Czochralski, and scull melting processes are the melt techniques most often used for gem materials. The various synthetics and the method of production are shown in table 3.

Enhancement of Gem Stones.—Enhancement of all types of gem materials through chemical and physical means has become much more commonplace and in the past few years has included a wider variety of gem 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]

A number of gem materials 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 dying. The treatments that alter only the surface of the gem material include surface coatings of various types, interference filters, foil backings, surface decoration, and inscribing. Chemical treatment is more widespread than the common dying of quartz, treatment of turquoise, and oiling of emeralds. Chemical treatment and impregnations have been used to enhance chalcedony, coral, ivory, pearl, tiger's eye, emerald, lapis lazuli, opal, ruby, sapphire, turquoise, beryl, quartz, jade, diamonds, and amber.[2]

TABLE 1

CSO ROUGH DIAMOND PRICE INCREASES, BY PERCENTAGE

Sept.	1949	25.0	Nov.	1967	16.0	Aug.	1973	10.2	Sept.	1982	2.5
Mar.	1951	15.0	Sept.	1968	2.5	Dec.	1974	1.5	Apr.	1983	3.5
Sept.	1952	2.5	July	1969	4.0	Jan.	1976	3.0	Aug.	1986	7.5
Jan.	1954	2.0	Nov.	1971	5.0	Sept.	1976	5.8	Nov.	1986	7.0
Jan.	1957	5.7	Jan.	1972	5.4	Mar.	1977	15.0	Sept.	1987	10.0
May	1960	2.5	Sept.	1972	6.0	Dec.	1977	17.0	Apr.	1988	13.5
Mar.	1963	5.0	Feb.	1973	11.0	Aug.	1978	30.0	Mar.	1989	15.5
Feb.	1964	7.5	Mar.	1973	7.0	Sept.	1979	13.0	Mar.	1990	5.5
Aug.	1966	7.5	May	1973	10.0	Feb.	1980	12.0			

TABLE 2

GUIDE TO SELECTED GEM STONES 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 alluminum silicate.	Blue green to light blue	Any	Medium to high	7.5–8.0	2.63–2.80	Double	1.58	Synthetic spinel, blue topaz	Double refraction, refractive index.
Emerald	do.	Green	Medium	Very high	7.5	2.63–2.80	do.	1.58	Fused emerald, glass, tourmaline, peridot, green garnet, doublets	Emerald filter, dichroism, refractive index.
Emerald, synthetic	do.	do.	Small	High	7.5–8.0	2.63–2.80	do.	1.58	Genuine emerald	Flaws, brilliant, fluorescence in ultraviolet light.
Golden	do.	Yellow to golden	Any	Low to medium	7.5–8.0	2.63–2.80	do.	1.58	Citrine, topaz, glass, doublets	
Morganite	do.	Pink to rose	Any	do.	7.5–8.0	2.63–2.80	do.	1.58	Kunzite, tourmaline, pink sapphire	Refractive index.
Calcite:										
Marble	Calcium carbonate	White, pink, red, blue, green, or brown	Any	Low	3.0	2.72	Double (strong)	1.49–1.66	Silicates, banded agate, alabaster gypsum	Translucent.
Mexican onyx	do.	do.	Any	Low	3.0	2.72	do.	1.6	do.	Banded, translucent.
Chrysoberyl:										
Alexandrite	Beryllium aluminate	Green by day, red by artificial light	U.S.S.R. (small), Sri Lanka (medium)	High	8.5	3.50–3.84	Double	1.75	Synthetic	Dichroism, inclusions in synthetic sapphire.
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.

See footnotes at end of table.

TABLE 2—Continued

GUIDE TO SELECTED GEM STONES 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
Corundum—Continued										
Sapphire, fancy	Aluminum oxide	Yellow, pink, white, orange, green, or violet	Medium to large	Medium	9.0	3.95–4.10	Double	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.
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:										
Amazonstone	Alkali aluminum-silicate	Green	Large	Low	6.0–6.5	2.56	—	1.52	Jade	Cleavage, sheen, vitreous to pearly, opaque, grid.
Labradorite	Alkali aluminum-silicate	Gray with blue and bronze sheen color play	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 straine	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	Crypto-crystall	1.65–1.68	Onyx, bowenite, vesuvianite, grossularite	Luster, spectrum, translucent to opaque.
Nephrite	Complex hydrous silicate	do.	do.	do.	6.0–6.5	2.96–3.10	do.	1.61–1.63	do.	Do.
Peridot	Iron magnesium silicate	Yellow and/or green	Any	Medium	6.5–7.0	3.27–3.37	Double (strong	1.65–1.69	Tourmaline chrysoberyl	Strong double refraction, low dichroism.
Opal	Hydrous silica	Colors flash in white, gray, black, red, or yellow	Large	Low to high	5.5–6.5	1.9–2.3	Isotropic	1.45	Glass, synthetics, triplets	Play of color.
Pearl	Calcium carbonate	White, pink, or black	Small	do.	2.5–4.0	2.6–2.85	—	—	Cultured and imitation	Luster, structure, X-ray.

See footnotes at end of table.

TABLE 2—Continued

GUIDE TO SELECTED GEM STONES AND GEM MATERIALS USED IN JEWELRY

Name	Composition	Color	Practical size[1]	Cost[2]	Mohs	Specific gravity	Refraction	Refractive index	May be confused with—	Recognition characters
Quartz:										
Agate	Silica	Any color	Large	Low	7.0	2.58–2.64	—	—	Glass, plastic, Mexican onyx	Cryptocrystalline, irregularly banded, dendritic inclusions.
Amethyst	do.	Purple	do.	Medium	7.0	2.65–2.66	Double	1.55	do.	Refractive index, double refraction, transparent.
Cairngorm	do.	Smoky	do.	Low	7.0	2.65–2.66	do.	1.55	do.	Do.
Citrine	do.	Yellow	do.	Low	7.0	2.65–2.66	do.	1.55	do.	Do.
Crystal, rock	do.	Colorless	do.	Low	7.0	2.65–2.66	do.	1.55	do.	Do.
Jasper	do.	Uniform or spotted red, yellow, or green	do.	Low	7.0	2.58–2.64	—	—	do.	Opaque, vitreous.
Onyx	do.	Many colors	do.	Low	7.0	2.58–2.64	—	—	do.	Uniformly banded.
Rose	do.	Pink, rose red	do.	Low	7.0	2.65–2.66	Double	1.55	do.	Refractive index, double refraction, translucent.
Spinel	Magnesium aluminum oxide.	Any	Small to medium	Medium	8.0	3.5–3.7	Single	1.72	Synthetic, garnet	Refractive index, single refraction, inclusions.
Spinel, synthetic	do.	Any	Up to 40 carats	Low	8.0	3.5–3.7	Double	1.73	Spinel, corundum, beryl, topaz, alexandrite	Weak double refraction, curved striae, bubbles.
Spodumene:										
Kunzite	Lithium aluminum silicate	Pink to lilac	Medium	Medium	6.5–7.0	3.13–3.20	do.	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.

The oldest and most common method of gem material 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 sapphire, topaz, beryl, tourmaline, quartz, zircon, amber, diamond, and zoisite.[3]

Mining.—Gem materials 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 baskets for carrying material. A larger operation may include drilling, blasting, and minimum timbering. Mechanized hauling and hoisting is done only at the larger mines.

Diamond mining in the kimberlite pipes of Africa and the U.S.S.R. and the lamproite pipes of Australia represent the ultimate in that huge quantities of ore must be mined to extract small quantities of diamond produced at as low a cost as possible.

Placer mining for gem stones 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, the Republic of South Africa, Namibia, and the U.S.S.R.

Processing.—Most gem stone material is broken or crushed where necessary and concentrated by various combinations of hand picking, washing, screening, or jigging. In large-scale operations, mineral benefication methods employ mechanization and the latest technology in all steps 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.

TABLE 3

SYNTHETIC GEM STONE PRODUCTION METHODS

Gem stone	Production methods	Company	Date of first production
Ruby	Flux	Chatham	1950's
		Kashan	1960's
		Knischka	1980's
		J.O. Crystal (Ramaura)	1980's
	Zone melt	Seiko	1980's
	Melt pulling	Kyocera (Inamori)	1970's
	Verneuil	Various producers	1900's
Star ruby	do.	Various producers (Div. of Union Carbide)	1900's
	Melt pulling	Kyocera	1980's
		Nakazumi	1980's
Sapphire	Flux	Chatham	1970's
	Zone melt	Seiko	1980's
	Melt pulling	Kyocera	1980's
	Verneuil	Various producers	1900's
Star sapphire	do.	Linde	1940's
Emerald	Flux	Chatham	1930's
		Gilson	1960's
		Kyocera	1970's
		Seiko	1980's
		Lennix	1980's
		U.S.S.R.	1980's
	Hydrothermal	Lechleitner	1960's
		Regency	1960's
		Biron	1980's
		U.S.S.R.	1980's
Alexandrite	Flux	Creative crystals	1970's
	Melt pulling	Kyocera	1970's
	Zone melt	Seiko	1980's
Cubic zirconia	Skull melt	Various producers	1970's

ANNUAL REVIEW

Production

In 1990, all 50 States produced at least $1,000 worth of gem materials. Ten States accounted for 95% of the total value of natural gem material produced. The States, in order of declining value of production, were Tennessee, Arkansas, Arizona, Montana, California, Oregon, Alabama, North Carolina, Utah, and Texas. Certain States were known for the production of a single gem material (i.e., Tennessee for freshwater pearls and Arkansas for quartz). Other States produced a variety of gem materials. Arizona produced the greatest variety of gem materials. 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 gem materials. North Carolina was 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 $20.7 million per year, with a high of $52.9 million in 1990 and a low of $7.2 million in 1982. The value of production for the past 10 years must be separated into two trends. The first trend was the period between 1981

through 1985, during which time approximately 24 operations reported production. Production average $7.4 million per year and was generally level. During the second trend, 1986 to the present, production averaged $34.0 million and was the result of an increase of 1,567% in the number of producers surveyed.

The reported production value of synthetic and simulant gem materials was $20.5 million in 1990. The reported value of production increased 9%. The average value of production of synthetic and simulant gem materials for the past 5 years was $16.2 million, with a high of $20.5 million in 1990 and a low of $10.3 million in 1986. Thirteen firms, five in California, four in Arizona, and one each in Massachusetts, Michigan, New Jersey, and Ohio, produced synthetic and simulant gem material. The six States, in order of declining value of production, were Massachusetts, California, New Jersey, Michigan, Ohio, and Arizona.

Arizona is well known for the widest variety of gem materials produced by any State. In 1990, gem material production 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. Arizona was the largest producer of turquoise, peridot, and petrified wood in terms of dollar value in the United States. It was also the world's largest producer of the first two gem materials. Additionally, there are four manufacturers of synthetic or simulant gem materials in Arizona that produce about $100,000 worth of material each year.

Arkansas is famous for the production of quartz crystals. Yet, Arkansas is second in value of production of freshwater pearls and shells and the only State in the United States that has had any sustained diamond production.

For the past 19 years hobbyists have found from 300 to 1,500 diamonds per year at the Crater of Diamonds State Park. Since 1972, about 13,000 diamonds have been recovered; this amount of diamond production is insufficient to classify the United States as a diamond-producing country. Still, the potential to become a diamond producer may be there, and efforts were underway to evaluate this potential more fully. The program to evaluate the diamond deposit was halted by legal actions after completing three exploration drill holes. The program is currently on hold, awaiting the outcome of the litigations.

Gem material production from California includes a variety of materials. California is the leading tourmaline producer in the United States and the only producer of benitoite. Additionally, California produces agate, alabaster, beryl, dumortierite, fire agate, garnet, gem feldspar, jade, jasper, kunzite, lepidolite, obsidian, quartz, rhodonite, topaz, and turquoise. Yet, even with this long list of gem materials, most people think of California in terms of its State gem benitoite, the production of high-quality tourmalines, and its fine orange spessartine garnets.

In May 1989, Pala International reported the discovery of the largest gem tourmaline pocket found in the Himalaya Mine during the past 12 years. The pocket yielded about 500 kilograms of tourmaline; 50% was carving or cabochon grade, less than 1% was faceting grade, and the remainder was specimen grade.

California also has four manufacturers of synthetic or simulant gem materials. The State is the second largest producer of synthetics and simulants in terms of value of total production.

Colorado is not known as a gem material producing State, but it does hold some gem stone honors. For 4 or 5 years prior to 1988, Colorado had the only commercially operated amethyst mine in the United States. It has the only commercially mined deposit of lapis lazuli in the United States and one of the few dig-for-fee topaz deposits currently operating. Additionally, the State was the first to commercially produce turquoise and still has commercially operated turquoise mines. The State also produced the United States' finest gem-quality rhodochrosite and a quantity of high-quality rhodonite.

Many different locations in the State produce aquamarine, the Colorado State gem stone. 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 14,269 feet, may be the highest gem stone location in the United States. White Mountain, separated from Antero by a small saddle, is only slightly lower at 13,900 feet.

Star garnet, the Idaho State gem stone, leads the list of gem materials 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 occur at several other locations in Idaho and are mined periodically by hobbyists or professional collectors for the gem stone market.

Opal is the second largest contributor to the total value of gem material produced in Idaho. The varieties produced include precious, yellow, blue, pink, and common. The Spencer opal mine is the largest producer. At the Spencer Mine, precious opal occurs as one or more thin layers within common opal that have partially filled gas cavities within a rhyolite-obsidian flow. About 10% of the material is thick enough to cut into solid gems; the remainder is suitable for making doublets and triplets. The Spencer Mine is also the source of the pink opal, which occurs as either pink common opal or pink bodied precious opal.

In recent years, an increasing amount of gem material (smokey quartz, aquamarine, topaz, and garnets) has been recovered from the Sawtooth batholith. A significant portion of the batholith lays within the Sawtooth National Recreation Area, administered by the Forest Service, U.S. Department of Agriculture. Herein lies a possible problem. The Forest Service may prohibit the collection of gem and mineral specimens from the National Recreation Area under CFR Title 36, 269.9b, which prohibits the

removal of "natural features of the land." Additionally, all mining is prohibited in a recreation area. It appears that material is still being collected from the area, but this may stop in the future. Hopefully, collectors and the Forest Service can arrive at some mutual understanding where hobbyists can collect material or possibly collect controlled amounts for the commercial market.

In the U.S. gem stone industry, Maine and tourmaline are almost synonymous. In 1822, Maine's Mount Mica was the site of the first gem stone production in the United States. In September 1991, Plumbago Mining Corp. was actively mining the Mount Mica pegmatite for gem material and mineral specimens. Over the years, Mount Mica produced hundreds of pounds 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.

Maine also produces fine-quality beryls—aquamarine, heliodor, and morganite. Pegmatites in Oxford, Androscoggin, and Sagadahoc Counties regularly produce fine-quality blue and blue-green aquamarine, rich yellow and gold colored heliodor, and rose and peach colored morganite. In 1989, the largest rose colored morganite on record was found at the Bennett Quarry near Buckfield in Oxford County.

In 1989, Plumbago Mining Corp. opened the most significant commercial amethyst mine in the United States near the town of Sweden in Oxford County. Reported production in the first year of operation was about 5,000 pounds of gem-quality and specimen-grade amethyst. The gem material has good deep purple color, but is mostly small pieces. An officer of the company did report the cutting of a 12-carat stone from the material and that some material recovered would yield stones as large as 20 carats.

Montana produces many different gem materials, some suited to faceting, while others are better suited to the cutting of cabochons, carvings, or objects of art. The gem materials that come to mind when Montana is mentioned are sapphires and Montana moss agate, with Dryhead agates a very close third. Yet, amethyst, amazonite, azurite, covellite, cuprite, garnet, onyx, opal, petrified wood, rhodochrosite, rhodonite, smokey quartz, sphalerite, and wonderstone (banded rhyolite) are also produced or have been produced in the State for use as gem material.

Since 1865 Montana has produced sapphires. In recent years, it appears that the 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 dig-for-fee sapphire operations on the Missouri River and Rock Creek.

Until 1989, the value of Nevada's gem material production was essentially dependent upon the production of turquoise and opal, and the production of turquoise was, and still is, declining. In 1989, Nevada reported the first major production of nephrite jade.

The Nevada jade is from a deposit near Tonopah. The material varies in color from different shades of green to black, and some is mottled with off-white to tan markings. The reported quality is from fine gem to carving-grade. Mine run jade is available from fist-size pieces to individual boulders that weigh more than 1 ton. The jade is very similar to good to fine Wyoming jade.

Nevada has been a major producer of turquoise since the 1930's, and until the early 1980's, the State was the largest turquoise producer in the United States. Estimates indicate that over the years, 75 to 100 different mines and/or prospects have produced sizable quantities of turquoise. Production varied from a few thousand dollars worth of material at some properties to more than a million dollars 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 occurs primarily as replacement of wood, or sometimes, the replacement of cones of conifer trees. The uses of the opal are greatly restricted because of a severe problem with crazing. Currently, two mines in Virgin Valley are open to individuals on a dig-for-fee 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, are found. During 1988 was the last time all four major gem materials 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 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 some dig-for-fee 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 gem materials.

Every year there is publicity concerning the discovery of large and valuable rubies and sapphires at one or more of the mines in Cowee Valley. No doubt large corundum crystals and pieces of corundum are found each year. Similarly, valuable rubies and sapphires may be found, but the number of large and valuable gems and the values of these gems often are over-stated. During the period when commercial mines operated in the area, gem material was found that would cut fine-quality 3- to 4-carat stones. Today, the amount of quality gem material has greatly declined. Most of the rubies found are not of top color or clarity and on

average are suitable for cutting stones of a carat or less. The sapphires tend to be larger than the rubies and high-quality sapphires are more abundant than high-quality rubies.

In 1875, emeralds were discovered near what is now Hiddenite, with the first attempts at commercial mining of emeralds in the Hiddenite area in 1881. Other attempts at mining were made in the 1920's, the 1950's, the 1970's, and the latest ended in 1990. At different times the emerald deposits in the Hiddenite area have produced large emerald crystals, and some significant stones have been cut from Hiddenite material. Yet, to date, it has not been possible to maintain an economically viable mine operation on any of the deposits. This includes the last attempt that would have mass mined the deposit and used a berylometer to sort the emerald from the waste rock. The berylometer worked well, but the amount of emerald present did not support the project.

Historically, Oregon has been known for the production of various picture and scenic jaspers, agates, 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, which includes both sunstone and heliolite, is currently the largest single contributor to the value of annual gem material production in Oregon. At least seven firms or individuals currently are producing sunstone and/or heliolite from three different geographic areas.

The other gem material to contribute significantly to the value of Oregon gem material production 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 produced 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 pearls and freshwater mussel shells of the 11 producing States. The fishing and marketing of freshwater pearls and mussel shells are not new in the United States or in Tennessee. There has been an established U.S. freshwater mussel fishing industry since the mid-1850's. The mussels are from the family Unioidae, of which about 20 different species are commercially harvested. During 1990, the value of U.S. mussel shell exports was more than $50 million.

To date, freshwater pearls from the United States have been a byproduct of the shell industry. Currently, the primary use of the shells is to make the bead nucleus used by the Japanese cultured pearl industry. Additionally, the shells are used in making cameos and as mother-of-pearl. With the coming of the freshwater cultured pearl farms in Tennessee and the increasing popularity of freshwater pearl jewelry with the U.S. consumer, this may change. In 1963, the first experimental U.S. freshwater cultured pearl farm was established. Since the technology for culturing freshwater pearls was proven in the late 1970's, six freshwater pearl farms have been established. These farms are the beginning of the U.S. freshwater cultured pearl industry, and the cultured pearl is the heart and future of the U.S. pearl industry.

The gem material that Utah is best known for, topaz, is not well suited for use as a gem stone, but it does make a fine mineral specimen. Topaz crystals have been collected from certain rhyolite flows in the Thomas Mountains for more than 100 years. Similar crystals also are found in select rhyolites in the Wah Wah Mountains. The crystals from the Thomas Mountains are predominately small, 10 to 20 millimeters long and 4 to 6 millimeters across, and crystals from the Wah Wah Mountains are even smaller. Occasionally, large gem-quality crystals are found. The color of the topaz varies from colorless to light yellow, sherry brown, rose or light pink. Unfortunately, the light yellow to sherry brown color fades to colorless if exposed to sunlight or heat and rose or light pink colored crystals are rare. Because of the size of the crystals and problem with color fading, the material yields only small to very small colorless stones.

Another Utah gem material with nearly a 100-year production history is gem variscite, first produced in about 1893 near Fairfield. The latest recorded commercial production was from near Lucin during the summer of 1990. Variscite occurs as fracture fillings or as nodules. The nodules may be solid, almost geode in nature, or fractured solid nodules that have undergone alteration. The color of the variscite varies from deposit to deposit and from location to location within the same deposit. It is a shade of light to dark yellow-green, but can occur as a dark, nearly jade green and so pale as to appear almost white. It also can have black and brown spiderwebbing.

Another gem material from Utah is snowflake obsidian. Snowflake obsidian (also known as flower obsidian) earns its name from the bluish-white or grayish-white patterns of cristobalite included into the normally black obsidian. During 1990, two different firms produced this material commercially.

Topaz, variscite, and obsidian from Utah are well known and are nice materials. But, in the author's opinion, the red beryl from the Wah Wah Mountains is the most remarkable and desirable of Utah's gem materials. Bixbite, the variety name for red beryl (called red emerald by some) occurs 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 cut stones. 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 produce a single gem material of note; they are Alaska with its two jade mines; Florida's agatized coral; Hawaii's black coral; Minnesota's thomsonite; New York's herkimer quartz; Ohio's flint; and South Dakota's rose quartz.

The value of production by individ-

ual gem material can be reported for those materials that have three of 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. Table 4 is a list by commodity in alphabetic order, with values in dollars rounded to the nearest thousand.

Consumption and Uses

Consumption of domestic gem material production 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.

Industrial uses of tourmaline include a simple laboratory instrument to show the polarization of light, as a material to measure the compressibility of fluids, and in gages for measuring high pressures. Mortar and pestle sets, knife edges for balances, textile rollers, and spatulas are some nongem uses of agate. The manufacturing of jewel bearings for timing devices, gages, meters, and many other types of instruments requiring precision elements used natural gem material. These uses are now mostly supplied by artificial and synthetic crystalline materials.

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 uses of synthetic and simulant gem crystals include applications in frequency controllers, polarizers, transducers, radiation detectors, infrared optics, bearings, strain gages, amplifiers, lasers, lenses, crucibles, and many more. A recently developed use is as connectors for optical fibers.

The 1990 estimated value of U.S. apparent consumption was $3,059 million, down about 18% from 1989's record high. The average annual estimated consumption for the past 10 years was $2,871 million, with a high of $3,711 in 1989 and a low of $1,642 in 1982. The trend for estimated consumption for the past 10 years was one of continued growth with about 68% total increase.

In 1990, the value of U.S. estimated apparent consumption of diamonds decreased 18% to $2.6 billion. The average annual value of apparent consumption of diamonds for the past 10 years was $2,293 million, with a high of $3,115 million in 1989 and a low of $1,642 million in 1982. The trend for the value of apparent consumption for the past 10 years was one of significant increase. The value of apparent consumption of diamonds increased 90% over the period.

The 1990 estimated apparent consumption of colored stones, led by emerald, ruby, and sapphire, was valued at $397.1 million, a decrease of 3%. The annual average value of consumption of colored stones for the past 9 years was $325.0 million, with a high of $406.9 million in 1989 and a low of $252.4 million in 1982. The trend for apparent consumption of colored stones for the past 9 years was one of fluctuating increases and decreases, but the general tread was one of increased consumption.

The estimated apparent consumption of pearls—natural, cultured, and imitations—was $16.5 million, a decrease of about 89% from that of 1989. This large decrease makes one wonder if there is not an error in the import data for pearls. The value was only 17% of the 9-year low reached in 1982.

Estimated apparent consumption of synthetic and imitation gem materials increased about 115% to $94.1 million. Average apparent consumption of synthetic and imitation gem materials for the past 9 years was $55.2 million per year, with a high of $109.1 million in 1987 and a low of $13.9 million in 1982. The trend for apparent consumption for the past 9 years was one of generally strong growth except for the significant decrease in 1989. Annual apparent consumption increased about 577% over the 9 years.

Prices

Demand, beauty, durability, rarity, freedom from defects, and perfection of cutting determine the value of a gem stone. But the major factor in establishing the price of gem diamond is the control over output and prices as exercised by the CSO Diamond Trading Co. Ltd. The CSO is a subsidiary of De Beers Consolidated Mines Ltd.

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 $6,200 and $7,000 and was $7,000 at yearend. The average value per carat of all grades, sizes, and types of gem-quality diamond imports was $525, a 29% increase compared with that of 1989. The average value of diamond imports for the past 10 years was $405 per carat, with a high of $525 in 1990 and a low of $353 in 1984. The trend for the average annual value of diamonds imported for the past 10 years was one of general decline, from the 10-year high in 1980 to stable prices in 1986, 1987, and 1988, followed by the 1989 and 1990 increases.

The average yearend wholesale purchase price of a fine-quality 1-carat ruby, paid by retail jewelers on a per stone or memo basis, was $4,200, an increase of 20% from that of 1989. The average value of ruby imports increased 49% to $48.71 per carat. The average annual value of ruby imports for the past 9 years was $37.93 per carat, with a high of $48.71 in 1990 and a low of $16.42 in 1984. The trend for the value of ruby imports for the past 9 years was one of rapid decline, 52% for the period from 1982 to 1984. This was followed by a steady, moderate increase.

TABLE 4

VALUE OF 1990 U.S. GEM STONE PRODUCTION, BY GEM MATERIALS

Gem materials	Value
Agate	$250,000
Beryl	105,000
Coral (all types)	60,000
Garnet	78,000
Gem feldspar	500,000
Geode/nodules	240,000
Fire agate	20,000
Jasper	148,000
Obsidian	27,000
Opal	146,000
Peridot	884,000
Petrified wood	633,000
Quartz	1,767,000
Sapphire/ruby	3,727,000
Topaz	26,000
Tourmaline	350,000
Turquoise	1,105,000
Total	10,066,000

The average yearend wholesale purchase price of a fine-quality 1-carat sapphire, paid by retail jewelers on a per stone or memo basis, was $1,600, a 14% increase from that of 1989. The average value of sapphire imports decreased 11% to $21.57 per carat. The average annual value of sapphire imports for the past 9 years was $23.22 per carat, with a high of $27.97 in 1987 and a low of $18.50 in 1984. The trend for the value of sapphire imports for the past 9 years was one of fluctuating increases and decreases. The 9-year period ended with the 1990 value 12% below the 1982 value.

The average yearend wholesale purchase price of a fine-quality 1-carat emerald, paid by retail jewelers on a per stone or memo basis, was $2,750, the same as for 1989. The average value of emerald imports decreased 28% to $43.65 per carat. The average annual value of emerald imports for the past 10 years was $57.18 per carat, with a high of $78.79 in 1988 and a low of $35.06 in 1984. The trend for the value of emerald imports for the past 10 years was one of fluctuating increases and decreases from 1981 through 1984. A steady moderate growth followed until the 2 years of decline in 1989 and 1990, the average value in 1990 being about 76% of the 1981 value.

Foreign Trade

The export value of gem materials increased 33% to $1,566 million, a record high. The quantity of diamonds exported increased 45% to 1,003,760 carats, and the value of diamond exports increased about 29% to $1,398.8 million. The average annual quantity of diamonds exported for the past 10 years was 496,477 carats, with a high of 1,003,760 in 1990 and a low of 184,871 in 1982. The trend for the quantity of diamonds exported for the past 10 years was one of moderate decline, 13%, during the first 2 years, followed by significant growth, 443%, from 1983 to 1990. The average annual value of diamond exports for the past 10 years was $643.6 million, with a high of $1,398.8 million in 1990 and a low of $292.8 million in 1982. The trend for the value of diamond exports for the past 10 years was one of decline, 16%, over 3 years, followed by 3 years of moderate growth, 32%, and then 3 years of significant growth, 112%. This resulting in record-high exports in 1990.

The export of other precious stones, cut but unset and other than diamonds and pearls, increased about 62% to $70.6 million. The average annual export value for the past 9 years for these natural gem stones was $42.9 million, with a high of $70.6 million in 1990 and a low of $27.7 million in 1984. The 9-year trend for exports value of these types of gem materials was one of fluctuating increases and decreases, but one resulting in a significant total increase, 139% for the period.

Exports of synthetic gem material decreased 8% to $42.5 million. The average annual value of exports for the past 9 years was $18.6 million, with a high of $46.0 million in 1989 and a low of $6.0 million in 1987 and 1988. The 9-year trend for the value of exports was one of extreme decline, 52%, for 1982–88, followed by steady significant growth, 608%, during the past 2 years.

Exports of natural, cultured, and imitation pearls, not set or strung, decreased about 74% to $0.9 million.

Reexports of gem material decreased 84% to $47.3 million.

The value of gem materials imported decreased 10% to $4,609.3 million from 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 gem material imports for the past 10 years was $3,839 million, with a high of $5,115 million in 1989 and a low of $2,384 million in 1982.

The value of imported gem diamonds decreased about 9% to $3,955.2 million from the 1989 record high of $4,358 million. The 10-year trend for the value of diamond imports was one of generally steady continuous growth

TABLE 5

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. 1989–Jan. 1990	Average[4] July 1989
0.25	G	VS1	$1,300–$1,400	$1,400
.25	G	VS2	1,100– 1,200	1,200
.25	G	SI1	880– 970	970
.25	H	VS1	1,100– 1,200	1,200
.25	H	VS2	1,000– 1,100	1,100
.25	H	SI1	860– 950	950
.50	G	VS1	2,500– 2,700	2,900
.50	G	VS2	2,300– 2,500	2,600
.50	G	SI1	1,900– 2,300	2,200
.50	H	VS1	2,300– 2,600	2,600
.50	H	VS2	2,100– 2,400	2,400
.50	H	SI1	1,800– 2,100	2,100
.75	G	VS1	2,900– 3,500	3,300
.75	G	VS2	2,700– 3,200	3,000
.75	G	SI1	2,300– 2,800	2,600
.75	H	VS1	2,600– 3,000	2,900
.75	H	VS2	2,300– 2,700	2,600
.75	H	SI1	2,100– 2,500	2,400
1.00	G	VS1	4,600– 4,600	4,600
1.00	G	VS2	4,100– 4,100	4,100
1.00	G	SI1	3,500– 3,500	3,500
1.00	H	VS1	4,100– 4,100	4,100
1.00	H	VS2	3,600– 3,600	3,600
1.00	H	SI1	3,200– 3,200	3,200

[1] Gemological Institute of America (GIA) color grades: D—colorless; E—rare white; 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. 161, No. 3, Feb. 1990.
[4] Jeweler's Circular-Keystone. V. 159, No. 2, Sept. 1989.

TABLE 6

PRICES OF U.S. CUT COLORED GEM STONES, BY SIZE[1]

Gem stones	Carat weight	Price range per carat in 1990[2]	Average price per carat[2]	
			Jan. 1989	Jan. 1990
Amethyst	1	$6- $18	$8.00	$13.00
Aquamarine	1	100- 250	175.00	175.00
Emerald	1	1,900-3,500	2,400.00	2,750.00
Garnet, tsavorite	1	500- 800	950.00	650.00
Ruby	1	3,000-4,000	3,000.00	3,500.00
Sapphire	1	800-2,000	1,050.00	1,400.00
Tanzanite	1	250- 350	354.00	300.00
Topaz	1	6- 12	7.50	9.00
Tourmaline, red	1	60- 125	92.50	92.50

[1] Fine quality.

[2] Jewelers' Circular-Keystone. V. 161, No. 3, Mar. 1990, p. 190. 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.

with an increase of 80% for the period. During the period, the value of imported uncut diamonds increased 42%, while the value of cut stones imported increased 89%.

The imports of cut diamonds decreased 29% in quantity and 11% in value to 6.3 million carats and $3,384.4 million, respectively. The average annual quantity of cut diamonds imported was 6.6 million carats, with a high of 8.9 million in 1989 and a low or 1.6 million carats in 1982. The trend for the quantity of cut diamond imports for the past 10 years was one of continued increases until the 1990 decline; the period still ended with imports 80% greater than at the beginning of the period. The average annual value of imported cut diamonds was $2,762.4 million, with a high of $3,805.5 in 1989 and a low of $1,641.0 million in 1982. The trend for the value of imported cut diamonds for the past 10 years was of strong growth and increases. The value at the end of the period was 88% greater than at the beginning.

The value of imports of other gem materials, led by emerald, ruby, and sapphire, was $558.9 million, an decrease of about 26% compared with that of 1989. Emerald imports decreased about 22% to $162.4 million. The average annual value of emerald imports for the past 10 years was $151.9 million, with a high of $207.5 million in 1989 and a low of $120.8 million in 1982. The 10-year trend for the value of emerald imports was one of fluctuating increases and decreases resulting in a 44% increase for the period.

The value of ruby imports increased 18% to $98.4 million, a record-high value for the past 10 years. The average annual value of imports for the past 10 years was $77.2 million, with a high of $98.4 in 1990 and a low of $58.7 in 1987. The 10-year trend for import values was one of extreme fluctuations. The period ended with values having increased 68% from the 10-year low and establishing a record high for the period.

The value of sapphire imports decreased 18% from the 1989 10-year high to $81.9 million. The average annual value of sapphire imports for the past 10 years was $81.8 million, with a high of $100.0 million in 1989 and a low of $63.3 million in 1982. The 10-year trend for the value of imports was one of extremely fluctuating increases and decreases. The period ended with the value slightly lower than at the beginning of the period.

The value of imported gem materials other than diamond, emerald, ruby, and sapphire decreased 41% to $216.2 million. The average annual value of imports was $325.3 million, with a high of $429.5 in 1988 and a low of $134.6 in 1981. The 10-year trend for the value of imports was one of fluctuating increases and decreases resulting in the period ending 61% higher than the period started.

World Review

De Beers, Cententary AG's diamond marketing arm, the CSO, reported 1990 sales of rough, uncut diamonds increased 2% over that of 1989 to $4.17 billion. Sales for the year were up, but sales for the second half of 1990 were 32% less than the sales for the first half of the year. Also, if the sales were adjusted for inflation, which was about 6% in the United States and higher in other leading consumer countries, the value of diamond sales actually decreased. The CSO markets from 80% to 85% of the total world production of natural diamonds. 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—U.S.S.R. (northeastern Siberia and in the Yakut A.S.S.R.); in Australia; and in South America—Venezuela and Brazil.

Foreign countries in which major gem stone 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.—Endiama, the state diamond company, signed a two-part agreement with De Beers' CSO that reestablished a trading relationship that was ended in 1985. The first part of the agreement calls for De Beers to provide a $50 million loan to Endiama to be used to increase the production from the Cuango area. De Beers will market all of the production from the Cuango area; the area accounts for about 80% of Angola's production.

The second part of the agreement calls for De Beers to spend $50 million over 5 years on the evaluation of the Camutue kimberlite in northeastern Angola and on the search for additional kimberlite sources of diamonds.

Any mines resulting from this agreement will be jointly developed by De Beers and Endiama.

Endiama also signed an agreement with Steinmetz Evens Diamonds for the sale of diamonds produced in the Andrada and Lucapa areas. The alluvial deposits of these areas are about depleted and are of little interest to De Beers.[4]

Australia.—Diamond production in Australia decreased slightly because of a decrease in the production from Argyle. Argyle produced 33.8 million carats compared with 1989 production of 34.4 million, a decrease of about 2%. Estimates of 1990 Bow River production are about 900,000 carats.

In a move to increase the market for diamonds from the Argyle mine, Argyle Diamonds of Australia announced a multimillion dollar advertisement program to promote champagne colored diamonds. The multipart program will be directed primarily at the U.S. market.

More than 90 companies are involved in diamond projects in Australia, with another 23 companies exploring for diamonds on offshore projects. The success of the Argyle mine and reassessment of old information has led to the latest rush concentrated in New South Wales, with some companies in northern New South Wales claiming to have discovered pipes larger than that at Argyle.

Miners in Coober Pedy claimed to have found the world's biggest opal; the uncut opal weighed 5.27 kilograms and has an estimated worth of $3 million. The stone is 233.37 centimeters long and 12.19 centimeters wide. The opal is milky white in color.

Botswana.—Corona Corp. agreed to acquire control of Repadre Capital Corp. and the new firm will be named Corona Diamonds International Corp. Repadre had agreed to a joint venture with Ampal (Pty.) Ltd. to develop Ampal's diamond licenses in Botswana. Ampal holds multiple prospecting licenses covering about 20,700 square kilometers upon which a number of kimberlites have been identified. Exploration drilling is schedule to start on 30 to 50 of these targets. Corona Diamonds could earn a 40% interest in the properties by spending about $1.75 million before December 31, 1991. Additional interests can be earned by further expenditures.

The Government of Botswana and Lazare Kaplan International Inc. (LKI) signed a long-term agreement for a diamond cutting and polishing factory in Botswana. The agreement represent a major investment by a U.S. company in Botswana. The factory will be a state-of-the-art plant using automated and manual equipment. LKI will manage the plant and train Botswana workers as operators. It is anticipated that the plant will ultimately employ at least 500 skilled workers.

The Government of Botswana and Mabrodiamn, 85% owner of Diamond Manufacturing Botswana (DMB), signed a contract to expand DMB's 12-year-old cutting factory at Garabone. The agreement was to expand the plant from its current 55 workers to 200 workers. The factory manufactures low-quality 2 grainer sawn rough, but some 10-carat sawn is manufactured also. Cutting factory labor costs in Botswana are lower than in Belgium, but higher than in the Far East.

Canada.—Uranerz Exploration and Mining of Canada reported finding two diamonds, one two millimeters and the other four millimeters, near Melfort in the area of Fort a la Corne. These diamonds are significantly larger than the microdiamonds found in the past. Microdiamonds have been found in the area by other companies, including Claud Resources and Monopros Ltd., a subsidiary of De Beers. None of the companies exploring in the area has yet to discover a commercial deposit of diamonds, but these larger stones do increase the interest of the companies exploring the area. Uranerz plans to spend $2 million on exploration in the area in the next 2 years.

China.—The Mineral Resources Bureau reports that geologists discovered 13 diamond deposits along the Tanlu Fault Zone that stretches across several Provinces in the eastern part of the country. The Bureau claims to have found more than 100 kimberlites and 4 diamond placers in Shandong Province, while in Liaoning Province it found 3 large primary deposits and 3 smaller placer deposits.

Cook Islands.—The Cook Islands received $25 million in aid from the U.S. Agency for International Development for the development of a black pearl industry. The pearl industry would be started on the island of Suwarrow and possibly extended to the islands of Pen-

TABLE 7

U.S. EXPORTS AND REEXPORTS OF DIAMOND (EXCLUSIVE OF INDUSTRIAL DIAMOND), BY COUNTRY

Country	1989		1990	
	Quantity (carats)	Value[1] (millions)	Quantity (carats)	Value[1] (millions)
Exports and reexports:				
Belgium	279,682	$216.8	267,010	$269.4
Canada	25,722	31.1	35,837	23.7
France	5,577	11.4	8,388	13.2
Hong Kong	140,686	253.5	163,845	316.4
Israel	250,888	214.2	248,766	221.0
Japan	114,634	206.8	98,777	282.9
Singapore	3,274	10.1	4,766	20.2
Switzerland	42,201	180.7	82,800	131.3
Thailand	39,575	16.4	51,211	35.1
United Kingdom	10,451	60.6	14,180	45.8
Other	137,798	42.1	28,180	39.7
Total	1,050,488	1,243.7	1,003,760	1,398.7

[1] Customs value.

Source: Bureau of the Census.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF DIAMOND, BY KIND, WEIGHT, AND COUNTRY

Kind, range, and country of origin	1989		1990	
	Quantity (carat)	Value[1] (millions)	Quantity (carat)	Value[1] (millions)
Rough or uncut, natural:[2]				
Belgium	57,962	$18.0	104,544	$26.1
Brazil	33,709	5.7	10,547	1.2
Israel	12,979	7.1	11,769	5.4
Netherlands	24,424	11.7	5,552	12.1
South Africa, Republic of	9,130	13.8	458	.4
Switzerland	12,268	11.9	1,653	3.6
United Kingdom	747,397	254.0	300,579	287.1
Venezuela	7,275	.9	8,923	.5
Other	284,292	229.5	779,030	234.4
Total	1,189,436	552.6	1,223,055	570.8
Cut but unset, not more than 0.5 carat:				
Belgium	1,531,997	962.7	769,047	326.9
Brazil	39,200	16.2	17,168	6.1
Canada	7,754	5.5	7,232	1.0
Hong Kong	101,828	48.1	176,077	45.4
India	3,136,459	792.4	2,946,261	768.8
Israel	1,784,444	1,104.3	471,820	224.0
Netherlands	19,227	24.1	4,363	2.4
South Africa, Republic of	10,707	15.7	8,326	7.5
Switzerland	41,986	75.6	12,894	4.7
United Kingdom	37,581	37.3	5,593	1.9
Other	138,808	57.0	80,997	39.8
Total	6,849,991	3,138.9	4,499,778	1,428.5
Cut but unset, more than 0.5 carat:				
Belgium	266,164	99.0	516,109	651.1
Hong Kong	68,930	19.5	15,811	32.8
India	1,176,503	312.0	181,619	113.0
Israel	318,288	178.5	983,684	942.0
Netherlands	4,809	10.5	10,844	24.9
South Africa, Republic of	1,245	.4	5,792	11.5
Switzerland	21,420	13.4	14,484	70.3
United Kingdom	11,116	8.2	28,288	52.6
Other	151,614	25.1	48,550	57.7
Total	2,020,089	666.6	1,805,181	1,955.9

[1] Customs value.
[2] Includes some natural advanced diamond.

Source: Bureau of the Census.

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Guinea.—Currently, at least four companies are either exploring for or mining diamonds in Guinea. Aredor, the company with the longest history in diamond operations in the country, is experiencing a decline in production and in profits. The decline in production is because of decreasing ore grades. The decreasing profits is because of a combination of lower diamond production and a lower sales price for diamonds. The 1990 average sales price for Aredor's diamonds was down 19% to $245 per carat.

Star Diamonds has a prospection license area 30 kilometers to the south and east of the Aredor lease. The alluvial deposits that are of the most interest are those on the flats near Bouro and those at the headwaters of the Bouloumba.

Sidam-Minorex is exploring in an area for diamonds near Forecariah, east of Conakry, and Hydro Mineral Exploration is exploring for diamonds near Bounoudou.

Brigade Aurifere de Guinee has a concession to mine gold in an area north of the Aredor lease in which diamonds may be found also.

Hong Kong.—Less than 50% (42 of 98) of the jadeite jewelry lots were sold at Christie's Swire Ltd.'s auction in October. The 42 lots brought in $1.4 million. The sale was disappointing according to Christie's, but the jadeite market is and always has been extremely volatile. In November, buyers purchased about 75% (90 of 121 lots) of the jadeite jewelry sold at auction by Sotheby's Hong Kong Ltd. The total purchase price of the jewelry was $4.02 million. According to a Sotheby's representative, the market for top-quality jade is strong, but the market for decorative materials is very soft.

India.—Imports of rough diamonds fell in 1990 by 16% in value and 37% in volume to $1.97 billion and 38 million carats, respectively. Total exports of polished stones for the year also declined, caratage decreased 13% to 8.7 million carats, and value fell 9% to $2.7 billion. The decline in demand of cut goods resulted in the closing down of thousands of production units in the past 12 months and as many as 20,000 workers laid off by yearend. The decreases were blamed on the recession in the United States and the Persian Gulf war. Cut diamonds account for 90% by value of gem and jewelry exports, which in turn account for nearly 20% of the country's total exports.

Indonesia.—Development of the Danau Seran diamond project in South East Kalimantan began in late 1990. Dry mining and a conventional diamond recovery plant will be used in place of a dredge. This approach is cheaper and easier to finance. The Danau Seran contains about 2.9 million cubic meters of diamondiferous gravel with a grade of 0.1 carats per cubic meter. The deposit will be mined over the next 3 years at a production

rate of 72,000 cubic meters per month. The group that put up the $2 million in financing will control a 25% equity interest. The interests of Indonesian Diamond Corp. (formerly Acorn Securities) and Keymead have been reduced to 44.7% and 10.3%, respectively, with PT Aneka Tambang (Indonesian Government) holding the remainder.[5]

Malaysia.—Boulders of nephrite jade were discovered in Sabah State in the northern part of Borneo. The boulders ranged in size from about 0.5 meters to 1.0 meters. The jade has a flawless area of good color that is suitable for jewelry. The source of the boulders and the commercial viability of the deposit are not known at this time.

Sierra Leone.—The Government of Sierra Leone granted a 20-year concession to Sunshine Mining Co. of the United States to mine and market diamonds from the Kono kimberlite deposit. Exploration and development work to date indicates the deposit contains about 2.4 million carats of recoverable gem-quality diamonds. Sunshine estimated the project capital costs at about $54 million.

The Government of Sierra Leone granted a lease to Intertarade Prospecting, a Swedish firm, to mine diamonds in an area north of Freetown. The firm announced plans to spend about $3 million dollars on deposits that are reported to be of marginal viability.

Wildcat Holdings PL, a wholly oned subsidiary of Pioneer Resources, entered into an agreement with Xerxes Ltd. to explore for diamonds in the Baoma district. The area is believed to contain both alluvial and kimberlite diamond deposits.

South Africa, Republic of.—The De Beers Mine, the smallest of the four mines De Beers Consolidated Mines Ltd. operates in Kimberley, is scheduled to close in October 1990. Treatment of surfaces stockpile ore at the mine will continue well into 1991. The mine was discovered in 1871 and operated as an open pit mine until 1885, at which time underground operations were started. The mine closed in 1908 and remained closed until opening once more in 1960 and operated until 1990.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF GEM STONES, OTHER THAN DIAMOND, BY KIND AND COUNTRY

Kind and country	1989		1990	
	Quantity (carats)	Value[1] (millions)	Quantity (carats)	Value[1] (millions)
Emerald:				
Belgium	10,605	$1.2	21,217	$1.1
Brazil	80,829	12.8	1,189,248	6.3
Colombia	429,390	73.1	382,051	58.2
France	5,345	4.0	10,202	2.5
Germany, Federal Republic of	23,902	3.2	44,811	2.1
Hong Kong	135,423	18.9	156,111	13.2
India	2,068,254	25.9	1,317,886	24.7
Israel	89,559	24.7	93,973	20.6
Japan	10,178	1.1	2,769	.2
South Africa, Republic of	146	(2)	52	(2)
Switzerland	60,265	28.6	144,394	18.9
Taiwan	1,681	.7	4,533	.2
Thailand	366,925	5.0	291,458	7.4
United Kingdom	6,187	2.5	9,722	2.6
Other	112,866	5.8	51,962	4.4
Total	3,401,555	207.5	3,720,389	162.4
Ruby:				
Belgium	7,760	1.1	4,250	.4
Brazil	8,093	(2)	1,562	.1
Colombia	337	(2)	346	.1
France	21,483	3.5	3,340	2.2
Germany, Federal Republic of	20,822	.8	11,580	.8
Hong Kong	79,583	6.1	49,175	5.3
India	455,954	1.6	313,583	2.3
Israel	26,326	3.8	12,857	1.1
Japan	796	0.4	13	(2)
Switzerland	70,098	19.7	190,056	26.6
Thailand	1,778,218	38.9	1,323,506	46.6
United Kingdom	3,596	2.9	66,831	6.5
Other	73,345	4.6	42,991	6.4
Total	2,546,411	83.4	2,020,090	98.4
Sapphire:				
Australia	30,439	.4	3,013	.2
Austria	377	(2)	202	(2)
Belgium	26,155	2.2	14,131	.5
Brazil	8,705	.2	2,827	.1
Canada	5,622	.6	2,126	.2
Colombia	358	.2	1,328	(2)
France	7,825	1.4	2,409	1.9
Germany, Federal Republic of	31,999	1.4	44,834	.9
Hong Kong	102,671	8.4	83,519	3.9
India	112,937	1.0	101,510	.8
Israel	29,535	4.7	26,140	1.5
Japan	2,532	.6	7,666	.1

See footnotes at end of table.

TABLE 9—Continued

U.S. IMPORTS FOR CONSUMPTION OF GEM STONES, OTHER THAN DIAMOND, BY KIND AND COUNTRY

Kind and country	1989 Quantity (carats)	1989 Value[1] (millions)	1990 Quantity (carats)	1990 Value[1] (millions)
Sapphire—Continued				
Korea, Republic of	9,024	(2)	204	(2)
Singapore	481	(2)	4,931	.6
Sri Lanka	63,184	4.1	106,211	5.4
Switzerland	67,086	15.6	91,574	11.3
Thailand	3,576,666	55.1	3,248,891	51.2
United Kingdom	9,435	2.5	11,135	1.8
Other	34,348	1.6	44,113	1.5
Total	4,119,379	100.0	3,796,764	81.9
Other:				
Rough, uncut:				
Australia		1.4		1.7
Brazil		36.0		37.4
Colombia		10.5		2.4
Hong Kong		2.2		(2)
Nigeria	NA	.7	NA	.1
Pakistan		1.4		.4
South Africa, Republic of		.2		.4
Switzerland		1.3		3.5
United Kingdom		(2)		.4
Zambia		.5		1.2
Other		11.1		16.3
Total	NA	65.3	NA	63.3
Cut, set and unset:				
Australia		10.7		6.1
Brazil		5.0		12.7
Canada		.2		.5
China		1.1		1.9
Germany, Federal Republic of		12.2		19.6
Hong Kong	NA	21.2	NA	18.5
India		3.7		5.8
Japan		118.3		11.7
Switzerland		1.3		1.7
Taiwan		1.8		3.4
Thailand		10.0		41.1
United Kingdom		2.4		2.1
Other		15.7		21.4
Total	NA	203.6	NA	146.5

NA Not available.
[1] Customs value.
[2] Less than 1/10 unit.

Source: Bureau of the Census.

The Kim Diamond Cutting Works, a diamond cutting factory, was constructed in Kimberley. The factory will employ at least 1,280 workers and will process 30,000 carats of local rough per week. The plant will produce from 0.01- to 0.30-carats stones for the export market.

Sri Lanka.—The Government of Sri Lanka changed the regulations on the export of geuda three times during 1990. The first change was made at the end of July when the agreement to sell geuda only to Thailand was ended and the sale of geuda was opened to buyers from all countries. In August, the exports of geuda was restricted to milky corundum; therefore, only firms specializing in the heat treatment of this type of geuda could export materials. In October, the regulations were amended to include silky, yellow silky, ottu, ooral, diesel, and dalan geuda. The Government descriptions used for geuda based on appearance under reflected light include milky (white, blue or yellow with a milky or soapy appearance), silky (white or blue with a shiny effect over the entire stone caused by rutile inclusions), yellow silky (yellow with shiny effect), ottu (blue patches or bi-colored), coral (color concentrated in patches without a definite outline and difficult to locate color source), diesel (brownish with oily appearance similar to diesel), and dalan (loosely sued for two or more of the above varieties in small sizes, also for large stones with many cracks and bubbles). Under the new system the number of carats of geuda exported in-

TABLE 10

VALUE OF U.S. IMPORTS OF SYNTHETIC AND IMITATION GEM STONES, INCLUDING PEARLS, BY COUNTRY

(Million dollars[1])

Country	1989	1990
Synthetic, cut but unset:		
Austria	3.7	3.6
France	.4	.8
Germany, Federal Republic of	9.4	9.6
Japan	.4	.6
Korea, Republic of	4.3	5.5
Switzerland	3.8	3.1
Other	7.4	9.4
Total	29.4	32.6
Imitation:		
Austria	40.0	53.6
Czechoslovakia	3.1	1.9
Germany, Federal Republic of	1.6	1.6
Japan	.4	.3
Other	12.2	3.2
Total	57.3	60.6

[1] Customs value.

Source: Bureau of the Census.

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF GEM STONES

(Thousand carats and thousand dollars)

Stones	1989		1990	
	Quantity	Value[1]	Quantity	Value[1]
Diamonds:				
Rough or uncut	1,189	552,557	1,223	570,750
Cut but unset	8,870	3,805,590	6,305	3,384,472
Emeralds: Cut but unset	3,402	207,546	3,720	162,375
Rubies and sapphires: Cut but unset	6,666	183,344	5,817	180,375
Pearls:				
Natural	NA	4,382	NA	3,734
Cultured	NA	144,335	NA	19,097
Imitation	NA	5,456	NA	3,814
Other precious and semiprecious stones:				
Rough, uncut	NA	65,298	NA	63,751
Cut, set and unset	NA	55,909	NA	119,866
Other	NA	NA	NA	5,917
Synthetic:				
Cut but unset	99,292	29,368	113,367	32,649
Other	NA	3,441	NA	1,911
Imitation gem stone	NA	57,323	NA	60,594
Total	XX	5,114,549	XX	4,609,305

NA Not available. XX Not applicable.
[1] Customs value.

Source: Bureau of the Census.

creased, but the value of geuda exports decreased.[6]

Tanzania.—The Government of Tanzania and Tanex Ltd., a company associated with De Beers Centerary AG, concluded an agreement to explore for diamonds over a large area south of Lake Victoria and to the south and west of the Williamson Mine. Exploration in the past has discovered several kimberlites that contained diamonds, but none were economical to mine.

U.S.S.R.—The Soviet Government entered into an agreement with De Beers giving De Beers exclusive marketing right to the U.S.S.R. diamond production for the next 5 years. The agreement was with Glavalmazzoloto, the organization that administers the sale and export of rough diamonds. Under the terms of the contract, a De Beers' subsidiary will provide a $1 billion advance against future production, but secured by the Soviet stockpile. It is estimated that the contract calls for a purchase of $1 billion worth of diamonds per year.

It is estimated that the U.S.S.R.'s diamond cutting industry employs about 16,000 workers. The eight Krystall factories at Moscow, Smolensk, Kiev, Barnaul, Vinnitsa, Yerecvan, 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, which 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 consumptions of rough and yield of finished can be estimated. It is estimated that during a year the U.S.S.R.'s diamond cutting industry processes about 3.8 million carats of rough that yields about 1.6 million carats of polished goods. The polished goods would be worth between $500 million and $550 million on the world market.

Reportedly, the U.S.S.R. is considering a joint venture with unnamed Western concerns to open a new diamond mine and cutting factory. The mine would be on a deposit about 100 kilometers north of Archngel. Reports indicate that the deposit contains 50% gem-quality diamonds.

Vietnam.—A new ruby mine in Hoang Lien Son district of Luc Yen, 270 kilometers west of Hanoi, produced about 1.12 million carats of ruby during 1990. It is estimated by company officials that about 30% of the rough or 336,000 carats is top quality faceting rough; 40%, or 448,000 carats, is medium quality for faceting and cabochons; and 30% is low quality for beads and cabochons. The mine is operated by a Thai-Vietnamese joint venture between B.H. Mining Co. Ltd. and the Vietnamese state gem enterprise, Vinagemco. It is planned for the production to be sold at auction in Hanoi.

Zaire.—It was reported that a 345.7-carat diamond was found in the Sediza Mine. The stone is said to be internally flawless with only a few minor surface blemishes. Early estimates of the stone's value are as high as $3.8 million.

Zambia.—The Government of Zambia reduced restrictions on the mining and marketing of gem stones. Miners can now retain 50% of foreign exchange earnings instead of 20%. Additionally, a gem stone board, run by miners, and an auction system will be established. The Government estimates that Zambia exported $200 million worth of gem stones in 1989, although only $10 million were officially reported.

Zimbabwe.—De Beers was unable to reach agreement with the Government of Zimbabwe on the development of the River Ranch Kimberlite deposit near the southern border at Beitbridge. The deposit was originally discovered in 1975. The Government of Zimbabwe was unwilling to grant De Beers' CSO an

exclusive marketing agreement. The Government wanted to market the production through its Minerals Marketing Corp., which would also retain a portion of the production for domestic processing. The Government has initiated procedures for the forfeiture of the River Ranch claims held by De Beers.

Current Research

An oval jade cabochon in a ring offered to Sotheby's Hong Kong Ltd. for its 1990 jadeite jewelry auction was found to have been treated with a new procedure to improve its appearance. Testing by the Hong Kong Gems Laboratory discovered a coating that is a highly adhesive, colorless organic resin mixed with a chemical compound that makes it resistant to high temperatures. The Gemological Association of All Japan found an oval jade cabochon that had exceptionally good color, luster, and transparency that was poor quality white jadeite treated with a green resinous coating. The coatings can be identified by immersing the piece in methylene iodide and shining a bright light on the stone to display the thin transparent layer of the coating.[7]

OUTLOOK

World demand for gem diamond can be expected to rise because of increasing effective personal income of the population 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 with 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 stone increases. Demand for synthetic and simulant gem materials for both personal and industrial consumption is expected to increase. The diversity of sizes, types, uses, and values of gem materials precludes any meaningful forecasting of future demand.

[1] Nassau, K. Gemstone Enhancement. Buttersworth, 1984, pp. 46–60

[2] Jewelry News Asia, No. 75, Nov. 1990, pp. 61–78.

[3] Pages 25–44 of work cited in footnote 2.

[4] Mining Journal. V. 316, No. 8103, Jan. 4, 1991, p. 1.

[5] Industry in Action Mining Journal. V. 315, No. 8096 Nov. 9, 1990, p. 357.

[6] Jewelry News Asia, No. 76, Dec. 1990, p. 28.

[7] Jewelry News Asia, No. 75, Nov. 1990, p. 90.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Gem Stone Producers in the United States, 1990.

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Mineral Industry Surveys, Annual Advance Summary Supplement: Gem Stone Production In Arizona, Oregon, Maine, Utah, Nevada, and Tennessee.

TABLE 12

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

(Thousand carats)

Country	1986			1987			1988				1989				1990[e]			
	Natural			Natural			Natural			Synthetic[3]	Natural			Synthetic[3]	Natural			Synthetic[3]
	Gem[2]	Industrial	Total	Gem[2]	Industrial	Total	Gem[2]	Industrial	Total		Gem[2]	Industrial	Total		Gem[2]	Industrial	Total	
Angola	240	10	e250	180	10	e190	950	50	e1,000	—	r1,165	r80	r1,245	—	1,200	80	1,280	—
Australia	13,145	16,066	29,211	13,650	16,683	30,333	r17,413	r17,413	r34,826	—	17,540	17,540	35,080	—	17,331	17,331	4 34,662	—
Botswana	9,590	3,500	13,090	9,368	3,840	13,208	10,660	4,569	15,229	—	10,676	4,576	15,252	—	12,146	5,206	4 17,352	—
Brazil	310	315	625	r300	r200	r500	353	180	533	—	350	r150	500	—	350	150	500	—
Central African Republic	259	99	358	304	108	412	284	59	343	—	r334	r81	r415	—	300	80	380	—
China[e]	200	800	1,000	200	800	1,000	200	800	1,000	15,000	200	800	1,000	15,000	200	800	1,000	15,000
Côte d'Ivoire[e 5]	10	4	14	15	6	21	8	3	11	—	r9	r3	r12	—	9	3	12	—
Czechoslovakia[e]	—	—	—	—	—	—	—	—	—	5,000	—	—	—	5,000	—	—	—	5,000
France[e]	—	—	—	—	—	—	—	—	—	4,000	—	—	—	4,000	—	—	—	4,000
Ghana[6]	88	498	586	65	400	465	r155	r465	r e620	—	r124	r370	r e494	—	129	386	515	—
Greece[e]	—	—	—	—	—	—	—	—	—	1,000	—	—	—	1,000	—	—	—	1,000
Guinea[6]	190	14	204	163	12	175	136	10	146	—	138	10	148	—	130	5	135	—
Guyana	3	6	9	2	5	e7	1	3	4	—	r3	r5	r8	—	3	5	8	—
India	13	3	16	r16	3	r19	r11	3	14	—	3	r12	r15	—	3	12	15	—
Indonesia[e]	6	22	28	7	22	29	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	63	189	252	r112	r183	r e295	67	100	167	—	r62	r93	r155	—	40	60	100	—
Namibia	970	40	1,010	971	50	1,021	901	37	938	—	r910	r17	r927	—	735	13	4 748	—
Romania[e]	—	—	—	—	—	—	—	—	—	5,000	—	—	—	4,500	—	—	—	4,500
Sierra Leone[5]	215	100	315	150	75	225	r12	r6	r18	—	r90	r39	r129	—	100	50	150	—
South Africa, Republic of:																		
Finsch Mine	1,821	3,208	5,029	1,455	2,701	4,156	1,372	2,548	3,920	—	1,613	2,997	4,610	—	1,462	2,716	4 4,178	—
Premier Mine	882	1,977	2,859	772	1,713	2,485	696	1,543	2,239	—	689	1,526	2,215	—	724	1,604	4 2,328	—
Other De Beers' properties[7]	1,428	529	1,957	1,427	546	1,973	1,388	531	1,919	—	1,360	520	1,880	—	1,240	474	4 1,714	—
Other	342	41	383	409	30	439	361	65	426	—	348	63	411	—	400	74	4 474	—
Total	4,473	5,755	10,228	4,063	4,990	9,053	3,817	4,687	8,504	e55,000	4,010	5,106	9,116	e60,000	3,826	4,868	4 8,694	60,000
Swaziland	23	16	39	48	32	e80	44	29	73	—	33	22	55	—	19	13	32	—
Sweden[e]	—	—	—	—	—	—	—	—	—	25,000	—	—	—	25,000	—	—	—	25,000
Tanzania[e]	133	57	190	105	45	150	105	45	150	—	105	45	150	—	105	45	150	—
U.S.S.R.[e]	r7,400	r7,400	r14,800	r7,400	r7,400	r14,800	r7,500	r7,500	r15,000	41,500	r7,500	r7,500	r15,000	41,500	7,500	7,500	15,000	41,000
United States	—	—	—	—	—	—	—	—	—	W	—	—	—	W	—	—	—	W
Venezuela[8]	r46	r165	r212	r38	r68	r106	r54	r74	r128	—	r70	r185	r255	—	88	245	4 333	—
Yugoslavia[e]	—	—	—	—	—	—	—	—	—	5,000	—	—	—	5,000	—	—	—	5,000
Zaire	4,661	18,643	23,304	3,885	15,540	19,425	r2,724	r15,439	r18,163	—	r2,663	r15,092	r17,755	—	2,700	15,300	18,000	—
Total[8]	r42,038	r53,702	r95,741	r41,042	r50,472	r91,514	r45,402	r51,494	r96,896	241,500	r45,992	r51,751	r97,743	246,000	46,921	52,175	99,096	245,500

[e] Estimated. [p] Preliminary. [r] Revised. W Withheld to avoid disclosing company proprietary data.

[1] Table includes data available through May 17, 1991. Total diamond output (gem plus industrial) for each country actually is reported except where indicated by a footnote to be estimated. In contrast, the detailed separate production data for gem diamond and industrial diamond are U.S. Bureau of Mines estimates in the case of every country except Australia (1986–87), Botswana (1987), Brazil (1987), Central African Republic (1986–89), Guinea (1986–89), and Liberia (1986), 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. Estimated distribution figures have been revised as necessary to correspond to reported total production figures.

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

[3] Includes all synthetic diamond production.

[4] Reported figure.

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

[6] Figures do not include smuggled artisanal production.

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

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

GERMANIUM

By Thomas O. Llewellyn

Mr. Thomas O. Llewellyn is a physical scientist with the Branch of Industrial Minerals. He has covered germanium for 4 years. Domestic survey data prepared by Tony E. Morris, mineral data assistant.

Domestic production and consumption of refined germanium were estimated at lower levels than those of 1989. The declines in germanium production and consumption were attributed to an existing oversupply of metal and to a lower demand from the military sector. Infrared systems and fiber optics continued to be the major end uses.

DOMESTIC DATA COVERAGE

Refinery production and consumption data for germanium are estimated by the U.S. Bureau of Mines based on discussions with domestic producers.

BACKGROUND

Germanium is recovered as a minor byproduct of the refining of base metal ores, and the potential supply of this metal, which is dependent on the level of zinc production, has historically exceeded demand.

Invention and development of the germanium transistor opened the path for the solid-state electronic field and, from 1950 through the early 1970's, provided an excellent market for germanium. Despite the continued growth of the electronics industry in the 1970's, germanium demand for transistors, diodes, and rectifiers declined because germanium was being replaced by electronic-grade silicon. However, the reduced demand for germanium in the electronics field was offset by a dramatic increase in demand for germanium in both infrared night vision systems and fiber-optic communication networks.

Definition, Grades, and Specifications

Germanium has a metallic appearance, 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-centimeters at 20° C (40 ohm-centimeters 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 Co., 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 Gordonville and Elmwood 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.

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 and extracting. 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.

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]

TABLE 1

U.S. IMPORT DUTIES FOR GERMANIUM MATERIALS

Item	HTS No.	Most favored nation (MFN) Jan. 1, 1990	Non-MFN Jan. 1, 1990
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.

ANNUAL REVIEW

Strategic Considerations

The importance of germanium as a strategic and critical material was determined by the Federal Emergency Management Agency, and, on July 6, 1984, it was included in the National Defense Stockpile (NDS) with an initial goal of 30,000 kilograms of germanium metal. On July 24, 1987, a new NDS goal of 146,000 kilograms was established, based on the Army's estimates for actual emergency conditions of mobilization.

Some of the metal inventory acquisitions made the previous year were delivered in 1990, and, as of December 31, the stockpile inventory was 58,287 kilograms of germanium metal.

Production

The U.S. Bureau of Mines estimated domestic refinery production from both primary and secondary materials to be 18,000 kilograms, a decrease of 10% compared with that of 1989.

In August, Hecla Mining Co., the owner of the only known mine and refinery in the world where germanium and gallium were recovered as principal products, closed the mine and refinery about 6 months after it reopened. The operation, near St. George, UT, had a production capacity of 20 metric tons per year of germanium and 7 metric tons per year of gallium. Most of the mined ore was stockpiled because of technical difficulties in the processing plant. The company expected to resume operations pending processing improvements and higher price quotations for the metal.

Consumption and Uses

The U.S. Bureau of Mines estimated that consumption of germanium decreased about 5.5% compared with the level of 1989. The estimated consumption pattern by end use of germanium in 1990 was as follows: infrared systems, 60%; fiber optics, 8%; gamma-ray, X-ray, and infrared detectors, 9%; semiconductors (including transistors, diodes, and rectifiers), 10%; and other applications (catalysts, phosphors, metallurgy, and chemotherapy), 13%.

Infrared systems continued to be the major end use for germanium. Infrared optics were mainly used for military guidance and weapon-sighting systems. Germanium-containing lenses and windows transmit thermal radiation similar to visible light transmission by optical glass. Germanium glass also was used for nonmilitary surveillance and monitoring systems in fields such as satellite systems and fire alarms. Germanium was used as a dopant in the core of many optical fibers employed in telecommunications.

Martin Marietta Corp. was applying a new transparent hard carbon coating to the night vision system windows of the *Apache* attack helicopter. The night vision system enables pilots to fly the helicopter a few feet above ground in darkness, operate under low-weather-visibility conditions, and detect tanks or other armored targets at night. The system's germanium optical windows were abraded by exposure to sand and dust, which affected the clarity of the television-like infrared picture. The carbon coating protection was designed to last more than 20 years compared to about 3 years achieved by the previously used thorium fluoride coating. The U.S. Army's expected savings on maintenance and spare parts cost on night

vision systems were estimated to be about $28 million during 3 years.[4]

Markets and Prices

Throughout 1990, domestic producer prices for germanium metal and dioxide, published by Metals Week, remained at the levels established in late 1981 of $1,060 and $660 per kilogram, respectively. However, discounting by producers was evident during 1990 because of competition from imported materials.

The Belgian producer's price for germanium metal, published by Metal Bulletin (London), remained at about $802 per kilogram throughout the year.[5]

Foreign Trade

In 1990, the estimated germanium content of imports was approximately 50,000 kilograms. Total imports of germanium materials increased significantly compared with those of 1989. France, Belgium, Canada, and the United Kingdom, in descending order of shipments, accounted for approximately 80% of the total U.S. germanium imports for 1990.

World Review

World refinery production was estimated at 76,000 kilograms, a decrease of about 7% compared with the 1989 level. The decline in world production was attributed to an oversupply and to a lower level of demand for the metal. Primary germanium was produced by MHO, Belgium; Johnson Matthey Electronics, Canada; Societe Miniere et Metallurgique de Penarroya S.A., France; Otavi Minon AG and Preussag AG, the Federal Republic of Germany; Pertusola Sud SpA, Italy; and Nippon Denshi Kinzoku and Sumitomo Metal Mining Co. Ltd., Japan. Germanium refineries also were in China and the U.S.S.R.

Capacity.—The data in table 3 represent rated annual production capacity for refineries on December 31, 1990. 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.

TABLE 3

WORLD ANNUAL GERMANIUM REFINERY PRODUCTION CAPACITY, DECEMBER 31, 1990

(Thousand kilograms)

	Capacity
North America:	
Canada	10
United States	60
Total	70
Europe:	
Belgium	50
Centrally planned economy countries	40
Other	65
Total	155
Asia:	
China	10
Japan	35
Total	45
World total	270

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.

Rated capacities of germanium refineries were estimated based on discussions with some officials from private industry, past and present production rates, and published capacity data.

Japan.—Germanium metal production was 3,368 kilograms, which was at about the same level as in 1989. Dioxide production decreased from 13,302 kilograms in 1989 to 12,350 kilograms in 1990.[6]

Spain.—Telefonica S.A., the state-owned telephone company, is turning to optical fibers to improve its telecommunications system. It has already installed about 12,000 kilometers of fiber optic cable, and an additional 21,000 kilometers of cable are expected to be installed before the end of 1993.[7]

United Kingdom.—British Telecom, London, will supply and install the first fiber-optic cable link in Vietnam. A 460-kilometer network system will connect Ho Chi Minh City with Nha Trang at an estimated cost of $6.3 million.[8]

TABLE 2

U.S. IMPORTS OF GERMANIUM MATERIALS, BY COUNTRY[1]

Country	1989		1990	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Belgium	15,985	$12,027,567	7,486	$7,611,049
Canada	2,407	1,470,524	5,469	2,841,950
China	3,195	1,607,868	2,078	655,351
France	7,973	5,313,134	21,087	12,709,770
Germany, Federal Republic of	3,421	1,145,407	2,992	1,088,355
Hong Kong	16	6,480	3,062	1,302,963
Israel	55	35,221	508	89,247
Japan	8	3,034	30	3,210
Netherlands	849	281,574	4	4,697
Singapore	15	8,503	16	5,000
Spain	—	—	1,346	243,184
Sweden	—	—	20	27,964
Switzerland	3,260	182,166	—	—
U.S.S.R.	—	—	307	121,321
United Kingdom	2,921	1,707,877	5,364	1,263,694
Total	40,105	23,789,355	49,769	27,967,755

[1]Unwrought and waste and scrap.

Source: Bureau of the Census.

Current Research

A new fiber-optic lighting system for automobiles was being developed by the Advanced Technology Department of General Electric Lighting. This system uses less power than two of today's halogen headlights, while providing the same amount of light. It has a potential application of replacing as many as 80 light sources now used in cars. Furthermore, the fiber system does not require conventional wiring nor light bulbs, and its small size (about 1 inch high) should allow car designers to taper the front end of the car to achieve a more aerodynamic curvature.[9]

The Roskill organization issued its 1990 germanium report. This comprehensive report discussed and analyzed world production of germanium by country and individual company. It also contained information on end-use markets, international trade patterns, and trends in prices.[10]

OUTLOOK

There were abundant supplies of germanium materials on the market in 1990. Germanium supplies are likely to remain high for the next 2 to 4 years because of an increased availability of concentrates from Canada and a considerable amount of germanium metal emerging into the world market from the U.S.S.R. For the second consecutive year, producers were forced to lower prices to maintain their share of the market.

Market analysts agree that all primary germanium producers will probably face difficult times in the near future. This assessment is based on a continuing global oversupply of germanium materials together with a low market demand.

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[4]Newly Developed Optical Coating Expected To Save Army $27.9 Million Over 3 Years. Martin Marietta Corp. Press release, Orlando, FL, Jan. 1990.

[5]Where necessary, values have been converted from Belgian francs (BF) to U.S. dollars at the average exchange rate of BF37.0 = US$1.00.

[6]Japan Metal Journal. V. 21, No. 11, Mar. 18, 1991, pp. 7-8.

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[8]Laser Focus World. Fiberoptics Industry Report. V. 26, No.1, Jan. 1990, p. 162.

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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, mineral data assistants, and Stephen L. Hays, supervisory mineral data technologist International data tables were prepared by Audrey D. Wilkes, international data coordinator.

Gold has been treasured since ancient times 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 1990. The U.S. gold mining industry produced a record 290,202 kilograms (kg) (9,329,994 troy ounces[1]) of gold, a 9% increase in production compared with that of the previous year. The State of Nevada was once again the Nation's dominant gold-producing State. For the second consecutive year the total demand for gold used in fabricated products in the market economy countries exceeded the record demand level set in 1988. Jewelry continued to be the dominant end-use sector.

The U.S. Bureau of Mines, in an effort to provide statistical data on gold that are consistent with international usage, reports gold data in kilograms and metric tons unless otherwise noted.

DOMESTIC DATA COVERAGE

Domestic mine production data for gold are developed by the U.S. Bureau of Mines from two separate, voluntary surveys of U.S. operations. One of these surveys is the lode-mine production survey of gold, silver, copper, lead, and zinc mines. Of the lode gold producers in operation to which a survey request was sent, 209 responded, representing 96% of the total lode-mine production of gold shown in tables 4 and 5. Production for the nonrespondents was estimated using reported prior-year production levels, adjusted by trends in employment, and other guidelines such as company annual reports, the news media, and State agency reports.

BACKGROUND

Gold lore and the use of gold predates written history. Gold has been considered a precious metal since ancient times, and the mystique and folklore associated with gold has been a part of the fabric of civilized society throughout history. Similarly, the search for gold has stimulated world exploration and trade for more than sixty centuries.

Gold mining in the United States began about 1800 in North Carolina, with Georgia joining in production in 1829 and Alabama in 1830; then Virginia, Tennessee, and later New Mexico became producers as prospectors moved west. The most important gold discovery, because of its influence on development in the Western United States and the amount of gold produced, was at Sutter's Mill in California in 1848. Later discoveries were made in most other Western States and territories.

Gold mining in Australia began about 1849 as an offshoot of the California gold rush. Russian gold mining had been expanding since the mid-18th century, and by the eve of the California gold rush, Russia was producing about two-thirds of the world's gold. Gold mining in the Republic of South Africa started in the 1870's. The last major gold rush began just prior to 1900 in Canada's Yukon and in Alaska.

Early mining was largely by placer methods, with a multitude of miners working stream deposits (placers) by hand mining techniques, a practice that continues to this day in many areas of the world. In the 1860's, the more difficult underground mining of lode deposits—the sources of the placers—became important. Cyanidation, a chemical process for gold extraction, was introduced about 1890, and the concentration of finely ground ores by selective adherence of mineral particles to rising bubbles, the flotation process, was first used for gold ores about 1900 and came into general use in the 1930's. Heap leaching, essentially a form of cyanidation, has come into general practice for treatment of low-grade ores only during the past 2 decades.

Cumulative world production to date is estimated at about 107,000 metric tons (3.4 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 11,300 tons (362 million ounces). The principal producing States, in declining order of cumulative production, are California, Nevada, Colorado, South Dakota, Alaska, Utah, and Montana; the remainder came from 11 other States. To date, lode gold mining has supplied about 50% of U.S. production; placer mining, 35%; and base metal mining, 15%. The Homestake Mine at Lead, SD, has accounted for about 10% of all U.S. gold production. Other major sources of past production include the Mother Lode and Grass Valley areas of California, the Comstock Lode and Goldfield areas in Nevada, Cripple Creek in Colorado, and the Fairbanks and Nome, AK, areas.

Most domestic gold mines were closed by Limitation Order L-208 in the early months of World War II (October 8, 1942) so that scarce equipment, supplies, and skilled workers could be focused on mining essential base metals. L-208 was revoked July 1, 1945. Because of increased cost and rehabilitation problems, only a few mines reopened after the war. During the resurgence of gold exploration and mining over the past decade, many deposits affected by L-208 have been reexamined or returned to productive status.

Definitions, Grades, and Specifications

Fineness refers to the weight proportion of pure gold in an alloy, expressed in parts per thousand; 1,000 fine gold is 100% pure gold. Commercially traded gold bullion is usually 995 fine or higher. The term "fine gold" may also be used to designate the particle size of gold in its native state; for example, a placer deposit with gold particles ranging from 0.38 millimeter (mm) to 0.76 mm (0.015 to 0.3 inch) in diameter contains fine gold, whereas a similar deposit with particles more than 1.5 mm (0.06 inch) in diameter contains coarse gold.

The term "karat," like fineness, refers to purity, but is expressed in 24ths; thus 24-karat (24k) gold is 1,000 fine or pure gold, and 10k gold is 10/24, or 41.7% gold. Although there are many 10k alloys, each 10k alloy contains 41.7% gold. Various 10k alloys, for example, differ from each other in the number, identity, and proportions of their other constituent metals. Gold alloys used in jewelry and certain other end uses are referred to as karat golds, whereas alloys used in dentistry and electrical devices are designated more precisely. Yellow, red, and green karat golds are essentially ternary alloys of 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 have also been used as components.

Having assumed the functions previously performed by the London Gold Market, the London Bullion Market Association (LBMA), established in 1987, sets standards for its members that are widely used in world gold trade. Refined gold bullion bars are generally designated as "good delivery bars." A good delivery bar, as set forth by the requirements of the LBMA, must contain 350 to 430 troy ounces of gold with a minimum fineness of 995. The bar must bear the stamp of one of the world's 49 approved 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 coating 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 250 square feet of gold leaf about four-millionths of an inch thick, while a similar quantity can be drawn into more than 80 kilometers (km) (50 miles) of wire.

As an illustration of gold's high specific gravity or density, 1 cubic foot of pure metallic gold weighs a little more than 1,200 pounds; one cubic inch of pure gold weighs about 311 grams (10 troy ounces); a lump or nugget of gold the size of a navy bean weighs about 3 grams (0.1 troy ounce), and a flake of gold the size of a grain of rice weighs about 0.18 gram (0.006 troy ounce).

The troy system of weights is generally used in the United States for gold and other precious metals; however, to aid in harmonizing world data collection, Government practice now dictates the use of the metric system of measure. The troy weight system is based on the troy ounce of 480 grains or 20 pennyweight. One troy ounce is equivalent to 1.097 ounces avoirdupois. Many nations use the metric system; in this system, the weight of gold is designated in standard metric units: gram, kilogram, or metric ton. The metric ton is equivalent to 32,150.7 troy ounces. In addition to the metric or troy systems, other units of weight applicable to precious metals may also be encountered. On the Indian Subcontinent, for example, the weight of gold may be expressed in terms of tolas; one tola of 999 fine gold weighs 11.1 grams (0.375 troy ounce).

Products for Trade and Industry

Although gold compounds are used in substantial quantities in electroplating, most of the gold sold in the international marketplace for industrial usage is in the form of metal or metal alloys. Many standard metallic forms are available, such as bars, rods, sheets, foils, wires, powder, granules, and shot. Conductive pastes and inks prepared with gold powder are widely employed in the electronics industry. Much jewelry gold is supplied as granules of specified karat content. Semimanufactured items for trade and industry may include gold jewelry findings or unassembled parts such as earring clamps, chain clasps, pins, etc.; dental findings; and inlaid, clad, and plated metals. Investment products such as bars, coins, and medallions are manufactured and sold by both industry and governments.

Industry Structure

In the United States during 1990, 92% of domestic gold production came from gold ore, and most of the remainder was a byproduct of copper and other base metal production. Placer gold production has declined to about 1% of the reported total production in recent years. Fifteen mines accounted for about 61% of domestic output in 1990; 81% came from mines in California, Montana, Nevada, and South Dakota. The leading producer in most recent years, Newmont Gold Co., provided about 18% of domestic output from its surface operations near Carlin, NV. Round Mountain Gold Corp.'s Round Mountain

heap-leaching operation, the Nation's fifth largest producer in 1989, moved up to second place in 1990. 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 British and other European companies.

The South African gold mining industry, accounting for about 30% of current world output, consists of about 3 dozen large underground operations and several dozen smaller mines. In a typical year, the Republic of South Africa's gold industry reportedly mills enough ore to cover 60 city blocks to a height of 20 stories; from this volume is recovered enough gold to fill a small bathroom. These mines are owned or controlled by six corporations that interlock through directorships and mutual shareholdings and have extensive mineral and industrial investments in many parts of the world. The corporations are Anglo American Corp. of South Africa Ltd., Anglovaal Ltd., Gencor Ltd., Gold Fields of South Africa Ltd., Johannesburg Consolidated Investment Co. Ltd., and Rand Mines Ltd.

Geology-Resources

The Earth's crust has been estimated to have an average gold content of about 0.0034 gram per metric ton (0.0001 ounce per short ton), or 3.5 parts per billion (ppb). Sedimentary rocks, especially sandstones, tend toward higher-than-average gold content. In igneous rocks, the content averages slightly higher in darkly colored "mafic" rocks than in lighter colored "felsic" rocks. Seawater typically contains about 0.011 ppb gold; however, content varies widely with location and may range from 0.001 to 44 ppb. Numerous attempts have been made over the years to recover gold from seawater; however, none have been commercially sustainable. The gold content in surface and ground waters lies within the range of analyses for seawater, but varies widely depending on source. For instance, waters from gold mines in southern Yakut, U.S.S.R., contain an average of 0.7 to 0.9 ppb. In Colorado, waters draining from gold mining and other areas contain up to 0.15 ppb, but with no distinct differences between gold-enriched and gold-barren areas. Hot-spring waters generally contain more gold than other waters.

Gold deposits are found in many kinds of rock. Hydrothermal deposits appear to be somewhat more common in acidic and intermediate igneous rocks; in silty, laminated carbonate rocks; and in silicious or aluminous sedimentary or metamorphic rocks. The general deposit types include hydrothermal, hydrothermal-metamorphic, metamorphic, replacement (lode, massive, and disseminated), and cavity filling (fissures, stockworks, saddle, reefs, breccias, and conglomerates).

Gold occurs mainly as native metal, alloyed with silver and/or other metals, and as tellurides. A naturally occurring alloy of gold and silver is known as electrum. Other gold minerals are rare. Gold is commonly associated with the sulfides of antimony, arsenic, copper, iron, and silver.

Chemical and mechanical weathering and erosion cause gold in the free or metallic form to be released from lode or primary deposits and to accumulate as nuggets and grains in residual deposits or placer deposits. Although the richest lode gold deposits have been small fissure vein types with quartz gangue, the so-called bonanzas, much larger quantities of gold have been mined from large, medium-grade deposits. U.S. gold ores average about 3.5 grams per metric ton (0.1 ounce per short ton) or less; however, the advent of chemical heap leaching now makes it possible for rock with suitable properties containing considerably less than 3.5 grams per metric ton to be considered ore.

Technology

Exploration.—Although a number of new techniques have come into use in the exploration for gold, the gold pan remains one of the simplest and most efficient low-cost means of finding visible gold and tracing it to its source. Collecting, crushing, and panning quartz samples from geologically favorable areas is a common basic procedure employed in prospecting for bonanza-type lode deposits. Neutron activation analysis and atomic absorption spectroscopy 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 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 $23.00, a substantial sum in many areas of the world. Obviously, mechanization, even on a small scale, would vastly increase the amount of material that could be washed. Needless to say, mining a higher grade deposit would be even more productive. Should the gold recovered be in the form of coarse nuggets, valued also for their use in jewelry or as specimens, the value of the day's production would be increased. For large-scale, open pit lode gold mining, computer models have been developed to analyze various production factors and establish optimum pit configurations and extraction efficiencies.

The South African mining industry, a leader in deep mining technology for many years, has evolved new methods of controlling problems relating to rock stress, dust, and virgin rock temperature. Both large and small water-powered rock drills, large-diameter raiseboring machines, and new types of rubber tired transporters have been developed in recent years to increase the efficiency of mining operations. Also, the South Africans have developed new techniques of shaft sinking, mineral processing, and extraction that are critical to the success of deep mining. At the Vaal Reefs Mine, for example, part of the gold ore is transported to the surface from a depth of more than 2,100 meters (7,000 feet) by hydraulic pumps. Much of the Republic of South Africa's current production is now coming from depths of 2,000 to 3,000 meters (6,600 to 9,800 feet) below surface, with some as deep as 3,600 meters (11,800 feet). The new generation of ultradeep mines are intended eventually to be mined to 4,500 meters (14,800 feet).[2]

Beneficiation.—Milling technology for gold is highly developed, and normal mill recovery rates range from 92% to 96%. Gold is recovered by cyanide leaching of gold ore contained in tanks or heaped on impervious leaching pads; by amalgamation, flotation, gravity concentration, and smelting; or by a combination of these processes. Increased exploitation of gold-bearing sulfide ores in recent years has led to the development and application of several technologies designed to render sulfide and refractory ores amenable to cyanide leaching; thus, process steps such as autoclaving, biological preoxidation, or fluid-bed roasting have recently been incorporated at a number of milling operations.

Smelting-Refining.—Many gold mining operations recover the gold from cyanide leach solutions by precipitation with zinc dust, though, in recent years, carbon-in-pulp (CIP) recovery technology has been adopted at a number of new mining operations. With CIP, activated carbon made from coconut shells or other durable carbon sources collects gold from the cyanided pulp until it contains 10 to 12 kg (300 to 400 ounces) of gold per ton of carbon. Gold with accompanying silver is desorbed or stripped from the carbon with a strong alkaline cyanide-alcohol solution. The precious metals are recovered from the strip solutions by electrodeposition on a stainless steel wool cathode. The cathode deposit is then refined into bullion or doré, a mixture of mostly gold and silver. The carbon is reused after being screen-sized and reactivated through controlled roasting. Generally, gold recoveries range from 92% to 97% of the feed content. Gold leaching processes in use or under development that do not employ cyanide as the principal lixiviant or dissolution medium include the application of thiourea, iodine, malonitrile, or various bioextraction techniques. Some of these alternate techniques, unlike the long-established, well-understood cyanide process, may be accompanied by unacceptable cost or environmental burdens. When gold is associated with copper ores, it travels with the base metal through concentration and smelting to the refining stage. It is eventually separated from the anode slimes that accumulate in electrolytic copper refining cells and is recovered as gold bullion in the precious-metals refinery. Gold losses in concentrating copper ores are about the same as for copper, but are negligible in smelting and refining.

Gold is refined by chlorination in the molten state (Miller process) and by electrolysis (Wohlwill process). Generally, gold bullion made by the Miller process is 996 to 997 fine, and bullion made by the Wohlwill process is 999.5 to 999.8 fine.

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 4,000 B.C. to barter for ingots of crude copper or other goods at a Mediterranean seaport.

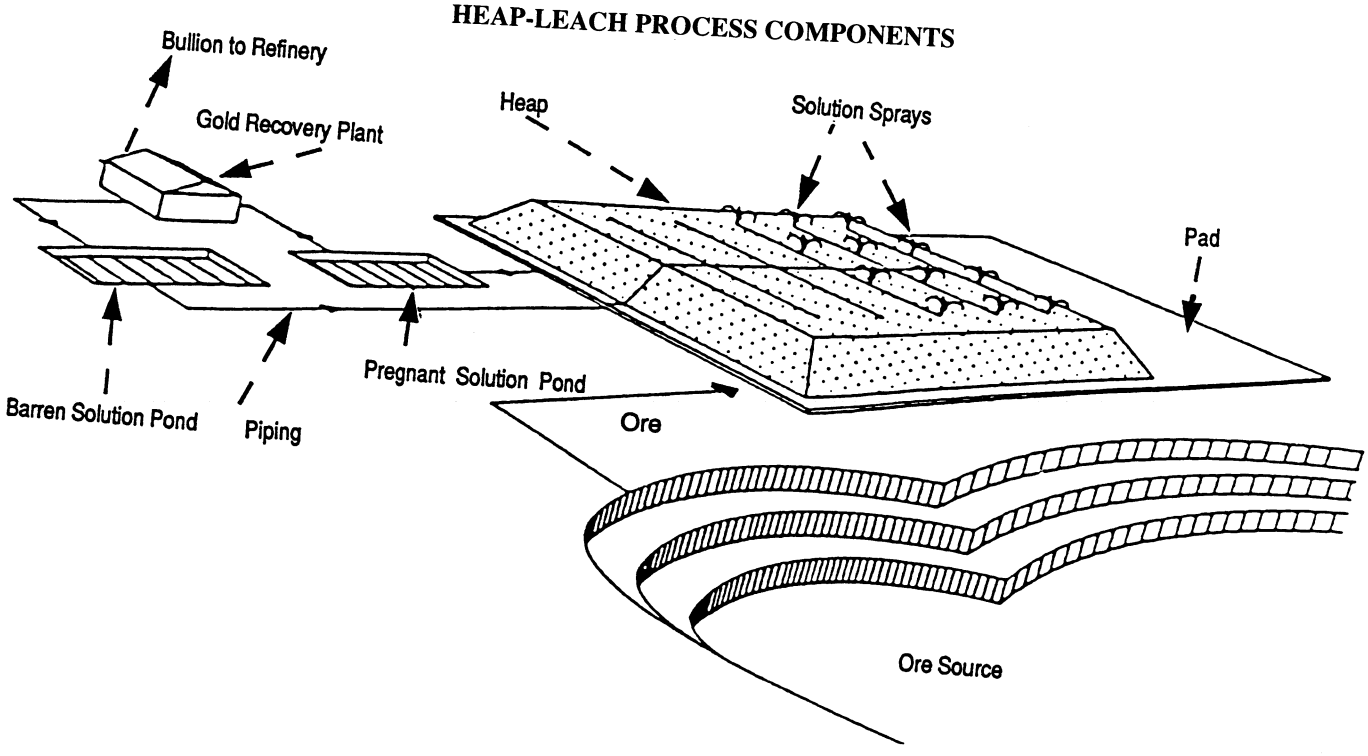
Precious-metals refiners throughout the world recover gold from scrap. In the United States, about 60% to 80% of the scrap comes from current manufacturing operations, and the remainder comes from old scrap in the form of items such as discarded jewelry and dental materials, used plating solutions, junked 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

FIGURE 1

HEAP-LEACH PROCESS COMPONENTS



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.

Economic Factors

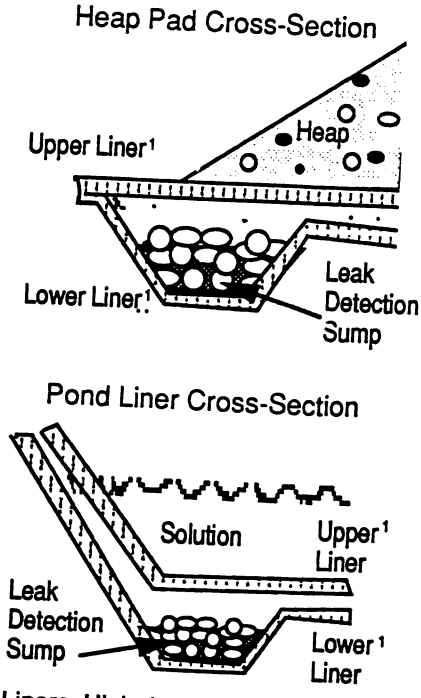
On January 31, 1934, following provisions of the Gold Reserve Act of that year, the official price of gold was raised by the U.S. Government from $20.67 per ounce to $35 per ounce. The value of $1 was thus established at 28.57 thousandths of a troy ounce, and gold flowed into the United States. By 1949, gold stocks held by the U.S. Department of the Treasury had risen to a peak of 21,708 metric 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 metric 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 1990, U.S. Treasury stocks stood at 8,146 metric 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

FIGURE 2

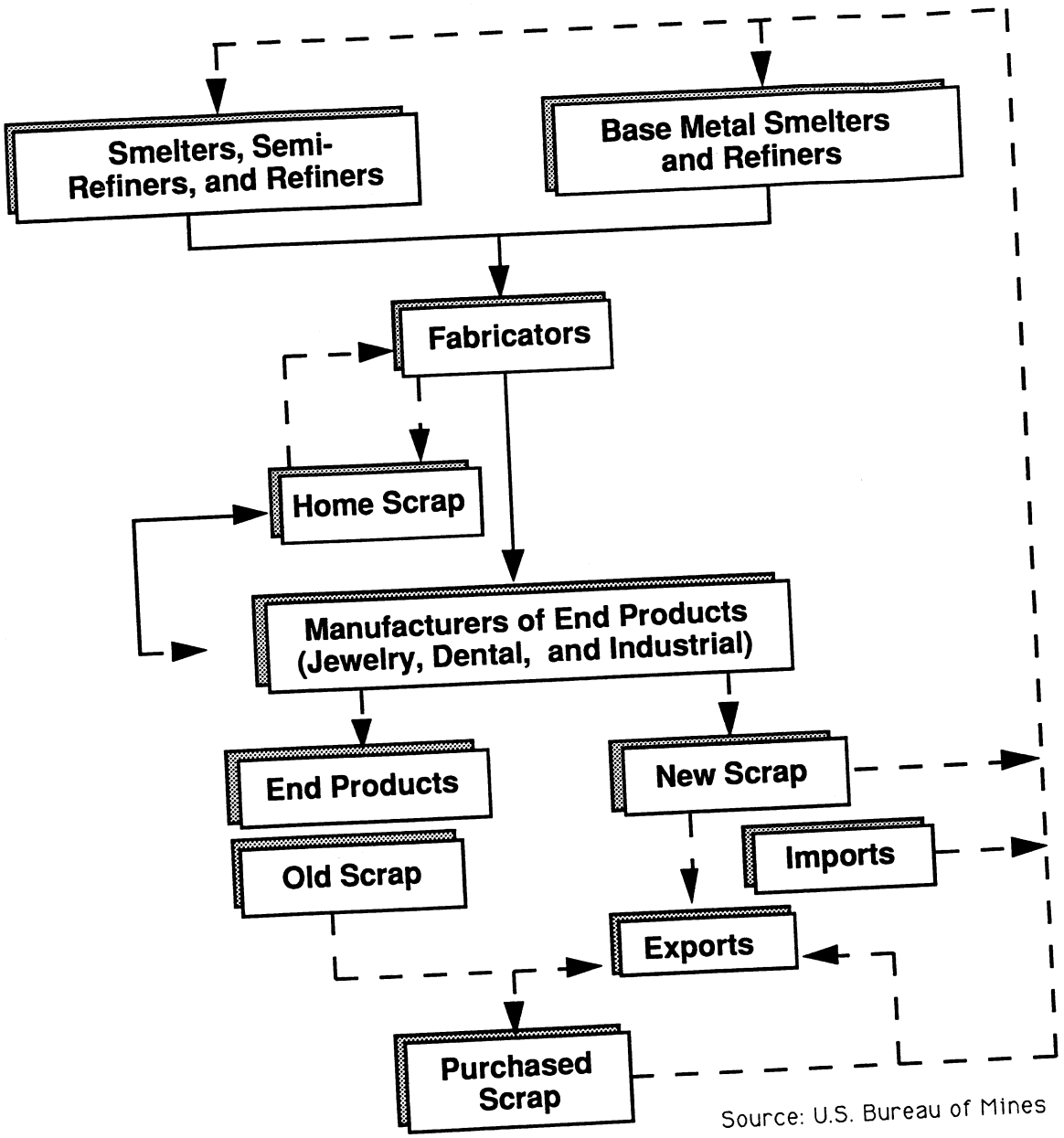
HEAP AND POND LINER CROSS SECTIONS



[1]Liners, High density, polyethylene or polyvinyl chloride 1 mm to 2.5 mm thick (60-100 mils)

FIGURE 3

SECONDARY GOLD CHART



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 metric tons (1,380 million ounces) in 1982; the volume in subsequent years has ranged from about 25,000 to about 35,000 metric 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 con-

sider a renewed role for gold in the U.S. economy, concluded that reintroduction of gold into the current monetary system would probably not serve to alleviate potential economic problems such as inflation. The prospects for a return to a gold standard in other countries would also seem to be uncertain. However, as a so-called "hard currency," gold may come to enjoy a greater role in world economics than it has in the recent past. This is especially important as the world economic system adjusts to accommodate rapidly changing political, economic, and trade practices and to address the many issues associated with the rapid growth in world population, dwindling resources, and slower growth in industrial productivity. Small-scale bartering arrangements involving gold continue as they have for centuries, especially in frontier mining areas such as those in South America, Africa, the western Pacific, and remote areas of North America where raw gold dust and nuggets may be used directly to purchase goods and services.

Prices.—The price of gold is a topic of continuing concern and interest to the producer and the consumer of gold alike; where it has been, where it will go, and the reasons behind its wild fluctuations over the past decade or so have been studied from every angle by numerous observers. Apparent causes for the price changes have been presented and speculation on their future directions have been offered.

Unfortunately, many of these sophisticated econometric models, forecasting the price using combinations of economic, political, and social factors, that proliferated in the early 1980's had all but disappeared from the public domain by the end of the decade. The course of future events cannot, of course, be forecast with accuracy, nor can the price of gold. Forecasting gold's price is unusually complicated because gold occupies a unique position among the world's commodities. Gold is both an internationally traded commodity and, at the same time, a long-established, universally acceptable storehouse of value, considered by many people worldwide to be superior to fiat paper currencies with fleeting longevity or fluctuating, unpredictable value. Unlike many commodity prices that are more or less tied directly to supply and industrial demand, the price of gold cannot be viewed as one would view the price of other goods or services in a free market. Gold also cannot be viewed strictly from the standpoint of the U.S. market alone, for international, political, and economic events that may impose a positive or negative influence on gold the commodity may be overshadowed by developments perceived to favor gold the medium of exchange. For example, citizens of nations that have been invaded by other countries during the course of their history tend to value the monetary and exchange aspects of gold more highly than countries such as the United States where this has not been the case. To them, gold is money or the preferred substance of wealth, and the ownership of even a small amount of physical metal ensures escape or a new beginning. Therefore, many individuals worldwide, as a matter of tradition or simple prudence, continue to hold small quantities of gold in the form of jewelry, coins, nuggets, etc., legally or illegally, as a portable form of universally accepted capital; for some, especially in developing countries, gold may constitute the only available and relatively risk-free form of old age or disaster insurance.

Although the average price of gold has declined from its record 1980 level of $612 per ounce, it remains considerably higher than the prices of the early 1970's. This high price level, not generally enjoyed in recent years by many other commodities, continues 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 0.3 gram or less of gold per metric ton (0.01 ounce per ton), depending on the stripping ratio, size and type of operation. Other important considerations include the characteristics of the ore processed and the mine's location with respect to the duration of the operational season and the infrastructural requirements. At Pegasus Gold's Zortman and Landusky Mine, in Montana, and its Florida Canyon Mine, in Nevada, the minimum or cutoff grade of ore mined during 1990 was 0.25 gram (0.008 ounce). 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; for example, the average cost to produce an ounce of gold in 1990 at the 2,400-meter-deep (8,000 foot) Homestake Mine in South Dakota, including a small contribution from a new surface pit, was $311. The cost was distributed as follows: mining and treatment, $277; administrative and general, $15; and taxes, $18.

Costs for processing gold ores can vary widely, depending on the treatment required. Recent advances in heap leaching of gold and extraction with activated carbon may afford lower capital and operating costs than those associated with conventional cyanidation. One recent advance, for example, is particle agglomeration, a technique developed and patented by the U.S. Bureau of Mines to increase the flow rate of leaching solutions through crushed ore. Fine particles of ore that would otherwise impede solution flow by blocking the spaces between coarser fragments are bound together or agglomerated through the addition of a water-soluble binder such as 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 of their future gold production, are able to maintain economic production even during periods when their production costs may exceed the existing market price of gold.

Taxes.—Taxes may be levied on mining operations for gold and other minerals at the Federal, State, and local levels. In addition to the usual business, occupation, and property taxes and licence fees required of all business enterprises, mining operations in many States are subject to severance or extraction taxes imposed on the yield or proceeds received from the sale of newly mined products. In 1989, the State of Nevada, for example, increased the net profits tax on State mineral production from about 2% to 5%. In 1986, a new Federal tax, the Customs User Fee, was adopted; it places a 0.22% levy on all imports, including gold and gold-bearing products. The fee was reduced to 0.17% on September 30, 1987. During 1990, the enabling legislation was extended to September 30, 1995, and minimum and maximum fees were established.

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 U.S.S.R. has 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 will eliminate its 6-decade-old tax exemption of income derived from gold production, including byproduct production from those copper operations where gold represents more than 40% of the total income.

Operating Factors

Environmental Requirements.—The costs associated with meeting various Federal, State, and local environmental requirements can vary considerably from one mine site to another. At mines utilizing cyanide recovery techniques in their milling or heap-leaching plants, special precautions, monitoring and leak detection procedures, and site design features are employed to avoid contamination of the surrounding environment and to reduce the exposure of wildlife to cyanide-laden process streams. For example, at the Mesquite Mine in California, two solution ponds with about 4 hectares (9 acres) of exposed area have been completely covered with plastic to minimize wildlife exposure as well as water loss to evaporation. A variety of processes have been developed in recent years to detoxify or neutralize spent ore prior to disposal or final site reclamation. New regulations pertaining to cyanide use on Federal lands were issued during 1990 (See Legislation and Government Programs). In an emergency, chemical breakdown of cyanide can be induced quickly with chlorine gas.

Because of the danger of mercury pollution, the use of mercury amalgamation in domestic gold operations is now virtually nonexistent. Despite Government efforts to control the use of mercury, the amalgamation process continues to be used in an environmentally detrimental manner in some unregulated frontier mining operations in the Amazon Basin and in the Philippines. Mercury and arsenic can be natural contaminants of gold ores, requiring troublesome or costly extraction processes. Other potential pollutants that may be byproducts from gold mining include antimony, bismuth, tellurium, and thallium. Two iron sulfides, pyrite and pyrrhotite, commonly occur in gold deposits and can be a source of stream pollution as they oxidize to sulfates and other soluble compounds. Pollution resulting from some placer operations may be reduced or eliminated through the use of properly designed settling ponds. Waste dumps, mill tailings, and excavations are increasingly subject to public scrutiny, and environment control costs must be taken into account along with other operating factors. Expanded mine safety requirements in recent years are another important cost factor.

Employment.—According to annual data prepared by the U.S. Department of Labor, employment in the Nation's gold mines and mills, exclusive of office employees, nearly tripled from about 7,000 in 1985 to almost 20,000 in 1990. The number of jobs available in both surface and underground mines and associated processing plants is not always directly proportional to mine production, reflecting instead variations in development activity, the price of gold, weather, type of mining operation, etc. During 1989, citing employment studies for mining in Nevada and South Dakota, the Economics Institute of Boulder, CO,[3] derived an employment multiplier of 19.4 jobs per $1 million of gold production, giving an estimate for total direct, plus indirect employment attributable to domestic gold production, of about 51,000 persons. A companion study covering the period 1979-90[4] showed employment multipliers and the industry's contribution to gross State products and State personal income for 11 gold-producing States. The report noted that induced employment from precious-metals production in Nevada, for example, accounted for between 14% and 20% of all new jobs created in Nevada from 1986 to 1989. An average employment multiplier of 20.3 jobs per $1 million in output was calculated for the 11-State area.

ANNUAL REVIEW

Legislation and Government Programs

On July 16, the President signed legislation, Public Law 101-332, authorizing the minting of 550 million special coins commemorating the 50th anniversary of Mount Rushmore National Memorial in South Dakota. Five hundred thousand $5 gold coins weighing 8.359 grams (0.268 troy ounce) each and 2.5 million $1 silver coins weighing 26.73 grams (0.859 troy ounce) each were included in the authorization. One-half of the surcharges on the coins, scheduled to go on sale January 1, 1991, were earmarked for renovation and preservation of the Mount Rushmore facilities.

The director of the U.S. Bureau of Land Management (BLM) announced on August 14 that BLM had revised its existing bonding policies for surface mines and mines using cyanide and other leaching agents on Federal lands administered by the Agency. According to the new bonding policies, mine operators had to post bonds to cover reclamation costs attributed to exploration and mining. The ceiling amounts for the bonds were about $2,500 per hectare ($1,000 per acre) for exploration and about $4,900 per hectare ($2,000 per acre) for mining operations. Operators having State bonds that met or exceeded the new reclamation requirements were not required to post a Federal bond. Mines using cyanide

TABLE 1

SALIENT GOLD STATISTICS

		1986	1987	1988	1989	1990
United States:						
Mine production	kilograms	116,297	153,870	200,914	r265,731	290,202
Value in dollars per troy ounce	thousands	$1,376,860	$2,216,026	$2,831,281	r$3,268,548	$3,609,954
Percentage derived from:						
Precious-metal ores		96	91	W	W	W
Base metal ores		2	6	W	W	W
Placers		2	3	2	2	1
Refinery production:						
Domestic and foreign ores	kilograms	75,618	112,368	137,829	183,685	204,856
Secondary (old scrap)	do.	47,266	63,843	r52,784	r37,144	32,019
Exports:						
Refined	do.	110,555	71,177	271,335	123,599	140,923
Other	do.	44,810	48,453	56,902	87,492	155,474
Imports for consumption:						
Refined	do.	429,242	75,365	57,590	96,967	64,755
Other	do.	60,621	44,174	34,867	55,537	32,764
Gold contained in imported coins[1]	do.	34,245	33,716	[2]17,947	[2]13,218	[2]8,429
Net deliveries from foreign stocks in Federal Reserve Bank	do.	145,938	95,146	208,277	132,231	51,464
Stocks, Dec. 31:						
Industry[3]	do.	28,771	23,390	38,360	r30,462	33,324
Futures exchange[4]	do.	87,370	81,647	44,634	69,727	50,881
Volume of U.S. Gold Futures Trading[5]	metric tons	26,365	33,100	29,920	r31,065	30,260
Department of the Treasury:						
American Eagle gold coin sales	kilograms	(6)	[7]82,704	[7]17,416	[7]16,544	[7]17,397
Bicentennial of the U.S. Congress[8]	do.	—	—	—	r[7]942	[7]591
Bicentennial of the U.S. Constitution coin sales	do.	—	(9)	[10]6,463	—	—
U.S. 1988 Olympic coin sales[11]	do.	—	—	r2,163	r[7]407	[7]105
Consumption in industry and the arts	do.	r110,795	r113,319	r111,836	r115,078	103,639
Price:[12] Average per troy ounce		$368.24	$447.95	$438.31	$382.58	$384.93
Employment[13]		8,300	11,100	13,100	r15,100	15,500
World:						
Production, mine	kilograms	r1,606,570	r1,660,529	1,848,237	p1,999,648	e2,049,946
Official reserves[14]	metric tons	r35,743	r35,646	r35,820	r35,647	35,611

eEstimated. pPreliminary. rRevised. W Withheld to avoid disclosing company proprietary data.
[1]Calculated by the Gold Institute from reports by the Bureau of the Census.
[2]Beginning 1988 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 (1987-88 only), and Mid-America Commodity Exchange.
[6]Sales program began on Oct. 20, 1986; sales adjusted and included in 1987 total.
[7]Fiscal year begins Oct. 1 of previous year indicated.
[8]Sales program began June 14, 1989.
[9]1987 sales included in 1988 based on fiscal year beginning Oct. 1.
[10]Total sales, program began July 1, 1987, and ended June 30, 1988.
[11]Sales program began Feb. 15, 1988; completed June 3, 1989.
[12]Engelhard Industries quotation.
[13]Mine Safety and Health Administration.
[14]Held by market economy country central banks and governments and international monetary organizations.
Source: International Monetary Fund.

or other leaching agents were required to post a bond equal to 100% of BLM's estimate of reclamation costs required by Federal or State regulations. The affected areas included leach heaps, pads or dumps, or those parts of an operation discharging cyanide-bearing tailings and fluids to impoundments or ponds. Facilities not included were various forms of vat leaching, metal recovery, and refining. The new policy immediately affected new mining operations. Existing cyanide operations were to comply within 6 months and any other operations by January 1, 1992.

On October 3, the President signed leg-

islation to authorize the minting of new gold, silver, and base metal clad coins to support the training of U.S. athletes participating in the 1992 Olympic Games. The legislation, Public Law 101-406, known as the "1992 Olympic Commemorative Coin Act" called for the minting of up to 500,000 $5 gold coins weighing 8.359 grams (0.268 troy ounces) each, up to 4 million $1 silver coins weighing 26.73 grams (0.859 troy ounces) each, and up to 6 million half-dollar clad coins. The coins issued under this act will be legal tender under existing provisions of the United States Code.

Strategic Considerations

Gold is not a National Defense Stockpile item; however, the Treasury had stocks of bullion amounting to about 8,146 metric tons (262 million ounces) at yearend 1990. Large quantities of gold were also held as commercial and private bullion stocks. Therefore, the availability of gold in times of national emergency appears to be ensured.

One strategic aspect of the domestic gold mining industry that is infrequently considered is that the industry constitutes a valuable pool of experienced personnel, including chemists, geologists, engineers, and metallurgists as well as miners, machinists, and heavy equipment operators. In the event of a national emergency, these skills may be readily directed toward the discovery, development, and production of strategic materials.

Issues

An issue of continuing concern to domestic exploration companies, gold producers, and to producers of other minerals as well is that of mineral land availability. Because the geological forces that form mountains and unique physiographic features are often responsible for producing mineral deposits, exploration for gold and other minerals frequently focuses on these areas of disturbance. The same rugged features that make certain areas attractive to the minerals explorer may also make them less accessible for mining because these areas may presently be more valued for their undisturbed or wilderness qualities than for their mineral potential. In recent years, the trend toward preserving increasingly greater areas of unevaluated wilderness land, on which exploration is prohibited or severely restricted, may lead to a decline in new discoveries as well as jeopardize national security.

Another issue of concern to the mining industry as well as law enforcement authorities has been the recent growth in telemarketing fraud and investment swindles involving sales of gold bullion and investment in questionable mining ventures. In late 1988, the North American Securities Administrators Association Inc. (NASAA) and the Council of Better Business Bureaus Inc. issued an Investor Alert entitled "Dirt Pile Gold Swindles." The alert was to educate the public regarding the organization, characteristics, and pitfalls of the classic "dirt pile" or "gold-in-the-ground" swindle. The NASAA is composed of representatives from the securities regulatory agencies of all 50 States plus Puerto Rico. Law enforcement authorities and various industry trade groups continue to police against other fraudulent practices, such as misrepresented gold quality marks on jewelry and bullion and faked collector coins.

Production

Of the 290 metric tons of gold (9.3 million ounces) produced in the Nation in 1990, 74% was attributable to the 25 leading producers. The average recoverable gold content of precious-metals ores processed from lode mines was 0.34 gram per metric ton (0.01 ounce per short ton), while placer gravels yielded an average of 0.57 gram per cubic meter (0.01 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.—Exploration expenditures in Alaska during 1990, much of which were directed toward gold exploration, rose 19% over expenditures of the previous year, according to a summary of 1990 mineral activity prepared by the Alaska State Division of Geological and Geophysical Surveys (DGGS).[5] Gold production of about 3,232 kg (103,909 ounces) was reported to the U.S. Bureau of Mines. However, an annual survey conducted informally by the DGGS suggests that a total of 7,206 kg (231,700 ounces), including 5,996 kg (192,800 ounces) of placer gold, was produced; the comparable total for 1989 amounted to 8,850 kg (284,617 ounces). About 216 placer mines and several lode mines operated during the year.

The new Greens Creek lode mine on Admiralty Island near Juneau was the State's largest gold producer during 1990,

TABLE 2

MINE PRODUCTION OF GOLD IN THE UNITED STATES, BY STATE

(Kilograms)

State	1986	1987	1988	1989	1990
Alaska[1]	1,501	3,812	4,210	5,756	3,232
Arizona	W	1,791	4,549	r2,768	5,000
California	13,238	18,277	22,442	29,804	29,607
Colorado	3,743	5,561	5,126	3,448	2,338
Idaho	2,191	3,041	3,218	3,057	W
Michigan	W	W	W	W	—
Montana	W	7,143	9,175	r12,434	13,012
Nevada	65,330	83,342	114,322	r153,995	176,551
New Mexico	1,240	W	W	1,076	888
North Carolina	(2)	—	—	—	—
Oregon	W	W	W	W	W
South Carolina	W	W	W	W	W
South Dakota	W	W	13,981	16,123	16,860
Utah	W	W	W	W	W
Washington	W	W	W	W	9,620
Total	116,297	153,870	200,914	r265,731	290,202

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: 1986—4,977; 1987—7,154; 1988—8,258 (revised); 1989—8,852 (revised); and 1990—7,206.

[2]Less than 1/2 unit.

producing 1,182 kg (38,000 ounces) of gold plus values in lead, silver, and zinc. Production at Citigold Alaska, Inc.'s Ryan Lode Mine, near Fairbanks, declined from that of the previous year. In late 1990, the company solved several processing problems associated with this heap-leaching operation. The Valdez Creek Mining Co.'s placer operation near Cantwell, the State's largest gold producer in 1989, focused efforts during 1990 on diverting Valdez Creek in preparation for resuming full production during 1991. Because of low gold prices and persistent operational losses, WestGold Inc. permanently closed its *BIMA* dredge in late 1990. The *BIMA*, the world's largest oceangoing bucketline dredge, had been operating seasonally offshore of Nome since 1986, recovering a total of about 4,200 kg (135,000 ounces) of gold.

As in previous years, a number of Alaskan properties were in various stages of exploration for gold during the year. Basic evaluation and/or drilling was conducted on a number of properties, including the Nixon Fork property near McGrath and at Chicken Mountain and Illinois Creek, both in the State's southwestern region. Also in the southwestern region, Cominco Alaska Inc. announced the discovery of a major copper-gold porphyry deposit near Iliamna. In the southcentral region, the Golden Zone and the Rainbow Hill properties near Cantwell underwent further evaluation.

Several advanced exploration projects under investigation over the past several years progressed toward commercial development. Fairbanks Gold Ltd. and Ventures Trident II continued to explore their Fort Knox property, 24 km (15 miles) northeast of Fairbanks. Progress during the year included the surface recovery and testing of bulk samples. The owners expected to begin a full feasibility study during 1991. Underground exploration work continued at the old Alaska-Juneau or A-J Mine immediately behind the city of Juneau. The owners, Echo Bay Mines Ltd. and W.G.M. Inc., continued to develop the mine's reserves, which increased by 50% during 1990 to about 103 metric tons (3.3 million ounces). Echo Bay also owned an interest in the old Treadwell Mine 1.6 Km (1 mile) west of Juneau and across the Gastineau Channel on Douglas Island. The Treadwell and the A-J Mines were both significant past producers of gold. At Berner's Bay, north of Juneau, Placer Dome U.S. Inc. and several partners continued drilling at their Jualin property, while several miles to the northwest, Echo Bay and Coeur d'Alene Mines Corp. continued exploration and mine development at their Kensington property, also a former producer. Ore reserves at Kensington were reported to have increased by 40% during 1990 to more than 59 metric tons (1.9 million ounces).

The State legislature ratified new legislation relating to the implementation of rental and net royalty fees from mining claims on all State lands and legislation requiring reclamation on all State, Federal, and private mining lands.

Arizona.—Arizona's largest producer of primary gold, Cyprus Gold Co.'s Copperstone Mine, near Quartzite, in La Paz County, produced at its full capacity of 3,110 kg (100,000 ounces) per year in 1990, or about 43% above capacity on-line during the previous year. The higher production rates during the year were attributed by Cyprus to higher ore grades and improved recovery. According to mine plans in effect at yearend, Copperstone's ore reserves were to be depleted by 1993.

In Yavapai County, Malartic Hygrade U.S. Inc., a subsidiary of Malartic Hygrade Gold Mines (Canada) Ltd., completed construction and startup of its new $3.4 million carbon-in-pulp mill at the Congress Mine; the first bar of gold was poured on August 14. Prior to Malartic's acquisition of the underground property and construction of the on-site 317-metric-ton-per-day (350-short-ton-per-day) mill, the previous owner, Echo Bay, had trucked the ore to a distant copper smelter for use there as a precious-metals-bearing flux. With the expanded facilities, the company expects to produce gold on-site at a rate of about 995 kg (32,000 ounces) per year.

Although several exploration or development programs were canceled or postponed, exploration for gold continued to be widespread throughout the State. Bond International Gold Inc. planned a drilling program near Prescott, but regulatory delays and an exploration permit that was too restricted led the company to terminate its interest in the area.

South of Yarnell in Yavapai County, Norgold Resources Inc. and ASARCO Incorporated conducted drilling and trenching on their Yarnell Mine Project. Asarco terminated its interest in the property near yearend. In southeastern Cochise County, Placer Dome U.S. Inc. and Oneida Resources Inc. reportedly drilled 137 holes on their jointly held Mexican Hat property. In Maricopa County, Wounded Bull Resources NL of Australia and Westmont Gold Inc. continued exploration on their Newsboy project near Wickenburg. Startup of the mine was projected for mid-1991.

During the year, the U.S. Bureau of Mines continued to investigate west-central Arizona and adjoining areas in California characterized by gold mineralization associated with extensional detachment faulting; several producing gold mines 80 km to 125 km (50 miles to 80 miles) south in California have been developed in similar structural environments.

California.—Following Nevada in gold production, California was, for the fourth consecutive year, the Nation's second largest gold-producing State. Three California mines, Mesquite, McLaughlin, and Jamestown, were among the Nation's top 25 gold producers in 1990.

Goldfields Mining Corp.'s open pit Mesquite Mine in Imperial County recovered gold by heap leaching of virgin ore supplemented by gold-bearing dump material. To the east of Mesquite at Glamis Gold Corp.'s Picacho Mine, Glamis completed construction of a new leaching site and began mining its Dulcina ore body. Glamis also began mining operations at its Yellow Aster Mine near Randsberg in Kern County, and December marked the first month of production at the company's Alto Mine near Copperopolis in Calaveras County.

Homestake's McLaughlin Mine near Lower Lake, about 113 km (70 miles) north of San Francisco, processed oxide and sulfide ore mined by open pit methods. In May, the company poured its first millionth ounce (31,000 kg) of gold since production began in 1985. McLaughlin is expected to ultimately yield a total of 93 metric tons (3 million ounces) during a mine life of 20 years. Because of lower oxide grades and unscheduled mill downtime, gold production during 1990 declined 6% from the record 8,823 kg (283,843 ounces) produced during the previous year.

Production at Sonora Gold Corp.'s 70%-owned Jamestown Mine in Tuolumne County was, at 3,163 kg (101,700 ounces), reportedly about 9% less than that of the previous year mostly because of lower prices and lower grade ore. Ongoing development of the mine's higher grade areas was expected, resulting in improved performance in the year ahead.

Numerous other California gold mines continued production during the year. Several properties that began or resumed op-

erations included the Plumas underground placer mine in Plumas County, which was reportedly opened in midyear by Siene River Resources Inc. of Vancouver, British Columbia. Royal Gold Inc. of Denver resumed production in November at its Sixteen-to-One Mine in Sierra County. Properties in various stages of exploration, permitting, or construction included the following: Amax Gold Inc.'s Hayden Hill property in Lassen County, Viceroy Resources Corp.'s Castle Mountain project in San Bernardino County, Royal Gold's Long Valley project in Mono County, and Tenneco Minerals Inc.'s Golden Dome property in Sierra County.

In November, voters in two California counties, Tuolumne and Nevada, defeated initiatives aimed at restricting mining operations. The Tuolumne County initiative targeted new mining operations and expansion of existing facilities. It would have required a 1,067-meter (3,500-foot) radius buffer zone around any operation that generates noise, vibration, traffic dust, nighttime light or glare, and toxic or potentially harmful runoff from the perimeter of excavations. The ballot initiative in Nevada County would have required a similar radius buffer between a surface mining operation and any "noncompatible" land use.

Colorado.—Gold mine production in Colorado declined for the third consecutive year, again largely reflecting reduced recovery at the Summitville Mine, the State's largest gold mine, and the closure of several other operations.

Gold production at the Summitville Mine of Galactic Resources Ltd. declined from the 1,074 kg (34,545 ounces) produced during 1989 to 864 kg (27,776 ounces) in 1990. Poor recovery rates at the seasonal open pit heap-leaching operation in Rio Grande County were cited as the principal contributing factor. If several potentially good exploration targets developed at Summitville during recent exploration prove to be worthwhile, the company may move to develop them using underground methods.

Ownership of the Sunnyside Mine at Silverton was assumed by a venture group composed of Echo Bay, Alta Gold Corp., and Washington Mining Corp., the operator. Washington Mining also had a joint venture with Gold King Consolidated Inc. on a portion of Gold King's claims adjoining Sunnyside. In the Cripple Creek area of Teller County, Golden Cycle Gold Corp. and Pikes Peak Mining Co., owned by NERCO Minerals, continued to produce gold from their jointly held heap-leaching operations and also conducted an extensive exploration and development program at holdings around Cripple Creek. Near the town of San Luis in Costilla County, Battle Mountain Gold Co. moved toward an early 1991 startup of its San Luis Mine. The new open pit and milling operation was expected to yield about 1,870 kg (60,000 ounces) of gold per year for at least 8 years.

In early 1990, Royal Gold Inc. ceased production at the historic Camp Bird Mine in Ouray County. First opened in 1896, the Camp Bird has been an intermittent producer of gold and silver as well as copper, lead, and zinc.

Exploration for gold, especially at or around some of Colorado's numerous former gold-producing mines, was conducted by a number of companies.

The second largest gold nugget ever found in Colorado was discovered in 1990. This 249-gram (8-ounce) nugget was found on the alpine slopes of Pennsylvania Mountain, west of Alma in Park County. Named the Turtle Nugget, it is 38 mm wide by 76 mm long (1. 5 by 3 in.). Colorado's largest gold nugget, weighing 373 grams (12 ounces) and measuring 76 by 51 mm (3 by 2 inches), was found at the same site in 1937. Both are on display at the Denver Museum of Natural History.

Idaho.—Exploration for precious metals increased in Idaho during 1990 to its highest level since the 1930's, according to a review of State mining activities prepared by the Idaho Geological Survey.[6] Exploration for disseminated gold deposits was especially active in the southwest and southeast parts of the State, on both sides of the Snake River Plain. The discovery several years ago of the Beartrack deposit in Lemhi County, the largest discovery in the State's history, continued to draw companies to the area.

The increased exploration activity notwithstanding, gold production declined from that of the previous year, reflecting, in part, the exhaustion of Coeur d'Alene Mines Co.'s Thunder Mountain Mine in Valley County. Despite the closure of Thunder Mountain, there were at least six new gold mines under active development and scheduled to begin production within the next 18 to 24 months. These properties include the Beartrack property, under development by FMC Gold; Pegasus Gold Inc.'s Black Pine property near Bridge in Cassia County, due to start in mid-1991; NERCO Minerals Co.'s Stone Cabin property in Owyhee County, where construction was due to begin in 1991; and Grouse Creek Mining Corp.'s Grouse Creek Mine, under development near Stanley in Custer County. U.S. Antimony Corp. (USAC) continued development of its planned open pit Yellow Jacket Mine in Lemhi County and final permits for Idaho Gold Corp.'s Buffalo Gulch Project near Elk City in Idaho County were received in September, and production was scheduled to begin in mid-1991. Idaho Gold's nearby Champagne Mine completed its first full year of production in 1990.

Hecla Mining Co. resumed production at its Yellow Pine Unit east of the town of Yellow Pine, in Valley County. The newly reopened and expanded seasonal heap-leaching operation produced an estimated 1,796 kg (57,747 ounces) of gold during the year. Also near Yellow Pine, Pioneer Metals Corp. continued seasonal heap leaching at its Stibnite-West End Mine. Several other gold mines as well as mines producing byproduct gold were in operation in Idaho during the year. USAC continued year-round operation at its flotation and vat leach mills at Preacher's Cove in Lemhi County.

During the year, the State Lottery Commission started a new "Scratch" game called Silver and Gold, which offered winnings payable in cash or silver and gold coins minted by the Sunshine Mining Co.'s Hayden Lake refinery. Sunshine Mining is reportedly the only U.S. mining company to mine, refine, and mint gold and silver.

Montana.—Following a trend established more than a decade ago, exploration expenditures in Montana continued to be directed primarily toward gold. According to a review of mining activities prepared by the Montana Bureau of Mines and Geology,[7] 1990 exploration investments were probably less than those of 1989, with the spending pattern shifting away from large expenditures on a few large projects to smaller expenditures dedicated to a larger number of targets. Exploration activity by both large and small companies was especially prevalent in southwestern Montana. With more than 13 metric tons (418,336 ounces) of gold produced during 1990, Montana maintained its position as the Nation's fourth largest gold-producing State.

Pegasus Gold operated four gold-producing mines in Montana during 1990: the Zortman-Landusky Mine in Phillips

County; the Beal Mountain Mine at German Gulch southwest of Butte; the Montana Tunnels gold, silver, lead, and zinc mine in Jefferson County; and the Basin Creek Mine in Lewis and Clark County. Collectively, these four properties, all surface operations, yielded 7,635 kg (245,500 ounces) of gold during the year. At the Zortman-Landusky site, Pegasus mined 11.8 million metric tons of ore at an average grade of 0.549 gram per metric ton (0.016 ounce per short ton) of gold plus values in silver. During the year, Pegasus completed construction of a new 54.4-million-metric-ton capacity leach pad on the Landusky side of the operation, and studies were underway during the year to expand the capacity of leaching operations on the Zortman side of the project. At the Beal Mountain Mine, near Anaconda, Pegasus completed its first full year of commercial production in May. In a move to overcome unexpected metallurgical problems encountered earlier at the company's Montana Tunnels Mine, Pegasus, in 1990, revised its mining plan and modified the crushing and flotation circuits at the mill. At the Basin Creek Mine, 29 km (17 miles) southwest of Helena, Pegasus constructed a new leach pad to overcome recovery problems suffered by the previous owners. However, additional difficulties that arose during 1990 forced the company to suspend mining before yearend. Leaching of the ore remaining on the pad was expected to continue through 1991.

In south-central Park County, the new underground Mineral Hill Mine completed its first full year of operation, producing about 1,220 kg (39,200 ounces) of gold. Several operational problems associated with mill design and processing that developed during the year were expected to be overcome in 1991, thereby enabling Mineral Hill to attain its designed output capacity of about 1,300 kg (42,000 ounces) per year. Mineral Hill is jointly owned by Homestake and American Copper and Nickel Co. In Jefferson County, near Whitehall, production at Placer Dome's Golden Sunlight Mine decreased 13% from the 3,469 kg (111,539 ounces) of gold produced in 1989. The company attributed the temporary decline to unexpected lower grade ore encountered while mining toward a higher grade area of the deposit. In September, Canyon Resources Corp. completed construction of a new 8.1-million-metric-ton leach pad at its Kendall Mine near Lewiston in Fergus County; with the new pad in operation, Canyon expects to nearly double output from the mine to 1,400 kg (45,000 ounces) by the end of 1991. Production and development work continues at Blue Range Mining Co.'s Geis Mine about 20 km (12 miles) southeast of the Kendall property. Employment at the Geis Mine nearly doubled during the year to 100 workers.

As in past years, many, generally small, intermittent placer operations were active along favorable drainages in western Montana.

Nevada.—Following a pattern established more than a decade ago, Nevada maintained its position as the Nation's principal gold-producing State; if Nevada were a sovereign nation it would be ranked as the world's fifth largest gold producer. Gold production in the Silver State amounted to more than 60% of the national total. Ten of the Nation's leading 25 gold mines in 1990 were in Nevada.

The State's and the Nation's dominant gold-producing company, Newmont Gold Co. (NGC), with operations generally centered around Carlin in northern Eureka County, reported gold production during 1990 of 52,132 kg (1,676,300 ounces). NGC's total cash costs of production, including royalties, general and administrative, and other expenses, amounted to $218 per ounce in 1990 compared with $227 per ounce in the previous year. Total costs for the year, including depreciation, ore depletion, and amortization, were $267 per ounce compared with $272 in 1989. Newmont's holdings in the Carlin area include nine ore deposits containing about 590 metric tons (18,892,000 ounces) of gold. Production during 1990 was derived from four surface or open pit mines feeding five nearby mills and three heap-leach facilities. In mid-1990, the company began a field test on two heap-leach pads to determine the feasibility of using bacteria to oxidize various types of low-grade refractory ores. The company noted that its strategy for the next 3 years will be to maintain production at approximately 47,000 kg (1.5 million ounces) per year from oxide ores while at the same time maintaining test programs and studies aimed at developing optimum methods of mining and treating refractory ores.

At the Goldstrike Mine, adjacent to NGC's Eureka County operations, American Barrick Resources Corp. proceeded with its Betze Development Plan (Betze Project) aimed at increasing gold production at the company's holdings from the 1990 level of about 11,000 kg (353,880 ounces) to about 28,000 kg (900,00 ounces) in 1992. Part of the expansion has been dedicated to expanding milling capacity, especially capacity designed to accommodate the gold-bearing sulfide ores present in the deeper mineralized zones controlled by the company. American Barrick also holds interests in the Pinson and Preble Mines, near Golconda in Humboldt County.

In the northern part of adjoining Elko County, three separate open pits were mined at Independence Mining Co.'s Jerritt Canyon Mine. The company was also proceeding with development of its nearby Burns Basin deposit, scheduled to begin production in 1991. To the north, in the Humboldt National Forest, the company's Big Springs Mine was designated by the U.S. Forest Service to be the Nation's first hard-rock national mining "showcase" for extracting minerals in an environmentally sound manner. Nearby, Homestake completed mining at its small Wood Gulch Mine. Near Midas in western Elko County, Ivanhoe Gold Co. poured the first bar of production gold at its new Ivanhoe (Hollister) Mine. The new mine is expected to produce about 1,900 kg (60,000 ounces) of gold annually.

The world's largest heap-leach gold mine and Nevada's second largest gold producer, the Round Mountain Mine in Nye County, processed more than 14 million metric tons (15,537,000 short tons) during the year for a total gold yield of 13,431 kg (431,872 ounces), representing a recovery rate of about 75%. Production during 1990 increased by more than 50%, reflecting the successful debugging and fine-tuning of new facilities installed during a major 2-year expansion completed in mid-1989. During the year, the company also produced gold from its satellite mining, milling, and leaching operations at nearby Manhattan, NV. Ore reserves at Manhattan were depleted during 1990, and the mill was placed on standby until 1993 pending development of the company's Masada deposit at Round Mountain. The company is owned by Echo Bay Mining (50%), Homestake (25%), and Case Pomeroy Inc. (25%).

Near Gabbs in Nye County, lower gold production at FMC Gold Co.'s Paradise Peak Mine reflected lower gold ore grades partially offset by improved recovery. Early in the year, plans were approved to move ahead with development of the nearby Ketchup Flat deposit. To the west, on the outskirts of Beatty, Bond International Gold Inc. completed its first full year of production in September at its new Bullfrog Mine. Nearby and to the east of Beatty, U.S. Nevada Gold Search Joint Venture also completed its first full year of production at its

Mother Lode Mine. The deposit was reportedly nearing depletion at yearend.

South of Battle Mountain in Lander County, Battle Mountain Gold Co., mining gold ore from three surface mines, Fortitude, Surprise, and Labrador, produced about 8,000 kg (258,000 ounces) of gold in 1990. During the third quarter, the company began operations at its new Copper Basin heap-leaching operation. The Surprise and Labrador pits both provided material for the new facility. Near yearend, owing to poor market conditions, the company suspended operations at its Canyon Placer operation.

Further to the south in Lander County, Echo Bay produced 7,932 kg (255,044 ounces) of gold at it McCoy and Cove Mines. Nineteen ninety was the first full year for operation of new milling facilities installed during a major expansion accomplished during 1988-89. Both mines extract gold and silver ore from surface and underground mining operations. An initial problem with bird kills in 1989, related to the toxicity of the tailings pond, was overcome during 1990 with the addition of an all-new, $3 million mill effluent treatment facility based on the patented Inco sulfur dioxide-and-air process. Near the McCoy and Cove operations, NERCO Minerals and Alta Gold Co. dedicated the opening of their new Elder Creek Mine. The new surface mine was expected to produce about 1,089 kg (35,000 ounces) of gold in 1990.

In Humboldt County, Santa Fe Pacific Gold Corp., a unit of Santa Fe Pacific Corp., poured the first bar of production gold at its new, wholly owned Rabbit Creek Mine, northeast of Winnemuca. The event marked the successful completion of 18 months of construction costing $77 million. The company anticipates an annual gold production rate at the new open pit and milling operation of more than 3,100 kg (100,000 ounces). Further west in Humboldt County, Amax Gold Inc. recovered and poured the millionth troy ounce (31,000 kg) of gold at its open pit Sleeper Mine. The first ounce of production gold was poured at the Sleeper Mine in March 1986.

In addition to the gold producers noted above, nearly four dozen other operations contributed to Nevada's overall performance during the year. Several mines were closed because of depletion of known reserves, while several others were placed on standby awaiting improved market conditions or further reserve development. Other properties beginning production during the year included Kennecott Rawhide Mining Co.'s Denton-Rawhide Mine in Mineral County, USMX Inc.'s Casino Mine in White Pine County, and Gold King Nevada Inc.'s Adelaide Crown Mine in Humboldt County.

In 1990, the Nevada State Environmental Commission approved the State's new mined land reclamation regulations, aimed at returning disturbed lands to productive postmining use. Effective October 1, the new regulations, which apply to both public and private lands, require mining and exploration companies to obtain reclamation permits prior to beginning a mining or exploration project. Existing projects must be permitted before October 1993.

South Carolina.—U.S. Bureau of Mines data on gold production in South Carolina are withheld to avoid disclosing company proprietary data. However, estimates prepared by others[8] suggested that South Carolina mines produced about 6,842 kg (220,000 ounces) during 1990. South Carolina's principal gold mines were the Ridgeway Mine in Fairfield County, the Brewer Mine in Chesterfield County, and the Haile Mine in Lancaster County.

Gold production during 1990 at South Carolina's largest gold mine, the Ridgeway Mine of Ridgeway Mining Co., amounted to 5,348 kg (171,974 ounces) compared with 5,365 kg (172,505 ounces) produced during 1989. The new open pit mine near the town of Ridgeway employs milling and vat leaching recovery methods. The mine is a joint venture between the RTZ Corp. PLC and Galactic Resources Ltd.

Piedmont Mining Co. reported that gold production at its Haile Mine, near Jefferson, increased 45% over that of 1989 to a record 6,966 kg (22,402 ounces). Production in 1990 came primarily from the mine's Champion Pit. The increased production was attributed to improved ore crushing facilities installed in early 1990 plus improvements made to the heap-leaching and recovery circuits. Mining operations at the Brewer Mine, owned by Westmont Mining Inc., were temporarily suspended in late 1990 following the failure of an earthen dam on the property.

Near the town of McCormick, in McCormick County, Gwalia (USA) Ltd. moved toward an early 1991 startup of mining and heap leaching at its Barite Hill Mine. Barite Hill was developed around several old mines, including the old Dorn Mine, which produced gold during the 1850's and 1930's. Gwalia is a wholly owned subsidiary of Gwalia International Ltd. of Australia.

Exploration for gold in South Carolina was quite active during 1990. Much of the work was focused on prospects in the Camden area of Kershaw County and northeastward along the Carolina Slate Belt. Some drilling reportedly was in progress at the old Leach Mine near Jefferson in Chesterfield County.

South Dakota.—For yet another year, the combined production from South Dakota's five primary gold mines was sufficient to maintain that State's position as the Nation's third largest gold-producing State. All five mines were in Lawrence County in western South Dakota.

The State's principal gold-producing mine, the Homestake Mine at Lead, was the Nation's fourth largest gold mine during 1990. Homestake, with the exception of a brief period during World War II, has been operating continuously and under the same ownership since 1877. Cumulative gold production since its inception has amounted to more than 1,120 metric tons (36 million ounces). During 1990, Homestake's production was 12,077 kg (388,312 ounces) compared with the previous year's 11,874 kg (381,788 ounces). Though primarily a deep underground operation, 21% of the 1990 production originated from the mine's recently reopened surface operation, known as the Open Cut. Mining at the Open Cut was first begun in 1885 on the site of the original gold strike made in 1876 by the two Moses brothers from Portland, OR, and their partner Hank Harvey. The partners reportedly named their claim "Homestake" in the hope that its rewards would be sufficient for them to return home in style, which they were. During 1990, Homestake began work on its new North Homestake Project, an exploration tunneling program to investigate deep gold mineralization discovered about 5 km (3 miles) north of the existing mine workings. The company also initiated work on a new $8.5 million mill expansion project aimed at providing sufficient milling capacity to handle more Open Cut ore.

Four other gold mines in Lawrence County, all open pit and heap-leaching operations, accounted for the balance of the State's production during the year. The State's second largest gold mine was Wharf Resources (USA) Inc.'s Annie Creek-Foley Ridge property, 5 km (3 miles) west of Lead. During the year, the company completed expansions at two of its four leach pads and expansion of a third pad was nearly completed by yearend. In the recovery plant area,

three of the mine's five collection ponds were also upgraded.

Eight km (5 miles) northwest of Lead, Bond Gold-Richmond Hill Inc. reportedly produced 1,210 kg (38,897 ounces) of gold at its new Richmond Hill Mine, while 8 km (5 miles) southwest of Lead, MinVen Gold Corp.'s new Gilt Edge Mine completed its second full year of operation for a reported yield of 1,030 kg (33,134 ounces) of gold. At the Golden Reward Mine 13 km (8 miles) southwest of Lead, Golden Reward Mining Co. reportedly recovered 924 kg (29,705 ounces) of gold thereby completing its first full year of operation.

Goldstake Explorations (SD) Inc. moved ahead with approvals for its Whitewood Creek Tailings Project in Lawrence, Butte, and Meade Counties. The company plans to reprocess relict gold mine tailings resulting from earlier mining operations.

In February, the Governor of South Dakota approved a 2-year moratorium, valid until January 1, 1992, on new gold and silver surface mines in the Black Hills. The measure bans new large-scale surface gold and silver mining operations in the Black Hills and allows existing mining operations to expand no more than 81 additional hectares (200 acres), and then only if previously mined areas were reclaimed. The moratorium bill was sponsored by the Governor and the South Dakota mining industry. In November, voters in South Dakota defeated an initiative aimed at restricting mining operations. The initiative would have restricted the total amount of land available to gold and silver mines in the Black Hills Region to about 1,255 hectares (3,100 aces). Wording of the measure in itself proved controversial as opponents and proponents argued whether surface facilities of underground mines also would be included. Two previous antimining initiatives presented since 1987 have been rejected by voters. Also during 1990, the State Department of Water and Natural Resources (DWNR) received a grant of about $95,000 from the Western Governor's Association. The DWNR was to develop a standardized test to better determine the long-term environmental effects of surface disposal of spent gold and silver ore, previously treated with a dilute sodium cyanide solution and then neutralized using hydrogen peroxide.

Utah.—Utah's principal gold as well as silver producer, the Bingham Canyon Mine near Salt Lake City, was the Nation's third largest gold- (and silver-) producing mine in 1990. Bingham Canyon, owned by RTZ and operated by the Kennecott Corp., produces gold as a byproduct of its copper mining operations. In September, Kennecott completed its first full year of production at its new Barney's Canyon Mine about 6.4 km (4 miles) north of Bingham Canyon. The new open pit and heap-leaching mine reportedly produced 4,292 kg (138,000 ounces) of gold during the calendar year.

Barrick's Mercur Mine in Tooele County achieved a record production of 3,776 kg (122,043 ounces) at a cash production cost of $238 per ounce during 1990. Factors behind the mine's record performance were excellent autoclave throughput, higher-than-planned ore grade and mill recovery, and the sustained performance of the mine's heap-leaching facilities. During 1990, Barrick expended $8.2 million on construction of a new leach area and associated recovery plant plus increased capacity at the mine's tailings dam.

In May, Tenneco Minerals Inc. completed its first full year of production at its Goldstrike Mine. The new surface and heap-leaching operation is near St. George in Washington County.

Washington.—The Washington State Division of Geology and Earth Resources in its annual review of State mineral industry[9] activity estimated that gold production during 1990 increased by 40% compared with that of 1989. Much of the increase reflected gold recovered from two newly opened deposits in Ferry County.

Washington State's largest gold producer and the Nation's second largest underground gold mine, the Cannon Mine, at Wenatchee in Chelan County, produced about 4,634 kg (149,000 ounces) of gold during the year compared with 4,678 kg (150,420 ounces) produced during the previous year. Cannon was owned by Asamera Minerals (U.S.) Inc., the operator, and Breakwater Resources Ltd. During 1990 Asamera, in joint venture with Breakwater, continued its surface and subsurface exploration for new gold deposits around Wenachee; several reportedly favorable drill intercepts were made in an area 5.6 kg (3.5 miles) southeast of the mine.

At Republic, in Ferry County, Hecla's Republic Unit, or Knob Hill Mine, milled a record 84,225 metric tons (92,843 short tons) to recover 2,532 kg (81,397 ounces) of gold plus values in silver during 1990. This production represented a nearly 10% increase over that of 1989. Hecla continued development of its new $6 million decline ramp, begun in 1989 to provide improved ventilation, more exploration stations, and easier access to the mine's Golden Promise area. Republic's cash production costs for gold in 1990 were about $130 per ounce.

In February, following 12 months of construction and startup testing at its new 1,361-metric-ton-per-day (1,500-short-ton-per-day) carbon-in-leach mill, Echo Bay began producing gold at its Kettle River project near Republic. Production during 1990 was 2,591 kg (83,310 ounces). The Kettle River project, a joint venture between Echo Bay and Crown Resource Corp., has been developed around four gold deposits, Kettle, Overlook, key East, and key West. Most of the mill feed processed during the year was derived from the nearby Overlook deposit; smaller tonnages of ore were trucked to the mill from the Kettle deposit near Curlew, 40 km (25 miles) north. Both Kettle and Overlook are mined underground with access provided by decline ramps rather than shafts.

The State reported that more than 70 companies and individuals conducted exploration for metals during 1990 and that gold was once again the principal target metal. Much of this activity was concentrated in northern Okanogan, Ferry, and Stevens Counties.

Consumption and Uses

The use of gold in the domestic market shown in table 9 accounts for only part of the overall market for commercial products. An important segment of market demand is also satisfied by imported gold-bearing products in various forms ranging from unfinished jewelry products, such as gold chain and findings, to electronic equipment containing gold components.

Contracts for gold futures traded during 1990 on the Nation's futures exchanges represented about 30,260 metric tons (973 million ounces) compared with the previous year when the equivalent of more than 31,000 metric tons (999 million ounces) was traded. The New York-based Commodity Exchange Inc. (COMEX) was, as in the previous year, by far the dominant exchange.

Sales of newly minted gold coins by the U.S. Mint declined for the third consecutive year. On October 20, the fourth anniversary of the American Eagle gold bullion coin program, the U.S. Mint had sold 168 metric tons (5.4 million ounces) of contained gold, all sourced, as mandated in the enabling legislation, from contemporary domestic gold mines.

Although gold loan activity between

TABLE 3

TWENTY-FIVE LEADING GOLD-PRODUCING MINES IN THE UNITED STATES IN 1990, 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	Smokey Valley Common Operation	Nye, NV	Round Mountain Gold Corp.	Do.
3	Bingham Canyon	Salt Lake, UT	Kennecott-Utah Copper Corp.	Copper ore.
4	Homestake	Lawrence, SD	Homestake Mining Co.	Gold ore.
5	Goldstrike	Eureka, NV	Barrick Goldstrike Mines Inc.	Do.
6	Jerritt Canyon (Enfield Bell)	Elko, NV	Independence Mining Co. Inc.	Do.
7	Mesquite	Imperial, CA	Goldfields Mining Corp.	Do.
8	McLaughlin	Napa, CA	Homestake Mining Co.	Do.
9	Fortitude and Surprise	Lander, NV	Battle Mountain Gold Co.	Do.
10	McCoy and Covedo	do.	Echo Bay Mining Co.	Do.
11	Sleeper	Humboldt, NV	Amax Gold Inc.	Do.
12	Chimney Creek	do.	Goldfields Mining Co.	Do.
13	Bullfrog	Nye, NV	Bond Gold Bullfrog Inc.	Do.
14	Paradise Peak	do.	FMC Gold Co.	Do.
15	Getchell	Humboldt, NV	FMG Inc.	Do.
16	Ridgeway	Fairfield, SC	Ridgeway Mining Co.	Do.
17	Wind Mountain	Washoe, NV	Amax Gold Inc.	Do.
18	Cannon	Chelan, WA	Asamera Minerals (U.S.) Inc.	Do.
19	Barney's Canyon	Salt Lake, UT	Kennecott Corp.	Do.
20	Mercur	Tooele, UT	Barrick Mercur Gold Mines Inc.	Do.
21	Zortman-Landusky	Phillips, MT	Pegasus Gold Inc.	Do.
22	Copperstone	La Paz, AZ	Cyprus Copperstone Gold Corp.	Do.
23	Golden Sunlight	Jefferson, MT	Golden Sunlight Mines Inc.	Do.
24	Crofoot and Lewis	Humboldt, NV	Hycroft Resources & Development Inc.	Do.
25	Jamestown	Tuolumne, CA	Sonora Mining Corp.	Do.

commercial depository banks and gold producers generally seemed to have peaked in 1988, it continued to be an acceptable method of financing new mine development or expansion of existing facilities.

In addition to its ages-old usage 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, connector, keyboard contracts, miniaturized circuitry, and as a dopant in some semiconductors. Modern solid-state electronic devices such as computers employ very low voltages and currents, and thus require connectors, switch contacts, soldered joints, and certain other components that remain chemically and metallurgically stable for the life of the device. Increasingly complex civilian, military, and aerospace electronic systems use gold to ensure dependable operations under a wide range of operating conditions. For example, because of its ability to provide reliable electrical connections, gold is used extensively in spacecraft such as the *Hubble Space Telescope* that must function flawlessly in the harsh environment of outer space. A more down-to-earth example would be the common touchtone telephone that has up to 33 gold contact points; gold plating employed on the contact surfaces of the quick disconnect between the telephone and the line ensures static-free reception.

Gold alloys have long been used in certain electrical instruments, for example, as wipers and windings in slide-wire potentiometers, where long-term reproducibility is essential. Gold-palladium alloy wires are used in thermocouples, especially those used to measure high temperatures encountered in some industrial processes and aircraft engines. Gold-containing brazing alloys such as gold-nickel alloy are important to the aerospace industry, especially in the assembly of some military jet turbine engines and high-performance rocket engines. Gold is used as a reflector of infrared radiation in radiant heating and drying devices and heat-insulating windows for large buildings. It is used in spacecraft such as the space shuttle, which relies upon gold to seal and protect its vital propulsion system from problems associated with hydrogen embrittlement. Gold-coated mirrors are the principal component of infrared jammers used on numerous military aircraft to confuse the guidance instruments of heat-seeking missiles.

Gold applied as organometallic liquids is used for the decoration of porcelain and glass dinnerware; gold leaf is used for the decoration of buildings, both inside and outside; and gold alloys are used in rupture discs in chemical process equipment and in the perforated "spinnerets" through which cellulose acetate fibers are extruded. Since 1975, 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.

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		Gold-silver ore		Silver ore	
		Metric tons of gold	Kilograms of gold	Metric tons of gold	Kilograms of gold	Metric tons of gold	Kilograms of gold
1986	2,281	55,050,375	110,217	788,434	883	5,019,289	691
1987	5,082	84,195,951	137,832	W	W	7,944,696	1,235
1988	4,754	127,883,933	181,891	W	W	9,573,505	2,075
1989	5,711	r169,380,297	r236,207	W	W	4,450,703	505
1990:							
Alaska	W	W	W	—	—	—	—
Arizona	(1)	W	W	W	W	—	—
California	W	19,540,618	W	—	—	—	—
Colorado	—	W	W	W	W	—	—
Idaho	—	W	W	—	—	W	W
Montana	W	W	11,010	—	—	—	—
Nevada	W	133,796,087	178,471	W	W	W	W
New Mexico	—	W	W	—	—	—	—
Oregon	W	—	—	—	—	—	—
South Carolina	—	W	W	—	—	—	—
South Dakota	—	9,054,024	17,870	—	—	—	—
Utah	—	6,433,467	9,968	W	W	158,578	9
Washington	—	W	9,620	—	—	—	—
Total	2,579	200,080,467	272,268	W	W	W	W
Percent of total gold	1	XX	92	XX	W	XX	W

	Lode				Total	
	Copper ore		Other[2]			
	Metric tons	Kilograms of gold	Metric tons	Kilograms of gold	Metric tons	Kilograms of gold
1986	r135,674,738	1,643	303,845	582	r196,836,681	116,297
1987	165,407,018	8,074	W	W	r258,688,990	153,870
1988	201,893,222	11,314	W	W	r340,614,832	200,914
1989	210,474,747	r17,620	W	W	r391,059,545	r265,731
1990:						
Alaska	—	—	W	W	347,063	3,232
Arizona	88,286,021	1,121	—	—	89,392,594	5,000
California	—	—	—	—	19,540,618	29,607
Colorado	—	—	W	W	1,679,010	2,357
Idaho	—	—	W	W	W	W
Montana	—	—	W	2,001	21,458,277	13,012
Nevada	W	W	3	226	136,074,173	179,078
New Mexico	W	W	—	—	30,231,997	888
Oregon	—	—	—	—	—	W
South Carolina	—	—	—	—	W	W
South Dakota	—	—	—	—	9,054,024	17,870
Utah	W	W	—	—	W	W
Washington	—	—	—	—	W	9,620
Total	156,177,067	W	W	W	363,581,387	294,527
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]Less than 1/2 unit.
[2]Includes lead, zinc, copper-lead, lead-zinc, copper-zinc, copper-lead-zinc ores, and old tailings, etc.

TABLE 5

LODE GOLD PRODUCED IN THE UNITED STATES, BY STATE

Year and State	Amalgamation		Cyanidation		Smelting of concentrates			Smelting of ore			
	Ore treated (metric tons)	Gold recovered (kilograms)	Ore treated (metric tons)	Gold recovered (kilograms)	Ore concentrated (metric tons	Concentrates smelted (metric tons	Gold recovered (kilograms)	Ore smelted (metric tons)	Gold recovered (kilograms)	Total ore processed[1] (metric tons)	gold recovered (kilograms)
1986	r771,323	1,048	r58,500,012	104,422	r136,836,551	r2,827,243	r 28,345	r145,197	2201	**r196,253,082**	r 2114,016
1987	W	W	r88,696,450	129,812	169,472,280	3,430,726	17,548	W	W	r258,688,990	2148,788
1988	W	W	r133,042,143	173,493	207,228,838	3,969,256	21,057	W	W	340,614,832	2196,161
1989	W	W	r172,294,506	r228,040	r189,266,803	r3,827,109	r30,283	W	W	r391,059,545	r 2260,021
1990:											
Alaska	—	—	W	W	W	W	W	—	—	W	W
Arizona	—	—	W	W	88,286,021	1,736,902	1,121	W	W	89,392,594	4,999
California	W	W	17,362,389	26,461	W	W	W	—	—	W	W
Colorado	102,660	384	W	W	W	W	W	318	1	1,679,010	2,357
Idaho	—	—	W	W	W	W	60	—	—	W	W
Montana	—	—	W	10,737	3,856,087	57,814	W	W	W	68,737,736	213,012
Nevada	—	—	135,921,989	178,823	W	W	W	W	W	136,074,173	2179,073
New Mexico	—	—	—	—	W	W	W	W	W	30,231,997	888
South Carolina	—	—	W	W	—	—	—	—	—	W	W
South Dakota	—	—	9,054,024	17,870	—	—	—	—	—	9,054,024	17,870
Utah	—	—	6,592,044	9,977	W	W	W	W	W	W	W
Washington	—	—	W	W	W	W	W	—	—	W	9,620
Total	W	W	199,644,031	264,833	163,749,630	3,649,072	25,828	W	W	363,581,387	291,949

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Total," where applicable.
[1]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.
[2]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[4]	
	Gold		Gold	
	Ore treated (metric tons)	Recovered[3] (kilograms)	Ore treated (metric tons)	Recovered (kilograms)
1986	r24,426,426	73,362	r34,073,586	31,060
1987	r29,228,356	74,807	r59,468,094	55,005
1988	r30,779,239	100,817	r102,262,904	72,676
1989	r42,464,260	121,716	r129,830,246	r106,324
1990	49,688,230	135,764	149,955,801	129,069

rRevised.
[1]May include small quantities recovered by leaching with thiourea, by boextraction, and by proprietary processes.
[2]Including autoclaves.
[3]May include small quantities recovered by gravity methods.
[4]May include tailings and waste ore dumps.

Stocks

Yearend stocks of refined bullion held by industrial users increased about 10% over those held at the end of 1989. On a quarterly basis, the sharpest declines in industrial stocks were reported during the second quarter of the year and may reflect a withdrawal of material by manufacturers to meet anticipated demand, especially for jewelry products destined for sale later in the year.

Yearend stocks of gold certified for delivery by COMEX, the Nation's largest futures exchange, declined substantially from those held at the end of the previous year.

Markets and Prices

The Engelhard Industries-London daily final price of gold ranged from a high of $425 per ounce in February to a low of $347 per ounce in mid-June. Despite the invasion of Kuwait by armed forces from Iraq and an escalation of tension in the Persian Gulf toward yearend, the average for the year amounted to about $387 per ounce, essentially unchanged from the average of $383 per ounce registered during the previous year.

Foreign Trade

Total U.S. exports of gold increased substantially in 1990. Switzerland was again the principal recipient nation, receiving large quantities of both refined bullion and doré. In addition to Switzerland, Hong Kong and the United Kingdom were also principal destinations for refined bullion shipments.

Canada continued, as it has for more than a decade, to be the Nation's principal source

TABLE 7

GOLD PRODUCED AT PLACER MINES IN THE UNITED STATES, BY METHOD OF RECOVERY[1]

Method of recovery	Mines producing	Washing plants	Material washed[2] (thousand cubic meters)	Gold recoverable		
				Quantity (kilograms)	Value (thousands)	Average value per cubic meter
Bucketline dredging:						
1986	3	4	3,120	948	$11,227	$3.598
1987	4	5	7,136	3,471	49,989	7.006
1988	3	4	5,775	2,590	36,497	6.320
1989	3	4	5,560	2,720	33,454	6.016
1990	4	4	3,454	1,528	19,010	5.504
Dragline dredging:						
1986	3	14	11	[3]113	1,342	[4]16.823
1987	3	3	71	[3]67	971	[4]8.190
1988	—	—	—	—	—	—
1989	—	—	—	—	—	—
1990	—	—	—	—	—	—
Hydraulicking:						
1986	1	1	76	1	17	.217
1987	—	—	—	—	—	—
1988	—	—	—	—	—	—
1989	—	—	—	—	—	—
1990	—	—	—	—	—	—
Nonfloating washing plants:						
1986	4	4	211	781	9,244	43.852
1987	6	6	636	465	6,698	10.526
1988	6	6	473	302	4,255	9.004
1989	4	4	72	92	1,134	15.851
1990	—	—	—	—	—	—
Underground placer, small-scale mechanical and hand methods, suction dredge:						
1986	24	24	679	438	5,180	7.631
1987	15	15	367	1,078	15,529	42.330
1988	13	13	838	[3]1,862	26,225	[4]31.292
1989	20	20	1,404	[3]2,899	35,654	[4]25.349
1990	21	21	1,043	1,050	13,066	12.478
Total placers:[5]						
1986	35	47	4,097	[3]2,281	27,010	[4]6.309
1987	28	29	8,210	[3]5,082	73,187	[4]8.867
1988	22	23	7,085	[3]4,754	66,977	[4]9.453
1989	27	28	7,036	[3]5,711	70,242	[4]9.975
1990	25	25	4,497	2,579	32,076	[4]7.122

[1]Data are only for those mines that report annually on the U.S. Bureau of Mines voluntary survey; there are many more, usually smaller and less well-established operations, mainly in Alaska, that do not report.
[2]Excludes tonnage of material treated at commercial sand and gravel operations recovering byproduct gold.
[3]Includes gold recovered at commercial sand and gravel operations.
[4]Gold recovered as a byproduct at sand and gravel operations not used in calculating average value per cubic meter.
[5]Data may not add to totals shown because of independent rounding.

of refined bullion. Imports of gold-bearing waste and scrap from Switzerland and the Dominican Republic were nearly double those of the previous year, while imports of waste and scrap from Taiwan, about 13,200 kg (424,000 ounces) during 1989, all but ceased during 1990.

World Review

World gold mine production has exceeded that of the previous year for 11 consecutive years. Gold Fields Mineral Services Ltd.,[10] continuing for the second year the annual statistical survey prepared over the previous 23 years by its predecessor, Consolidated Gold Fields PLC, noted that world demand for gold in the market economy countries (MEC) reached another new record, surpassing the previous record set in 1989.

Gold Fields began its summary by fo-

TABLE 8

U.S. REFINERY PRODUCTION OF GOLD[1]

(Kilograms)

Raw material	1986	1987	1988	r1989	r1990
Concentrates and ores:					
Domestic and foreign	75,618	112,368	137,829	183,685	204,856
Old scrap	47,266	63,843	52,784	37,144	32,019
New scrap	r56,539	r45,166	80,702	127,086	135,643
Total[2]	r179,422	r221,376	271,315	347,915	372,518

rRevised.
[1]Data may include estimates.
[2]Data may not add to totals shown because of independent rounding.

TABLE 9

U.S. CONSUMPTION OF GOLD,[1] BY END-USE SECTOR[2]

(Kilograms)

End use	1986r	1987r	1988r	1989r	1990
Jewelry and the arts:					
Karat gold	53,247	58,635	57,959	60,877	55,375
Fine gold for electroplating	2,689	3,133	1,469	1,283	429
Gold-filled and other	9,890	9,256	7,598	7,364	8,132
Total[3]	65,827	71,024	67,027	69,524	63,936
Dental	7,921	6,944	7,576	7,927	8,700
Industrial:					
Karat gold	2,135	1,892	1,104	1,215	1,020
Fine gold for electroplating	11,579	12,343	15,088	20,684	17,251
Gold-filled and other	23,143	21,010	21,034	15,723	12,725
Total[3]	36,858	35,245	37,226	37,621	30,996
Small items for investment[4]	189	106	7	7	7
Grand total[3]	110,795	113,319	111,836	115,078	103,639

rRevised.
[1]Gold consumed in fabricated products only; does not include monetary bullion.
[2]Data may include estimates.
[3]Data may not add to totals shown because of independent rounding.
[4]Fabricated bars, medallions, coins, etc.

TABLE 10

YEAREND STOCKS OF REFINED GOLD IN THE UNITED STATES

(Kilograms)

	1986	1987	1988	1989	1990
Industry	28,771	23,390	38,360	r30,462	33,324
Futures exchange[1]	87,370	81,647	44,634	69,727	50,881
Department of the Treasury[2]	8,149,938	8,160,251	8,144,782	8,146,255	8,145,519
Earmarked gold[3]	10,348,006	10,252,982	10,044,519	9,911,928	9,861,101

rRevised.
[1]Commodity Exchange Inc. only. Stocks held by other exchanges estimated to be less than 2% of totals shown.
[2]Includes gold in Exchange Stabilization Fund.
[3]Gold held for foreign and international official accounts at New York Federal Reserve Bank.

cusing on the lackluster performance of the gold price, which translated, for both producers and traders alike, into a generally disappointing year. The company noted that even the unsettling political events in the U.S.S.R., and Iraq's invasion of Kuwait in August failed to spark sustained investor interest in gold or translate into higher gold prices. Although the price of gold in terms of U.S. dollars was for the most part unchanged from that of the previous year, the gold price in other currencies was generally lower, especially in terms of deutschemarks and Swiss franks. In real terms, the price in most major currencies fell to the lowest levels seen since at least 1978.

Despite earlier predications by many observers of a decline in karat jewelry fabrication demand during 1990, data on gold usage assembled by Gold Fields indicated that overall demand ended the year showing a significant increase.

The growth in total world mine production increased by only 3%, the lowest rate of increase since 1981. However, strong growth in both the United States and Australia and greater than expected production in the Republic of South Africa combined to offset declines elsewhere.

The centrally planned economy countries continued as in the year past to be major suppliers of gold to the Western World, with net sales to the West amounting to 380 metric tons (12.2 million ounces), including 285 metric tons (9.2 million ounces) attributed to the U.S.S.R.

Unlike 1989, when the world's central banks sold 225 metric tons (7.2 million ounces) into the market, those establishments were neither large sellers nor large purchasers of gold during 1990. Old scrap entering the market during the year totaled about 441 metric tons (13.7 million ounces), an increase of 36% over similar activity during 1989. Gold Fields attributed part of this increase in scrap supplies to the selling back of coins in Japan and distress and precautionary selling from a number of Middle Eastern countries after the start of the crisis in the Persian Gulf.

Overall gold jewelry fabrication demand rose 6% to a new high of 1,986 metric tons (63.8 million ounces) in 1990. In spite of the market problems encountered by a number of computer manufactures in Europe and North America, gold usage in industrial applications, especially electronics, rose 4% over that of the previous year. Dental gold usage rose only marginally. Declining interest in bullion coins during 1990, especially in the Far East, combined

TABLE 11

U.S. GOLD PRICES[1]

(Dollars per troy ounce)

Period	Low		High		Average
	Price	Date	Price	Date	
1986	326.70	Jan. 2	438.50	Oct. 8	368.24
1987	391.51	Feb. 18	501.25	Dec. 14	447.95
1988	396.62	Sept. 26	485.37	Jan. 8 and 11	438.31
1989	357.00	Sept. 15	416.86	Dec. 11 and 12	382.58
1990:					
January	396.32	Jan. 3	422.12	Jan. 24	411.46
February	408.89	Feb. 27	425.12	Feb. 7	418.20
March	369.28	Mar. 27	406.69	Mar. 6	394.38
April	369.03	Apr. 30	379.69	Apr. 5	375.54
May	364.32	May 31	376.39	May 22	370.41
June	347.09	June 14	364.73	June 1	353.58
July	352.70	July 12	374.03	July 25	363.78
August	371.73	Aug. 1	415.15	Aug. 21	396.34
September	379.79	Sept. 11	409.74	Sept. 28	390.77
October	366.02	Oct. 16	398.32	Oct. 9	382.03
November	377.59	Nov. 16	388.21	Nov. 26	383.11
December	370.00	Dec. 6	394.60	Dec. 31	379.48
Year	347.09	June 14	425.12	Feb. 7	384.93

[1]Engelhard Industries daily quotation.

Source: Metals Week.

with a steep 66% reduction in Mexican coin fabrication, resulted in an overall 10% decline in the fabrication of official coins.

Total identified gold bar hoarding during the year declined 59% from the 514.6 metric tons (16.5 million ounces) hoarded during 1989. Though the fall-off in the demand for these products was particularly evident in Hong Kong, Japan, and Taiwan, the steepest decline was registered in Brazil, where imposition of the Government's economic reform plan and the subsequent liquidity squeeze precipitated a dramatic increase in dishoarding from the private sector.

Capacity.—Rated annual production capacities for gold mines, as of December 31, 1990, are shown in table 14. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time at a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

A telephone survey of leading domestic producers responsible for 75% of then current output was conducted in late 1989. The survey indicated a capacity utilization rate of better than 97%. Incomplete data on the utilization rate at that time for those mines responsible for the remaining 25% of production suggested that although most are probably operating at a rate comparable to that of the leading producers, some, for a variety of reasons, may be operating at rates low enough to reduce the overall utilization rate to about 96%. This estimated rate probably reflects the level of performance in most of the other industrialized nations.

Because of the size, diversity, and explosive growth of primary gold production over the past decade, comprehensive world capacity data that would include all operating units that contribute to national totals are generally not available. Therefore, in the absence of appropriate data, certain broad assumptions were employed to derive international capacity numbers that are compatible with production data shown in table 15.

Optimum engineering capabilities may be more or less restrained by a combination of factors relating to Government and business attitudes, climate, location, ore grade and hardness, and mineralogy. With these and other considerations in mind, the author derived conversion factors and applied them to annual production data to approximate rated annual capacity for each producing nation.

Production data for individual nations, depending upon their perceived circumstances, was estimated to reflect from 75% of maximum capacity utilization for some essentially nonindustrialized nations to 96% utilization for most industrialized nations.

Reserves.—Demonstrated U.S. reserves of gold are about 4,980 metric tons (about 160 million ounces), and the reserve base is 5,480 metric tons (176 million ounces). Most of the U.S. gold reserve base shown in table 14 is confined to 18 States, with about 80% of the total in Alaska, California, Idaho, Montana, Nevada, and Washington. A dominant portion of the reserve base occurs in lode deposits.

Total world reserves shown in the table approximate 42,200 metric tons (1.4 billion ounces), of which nearly one-half is in the Republic of South Africa. The world reserve base for gold totals about 48,400 metric tons (1.6 billion ounces). Reserves of gold in the U.S.S.R. are believed to be about 6,220 metric tons (200 million ounces).

Estimates of reserves become available only over an extended period of time. The reserves shown for Australia, Brazil, Canada, and the United States generally reflect post-1980 data and the success of exploration efforts frequently initiated years earlier in response to rising prices.

Australia.—Australian gold production, at 242,299 kg (7,789,913 ounces), surpassed for the third consecutive year the production record of 118,180 kg (3.8 million ounces) set in 1903. Production has also increased for 10 consecutive years.

Imposition of a new tax on gold mining profits, scheduled to take affect January 1, 1991, reportedly resulted in a surge in production during the final quarter of the year as mines rushed to maximize their production before the long-established tax exemption on gold mining ended at yearend. For many mines, maximizing production meant increasing ore output and/or high-grading—mining only higher grade portions of the ore body. High-grading was expected to shorten the productive lives of a number of Australian gold mines.

Accounting for more than 70% of Australia's production during 1990, the State of Western Australia was the nation's leading producer. Australia's two largest gold mines, Boddington and Telfer, were

TABLE 12

U.S. EXPORTS OF GOLD, BY COUNTRY[1] [2]

Year and country	Ores and concentrates[3]		Wastes and scrap		Doré and precipitates		Refined bullion		Total[4]	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
1986	166	$1,589	30,452	$352,471	14,192	$158,005	110,555	$1,306,958	155,365	$1,819,023
1987	1,385	19,818	28,092	390,832	18,976	264,008	71,177	1,034,186	119,630	1,708,844
1988	1,384	18,449	35,709	492,840	19,809	265,051	271,335	3,882,757	328,237	4,659,098
1989	16	165	44,541	542,150	42,935	242,690	123,599	1,490,151	211,091	2,275,156
1990:										
Belgium	—	—	2,130	25,554	40	423	—	—	2,171	25,977
Canada	—	—	22,041	173,999	12,904	162,276	12,725	166,240	47,670	502,518
China	—	—	—	—	—	—	152	1,783	152	1,783
France	1	5	23,529	293,095	17,082	38,008	320	4,032	40,932	335,140
Germany, Federal Republic of	—	—	2,703	33,073	1,411	17,424	3,354	41,171	7,468	91,668
Haiti	—	—	209	1,644	—	—	—	—	209	1,644
Hong Kong	—	—	131	1,650	1,019	11,936	31,033	36,640	32,182	379,990
Israel	—	—	110	544	81	1,306	—	—	191	1,850
Italy	—	—	315	4.029	80	931	41	452	437	5,412
Japan	313	3,504	5	70	144	1,506	634	8,471	1,096	13,550
Korea, Republic of	1	8	35	442	—	—	107	1,259	143	1,707
Mexico	—	—	23	170	1,937	25,442	4,390	51,014	6,350	76,626
Netherlands	—	—	482	5,901	—	—	—	—	482	5,901
Singapore	—	—	—	—	998	13,769	5,908	70,299	6,906	84,068
Sweden	—	—	864	10,434	107	1,152	—	—	971	11,586
Switzerland	2	15	3	21	52,059	136,434	40,456	499,599	92,519	636,069
United Kingdom	—	—	14,359	178,460	335	3,328	41,418	504,357	56,112	686,146
Yugoslavia	11	179	—	—	—	—	119	1,324	130	1,503
Other	1	8	5	64	6	44	269	3,064	279	3,180
Total[4]	328	3,721	66,943	729,150	88,203	413,980	140,923	1,719,470	296,397	2,866,320

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and 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.

in Western Australia. Boddington, producing an estimated 14,000 kg (450,000 ounces), was also the nation's leading producer. During the year, the Worsley joint venture, managers of the Boddington operation, announced plans to install a new ore treatment plant designed to handle recently encountered mineralization in the main gold ore body found to be enriched with both copper and gold. At the Telfer Mine, near Nullagine, the nation's second largest gold mine, Newmont Australia Ltd. and BHP Gold reportedly moved ahead with plans to expand annual production at the mine to about 11,000 kg (350,000 ounces) by mid-1991. The plan called for the development of an underground mining project in conjunction with the existing open pit.

Near the town of Cue, AMC Gold Ltd. and Placer Pacific Ltd. completed their first full year of production at the Big Bell open pit mine. The partners were also considering a plan to develop an associated underground operation to begin when the existing near-surface ore has been exhausted. Western Mining Corp. (WMC), Australia's largest gold-producing company, with complete or partial interests in six Western Australian mines, registered substantial production increases at several of its mines in that State. The company's largest mine, the wholly owned Kambalda operation, mining ore from five open pits in the Kambalda-St.Ives area, recovered 6,327 kg (303,447 ounces) during the financial year ending June 30th. The company's four remaining mines in the State had a combined production of 12,547 kg (403,441 ounces). WMC also has gold mining interests in three other Australian States.

At Kalgoorlie, the so-called "Super Pit," 50% owned by Homestake Gold of Australia Ltd., produced about 10,000 kg (32,000 ounces) of gold during the year. The large open pit represents an amalgamation of several separate gold mines along Kalgoorlie's famous Golden Mile.

New mines beginning production during the year in Western Australia included the Granny Smith Mine near Laverton, owned by Placer Pacific and Delta Gold NL, and the Plutonic Mine, 180 km (112 miles) northeast of Meekathara. Plutonic was owned by Plutonic Resources Ltd. Several other mines were in various stages of development in the State during the year.

In Australia's Northern Territory, the Granites Mine of AMC Gold was the Territory's largest gold mine, reportedly producing a record 8,346 kg (268,343 ounces) in 1990. The first bar of production gold reportedly was poured at Dominion

Mining Co.'s, White Range Mine, northeast of Alice Springs in the Northern Territory.

Kidston Gold Mining Ltd.'s Kidston Mine in Queensland was that State's largest producer, recovering about 7,362 kg (236,710 ounces) in 1990. The 15% increase in production over that of the previous year represented adoption of a revised mining plan formulated to maximize recovery before imposition of the new tax at yearend. Also in Queensland, Pancontinental Mining Ltd. began base metal and gold production in January at its 50%-held Thalanga Mine. Initial surface production was expected to be replaced later by underground mining.

In New South Wales, CRA Ltd. announced plans in late 1990 to proceed with development of its Peak Mine near Cobar. The new underground operation, scheduled for production in 1992, was expected to produce 3,110 kg (100,000 ounces) of gold per year in addition to values in copper, lead, and zinc.

Canada.—Canada was the world's fifth largest gold-producing nation during 1990, following Australia.

According to a report prepared by the Canadian Government,[11] proven and probable reserves of gold contained in minable ore deposits declined by about 70 metric tons (2.25 million ounces) compared with revised estimates for the previous year. The report noted that although the decline, to

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF GOLD, BY COUNTRY[1 2]

	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)
1986	1,170	$13,094	16,184	$159,786	43,267	$504,457	429,242	$5,016,558	489,863	$5,693,896
1987	1,429	17,926	13,955	160,073	28,790	402,026	75,365	1,052,941	119,539	1,632,966
1988	2,621	34,141	6,468	79,483	25,778	355,763	57,590	799,901	92,457	1,269,288
1989	2,426	7,103	39,952	115,685	13,159	157,952	96,967	1,198,734	152,504	1,479,473
1990:										
Australia	—	—	—	—	—	—	120	1,505	120	1,505
Belgium	(5)	3	—	—	—	—	138	1,648	139	1,651
Bolivia	—	—	19	182	—	—	6,646	79,100	6,665	79,282
Brazil	—	—	7	71	—	—	496	6,174	504	6,245
Canada	12	25	3,486	18,408	18	252	32,961	408,648	36,477	427,333
Chile	—	—	—	—	425	5,252	6,614	82,199	7,038	87,451
Costa Rica	171	18	1	4	—	—	10	154	182	176
Dominican Republic	—	—	2,271	12,242	3,659	43,727	131	1,638	6,060	57,607
Ecuador	—	—	—	—	7	98	473	5,387	480	5,485
France	—	—	140	1,004	—	—	97	320	237	1,324
Guyana	—	—	159	1,479	56	488	102	1,232	317	3,199
Haiti	—	—	178	988	—	—	—	—	178	988
Hong Kong	—	—	1,698	16,409	—	—	(5)	1	1,698	16,411
Liberia	—	—	158	1,670	—	—	—	—	158	1,670
Malaysia	—	—	593	546	—	—	—	—	593	546
Mexico	5,111	7,705	340	1,403	16	125	168	1,990	5,635	11,223
Netherlands	—	—	562	627	—	—	—	—	562	627
Panama	—	—	58	527	—	—	189	2,120	247	2,647
Peru	—	—	13	133	21	245	4,644	56,920	4,678	57,298
Philippines	—	—	716	347	—	—	—	—	716	347
Switzerland	1	7	12,121	144,732	—	—	10,540	127,797	22,662	272,536
Trinidad and Tobago	—	—	345	4,556	—	—	7	83	352	4,639
United Kingdom	—	—	35	303	—	—	240	3,004	276	3,306
Uruguay	—	—	—	—	—	—	814	10,653	814	10,653
Yugoslavia	—	—	—	—	—	—	100	1,303	100	1,303
Other	50	598	274	1,341	41	448	264	3,127	631	5,516
Total[4]	5,346	8,355	23,173	206,975	4,245	50,635	64,755	795,007	97,519	1,060,971

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and 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.
[5]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 14

WORLD GOLD ANNUAL PRODUCTION CAPACITY RESERVES, AND RESERVE BASE,[1] DECEMBER 31, 1990

(Metric tons)

Country	Rated mine capacity[e]	Reserves[1]	Reserve base[2]
Australia	250	1,500	2,700
Brazil	95	980	1,080
Canada	170	1,750	1,920
China	120	NA	NA
South Africa, Republic of	630	20,000	22,000
U.S.S.R.	285	6,220	7,780
United States	300	4,980	5,480
Other	380	6,760	7,430
World total[3]	2,230	42,200	48,400

[e]Estimated. NA Not available.
[1]Reserves listed for countries other than Australia, Canada, the Republic of South Africa, and the United States may, in some instances, include inferred reserves.
[2]The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resourses).
[3]Data may not add to totals shown because of independent rounding.

1,748 metric tons (56.2 million ounces), amounted to only about 4%, it marked the first significant reversal in the strong growth in gold reserves that took place during the 1980's.

Canada's Province of Ontario was again that nation's leading gold producer, followed by the Province of Quebec. In Ontario, the three large mines at Hemlo, the Page-Williams Mine, the Golden Giant Mine, and the David Bell Mine, were that Province's dominant producers with 18,477 kg (594,128 ounces), 13,715 kg (441,000 ounces), and 9,893 kg (318,098 ounces), respectively. All three of these large mines were developed and opened during the mid-1980's. Several mines began or resumed production in Ontario during the year, including the Hoyle Mine at Timmins, the Kerr Mine, and the new Cheminis Mine.

In Quebec, Noranda Inc., Cambior Inc., and Nova-Cogesco Resources Inc. opened the new Silidor Mine in April. The new underground operation 4.8 km (3 miles) north of Rouyn-Noranda was expected to yield about 2,286 kg (73,600 ounces.) of gold during its first full year of operation. Lac Minerals Ltd. began production at its new Bosquet No. 2 Mine at Cadillac. Bosquet was expected to produce about 4,510 kg (145,000 ounces) per year.

Gold exploration and development activity in Canada's third largest Province, British Columbia, remained high during 1990, especially on the Iskut River-Eskay Creek area of northwestern British Columbia. During 1990, Corona Corp. gained controlling interests in the two companies holding the large, high-grade Eskay Creek property 80 km (50 miles) north of Stewart. By yearend, extensive surface and underground exploration was underway, including an access ramp and crosscuts driven into a rich part of the deposit, which forms an extensive continuous ore body known as the mine contact ore lens. Numerous companies explored and held land positions and developing properties in the Iskut River-Eskay Creek area by yearend. The largest gold project announced in Canada during 1990 was Cominco Ltd.'s new Snip gold-copper-silver property in the Iskut River area. Snip was expected to begin production in 1991. Another large project scheduled for startup in 1993 was Placer Dome's Mount Milligan copper-gold property, 161 km (100 miles) north of Prince George.

Production was begun in February at Homestake's 73%-held Golden Bear Mine in northwestern British Columbia. The newly reopened open pit and milling facility was operated by North American Metals Corp. Production during the year was extremely limited owing to startup difficulties. In late 1990, MinVen Gold Corp. closed its Blackdome Mine in Clinton owing to declining ore grades.

In the Northwest Territories, Northwest Gold Corp. poured its first gold bar at the Colomac Mine in May. Recovery and operating difficulties subsequently led the company to write down its investment in the open pit property in November. Exhaustion of reserves led to the closure of two gold producers in the Northwest Territories during the year: the Yellowknife tailings reprocessing project and the Ketza River Mine. In the Province of Saskatchewan, the Jasper Mine of Cameco Inc. and several partners began production in April. Total production during the 2-year life of the mine was expected to be about 2,600 kg (83,590 ounces). The Seabee Mine of Claude Resources Inc. moved closer to startup, planned for 1991.

Ghana.—A new gold mine commenced production during October in Ghana, West Africa's most prolific gold-producing country. At Bogosu, about 30 km (19 miles) north of Tarkwa, Canadian Bogosu Resources Ltd. began production at its 1.1-million-ton-per-year Bogosu gold mine. The new open pit operation was expected to produce about 4,300 kg (138,000 ounces) of gold in its first year, increasing to about 5,200 kg (167,000 ounces) per year in 1992. The company was a joint venture of Canadian-based Sikaman Gold Resources Ltd.; Billiton International Metals B.V., a subsidiary of Royal Dutch Shell; the International Finance Corp.; and the Government of Ghana. Sikaman also announced the startup of production from the Goldenrae placer mine, on the Kwabeng concession near Kibi, about 100 km (62 miles) northwest of Accra, the capital. Sikaman was in joint venture on this property with ITM International S.A. of Luxembourg, the Government of Ghana, and a local Ghanaian cooperative. The mine, which began production on October 15, was expected to produce about 700 kg (22,500 ounces) of gold per year.

India.—In April, India's 28-year-old Gold Control Act was repealed. Repeal of the act, which prohibited individuals from holding raw gold, severely restricting metal imports and limiting goldsmiths' stocks to 100 grams (3.2 ounces), was expected to spur indigenous jewelry fabrication and reduce gold smuggling. The change may, however, severely affect the mining of new gold at India's high-cost mines.

Latin America.—In March, the Government of Brazil began to implement its Collar Plan, which called for the imposition of taxes on gold transactions and sweeping currency reforms. These reforms aimed at reducing inflation by removing two-thirds of Brazil's currency from circulation. This action left Brazil's independent miners or "garimpeiros" at first without

buyers for their product and later with a severely weakened market with low gold prices, combined with escalating fuel and living expenses. Implementation of the Collar Plan as well as ongoing efforts by the Government to evict gold miners from the indigenous Indian reserves in Roraima, near the border with Venezuela, had a severe impact on garimpeiro gold production.

Despite the problems in the informal mining sector, gold production from the regulated or formal sector rose during the year, reflecting the startup of several new mines, expansions at existing mines, and the first full year's contribution of several new mines started during the previous year. New mines beginning production during 1990 included the new Corregio Sitio Mine of Mineraçâo Morro Velho S.A. near Santa Barbara in the State of Minas Gerais. This new open pit mine employs heap-leaching recovery methods. Also in Minas Gerais, Brazil's State-owned Cia. Vale do Rio Doce (CVRD) reportedly began production at two small mines known as Riacho de Machado and Caetes. In September, CVRD began production at its new Maria Prêta Mine in the State of Bahìa. The new open pit operation was expected to produce 700 kg (22,500 ounces) of gold per year over the next 6 years. CVRD also operated the Fazenda Brasileiro Mine near Serrinha in Bahìa. Fazenda Brasileiro, Brazil's first heap-leaching operation, began production in 1985.

Gold production in Chile rose 22% over that of the previous year, reflecting in part the first full year of production at Placer Dome and TVX Gold's La Coipa Mine. Production at the nation's largest gold mine, El Indio, declined somewhat during 1990 to 6,700 kg (215,400 ounces) as did production at Homestake's El Hueso Mine and Anglo American's 56%-held Marte Project, where crushing problems and poor rates of recovery kept the mine from reaching its full potential.

In December, Niugini Mining Ltd. reportedly poured its first doré bars and made its initial bullion shipment from its new wholly owned San Cristobal Mine about 100 km (60 miles) from the Chilean port city of Antofagasta on the South Pacific Ocean. The new heap-leaching operation, high in the Andes Mountains, was expected to yield about 1,900 kg (61,000 ounces) of gold and more than 3,700 kg (120,000 ounces) of silver per year. Niugini Mining, based in Papua New Guinea, was 57% held by Battle Mountain Gold Co. (BMG) of Houston, TX.

Bolivia's largest gold mine, Kori Kolo, owned and operated by Inti Rami, 85%-owned by BMG, increased production from 311 kg (10,000 ounces) in 1989 to 715 kg (23,000 ounces) in 1990. The mine also more than doubled its silver output in 1990 to 4,323 kg (139,000 ounces). In October, BMG announced the discovery of about 128 metric tons (4.1 million ounces) of proven and probable gold reserves beneath the mine's shallow oxide ores. At yearend, six drill rigs were working to define possible extensions of the deposit.

Oceania.—Gold production in Papua New Guinea, although 14% greater than in the previous year, continued to suffer from the absence of byproduct gold from CRA's 53.6%-held Bougainville Copper Mine on Bougainville Island. Bougainville was closed in May 1989 because of violence associated with a secessionist movement's dispute with the Government of Papua New Guinea.

Construction and commissioning of the first stage plant at Placer Pacific Ltd.'s Porgera Mine, in the highlands of Enga Province on the New Guinea mainland, was completed in August, and commercial gold production started on September 1. Production from the first full year of production was expected to be about 26,400 kg (849,000 ounces). Placer holds a 23% interest in the Porgera joint venture. In May, Misima Island Mines Pty. Ltd., (Placer 61%) completed its first full year of production at the Misima Island gold and silver mine in Milne Bay Province. Production for the calendar year at the large open pit operation amounted to 9,864 kg (317,167 ounces). Under the partners' long-term mining plan, 1991 production was scheduled to decline by 40%, and unit production costs were expected to increase somewhat because of the reduced volume of ore processed. Byproduct gold production at the OK Tedi copper-gold mine, at Mount Fulbian in the far west of Enga Province, amounted to 13,808 kg (444,000 ounces) during 1990 compared with 15,985 kg (514,000 ounces) produced during 1989. During the year, OK Tedi Mining Ltd. and the Government of Papua New Guinea reportedly reached an agreement on a long-term environmental management and monitoring program aimed at protecting the quality of the nearby Fly River.

Negotiations between CRA, national and Provincial governments, and local land owners were concluded, and a joint venture, Mount Kare Alluvial Mining Pty. Ltd. (MKAM), was formed to mine the Mount Kare alluvial deposits found in 1988 by CRA. MKAM consisted of CRA in partnership with 5,000 local landowners. The property is in Enga Province about 18 km (12 miles) southwest of the Porgera Mine. CRA also holds interests in the Wafi prospect, in Marobe Province, and the Hidden Valley property near Wau in eastern New Guinea.

Negotiations were begun between the Government of Papua New Guinea and the partners RTZ and Niugini Mining Ltd. regarding the development of the giant Lihir Island gold deposit. A final development plan was expected to be ready by early 1991.

In West Irian, on the western or Indonesian side of the island of New Guinea, Freeport Indonesia Inc. began mining in January at its recently discovered Grasberg deposit. Grasberg, a large copper-gold-silver deposit adjacent to Freeport's existing Ertsberg deposit, was reported by the company to possess the largest published gold reserves of any single operating mine in the world: 208 metric tons (6.7 million ounces). Gold production from the two deposits during 1990 totaled 8,832 kg (284,000 ounces) plus significant values in copper and silver. In the Province of East Kalimantan, development of the Kelian gold project, 68%-held by CRA, moved ahead with more drilling and construction and the approval by the government of the company's feasibility plan. On Wetar Island, about 48 km (33 miles) north of East Timor, Billiton International Metals BV, a subsidiary of the Royal Dutch Shell Group, began production at its Lerokis gold, silver, and barite mine. The new surface mining operation was expected to produce about 1,700 kg (55,000 ounces) of gold, about 25,000 kg (800,000 ounces) of silver, and 100,000 metric tons (110,000 short tons) of barium annually. Exploration for gold in Indonesia was active throughout the year.

New Zealand's second lode gold mine, the Macraes Mine, began production in late 1990. The new open pit operation, wholly owned by Macraes Mining Ltd., was in the Otago region of New Zealand's South Island. Production during the first year of operation was expected to exceed 1,710 kg (55,000 ounces), increasing to about 2,800 kg (90,000 ounces) per year thereafter. On New Zealand's North Island, on the Coromandel Peninsula, Cyprus Minerals continued development of its Golden Cross Project. Open pit and underground mining was expected to begin in mid-1991 and should yield about 3,420 kg (110,000 ounces) of gold per year.

Philippines.—A July 16 earthquake on the island of Luzon in the northern Philippines severely impacted gold production at one open pit mine and four underground mines operated by the Benguet Corp., one of the Philippines' top gold and copper producers. A loss of electrical supply from nearby Baguio City, a result of the disturbance, reportedly resulted in a loss of pumping capacity and subsequent flooding of the underground mines and a substantial decline in monthly gold production. Some production at the open pit was resumed, but, as of early August, flooding had prevented reopening of the underground mines.

Gold mines on Luzon operated by Lepanto Consolidated Mining and Philex Mining Corp. were also affected by the earthquake. Philippine Government investigations during 1990 reportedly estimated that as much as $1 billion worth of gold mined by the unregulated mining sector are smuggled out of the country each year.

South Africa, Republic of.—The Republic of South Africa, which accounted for about 30% of the world's gold production during 1990, managed, in spite of increasing economic burdens related primarily to the stagnant gold price during 1990, to produce nearly as much gold as it produced during 1989. Despite a nearly 10% increase in the average working costs and a decline in the working profits at the 36 mines that represent the membership of the Chamber of Mines of South Africa, total gold production in 1990, at 602,789 kg (19,379,666 ounces), was less than 1% below that of the previous year. The increase in working costs, which put many mines at a severe disadvantage, led many operations to concentrate on mining higher grade materials, thus reducing cost by mining and processing fewer tons of ore than in the previous year. About 111.2 million metric tons (122.6 million short tons) was milled in 1990 compared with 113.7 million metric tons (125.3 million short tons) in 1989. The emphasis on higher grade ore was also reflected in the average grade processed, which rose from 4.99 grams per metric ton (0.146 ounce per short ton) in 1989 to 5.05 grams per metric ton (0.147 ounce per short ton) in 1990. Production costs for 36 mines during 1990 averaged $351 per ounce compared with less than $300 per ounce in the previous year. Production costs for individual mines ranged from a low of $208 per ounce at the combined Driefontein operations of Gold Fields of South Africa (GFSA) to a high of $512 per ounce at Johannesburg Consolidated Investment Co. Ltd.'s (JCI) new H.J. Joel Mine, which began production in mid-1988.

The largest South African gold mines in terms of individual output, in metric tons of gold, included Anglo American Corp. of South Africa Ltd.'s (AAC) Freegold Mine with 114.8; Vaal Reefs, also AAC, at 73.4; GFSA's Driefontein Mine with 53.4; AAC's Western Deep levels operations with 38.5; and Anglovaal Ltd.'s Hartebeestfontein with 30.5.

In addition to the major mining groups or "houses" mentioned above, GFSA, JCI, AAC, and Anglovaal, there were two additional groups, Gencor Ltd. and Rand Mines Ltd.

As an employer of about 400,000 workers, mostly semiskilled or unskilled, the Republic of South Africa's gold mining industry is very labor intensive. According to the Chamber of Mines, labor costs make up about 52% of the total operating costs in South African gold mines. As a consequence of continued high currency inflation, rising labor and material costs, and weak gold prices, each of the six mining groups announced reductions in their labor forces during the year, and more than 30,000 jobs were eliminated at yearend. A number of individual mines or sections of mines faced the risk of closure. After only 15 months of operation, higher than anticipated costs and other negative economic factors forced the late 1990 suspension of operations at Rand Mine's new Barbrook Mine in the Eastern Transvaal.

Exploration expenditures by the major groups as well as individual exploration firms continued to advance during 1990, with some companies focusing their exploration in areas outside the known productive areas of the Witwatersrand Basin. The Chamber of Mines has been at the forefront of research and development aimed at improving mining methods and working conditions, especially with respect to deep underground mines. During the year the Chamber reportedly completed 4 years of research work on a project, known as the Portable Seismic System, developed toward anticipating and controlling potentially fatal rockbursts in deep underground workings. Cost-cutting measures announced by the Chamber near yearend resulted in a reduction in its research and development capabilities and greater emphasis on its commitment to health and safety.

U.S.S.R.—For the first time in nearly 5 decades, estimated Soviet gold production was surpassed by the performance of U.S. gold mines, thereby placing the U.S.S.R. in third place among the world's gold-producing nations. Some Western analysts attributed the 10% to 12% decline in estimated production in 1990 to the continuing crisis in the U.S.S.R. as well as labor strikes at some of the mining cooperatives or "artels" operated in the far eastern areas of the U.S.S.R.

Svzal, a new Soviet-Alaskan joint venture, was established in February to develop mineral deposits and market combined mining technology in both the U.S.S.R. and North America. The joint venture was formed by Severovostokzoloto, the largest gold mining association in the Soviet Far East, and Bering Straits Trading Co. of Anchorage, AK.

In October the U.S.S.R. reportedly began to mint a 999-fine legal tender commemorative gold coin known as the "Glasnost/Perestroika" or "Peace" coin. It was the first such issue to be made available to buyers outside of the U.S.S.R. since the 1980 Moscow Olympic Coin Program.

Current Research

The U.S. Bureau of Mines maintains nine research centers throughout the Nation, and most conduct research into various aspects of mining, may be directly or indirectly beneficial to the gold mining industry.[12] Because gold mining is pursued in many nations, the results of this ongoing work may, like the Bureau's earlier work in heap leaching, ultimately benefit a broad segment of the industry worldwide. In 1990,the Bureau's research relating to gold mining generally focused on the use of cyanide in the recovery process. The Bureau addressed several questions regarding the use of cyanide, including such topics as the mass balance of cyanide in the leaching process, the mobility of metals in the heap during heap leaching, the peristence of cyanide in the environment, and protection of wildlife.

A joint Bureau-university-industry effort was commissioned to assist in defining future environmental needs relating to gold mining and cyanide use. Six priority areas chosen for research included the following: mine and mill closure, cyanide destruction, seepage, wildlife protections, acid mine drainage, and cyanide alternatives.

Several reports on research relating to gold were issued by the Bureau during 1990.[13]

OUTLOOK

Because gold is an internationally traded commodity serving not only the industrial and jewelry end-use sectors but the investment and central bank sectors as well, the outlook for gold supply, demand, and prices must be viewed from a global viewpoint.

Gold Fields Mineral Services,[14] in its annual review of supply and demand, acknowledges the pitfalls of long-term forecasting by limiting its outlook to the immediate future. Addressing gold supplies, Gold Fields expected that with the growth in exploration and mine production having slowed dramatically, world output is likely to peak in the next year or so. The reduction in exploration also implies that mine production would not be able to respond quickly to any future increase in the gold price. The continuing crisis in the U.S.S.R. is likely to result in further substantial sales from that source in 1991. Gold Fields did not expect that central banks would become heavy sellers of gold in the future, and some buying is probable. On the demand side, assuming continued weakness in consumer spending, Gold Fields expects that fabrication of gold jewelry is likely to show little increase during 1991.

On the domestic scene, if the price of gold remains at levels acceptable to the domestic mining industry, gold production may be expected to grow, but at a slower rate than that of the past several years. The hectic pace of exploration seen in recent years appears to have peaked or at least shifted somewhat toward the base metals or to opportunities elsewhere, such as Mexico or Chile or even the U.S.S.R. Many small mines opened in recent years will probably close as their limited ore reserves are depleted. This loss in production will probably be offset by some new mines and especially expanded production at established larger mines where the focus has shifted toward exploiting their large reserves of gold-bearing sulfide ores. Any growth in production must assume, of course, that a relatively stable and, above all, a predictable regulatory climate will continue to prevail; this applies especially to those regulations dealing with environmental protection and access to public lands.

On the demand side, the near-term outlook for continued strength in the all-important jewelry sector depends on a number of unpredictable factors such as an upturn in discretionary consumer spending, the continuance of acceptable gold prices,

TABLE 15

GOLD: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Argentina	944	990	962	1,150	1,200
Australia	75,079	110,696	156,950	203,563	[3]242,299
Bolivia	763	2,755	4,889	3,595	6,000
Botswana[e 4]	r25	r31	r21	r66	45
Brazil[e 5]	67,500	83,700	100,200	100,000	80,000
Burkina Faso[e]	1,866	r7,000	r9,300	r7,600	7,800
Burundi	31	26	14	25	25
Cameroon[e]	[3]8	8	8	8	8
Canada	102,899	115,818	134,813	159,494	[3]164,991
Central African Republic	e187	223	382	328	300
Chile	r17,947	17,035	20,614	22,559	[3]27,591
China[e]	66,000	72,000	78,000	r90,000	100,000
Colombia	39,995	26,550	29,020	27,090	28,000
Congo[e]	16	16	16	16	16
Costa Rica[6]	361	300	313	387	400
Cote d'Ivoire (formerly Ivory Coast)	5	7	6	13	20
Dominican Republic	8,837	r7,651	5,785	5,238	[3]4,312
Ecuador	9,870	9,500	8,050	13,000	10,000
Ethiopia[7]	923	r643	728	745	800
Fiji	2,952	2,962	4,273	4,221	4,150
Finland	1,172	e1,800	2,035	2,491	2,800
France	2,382	2,225	2,753	3,537	3,600
French Guiana	326	514	522	550	550
Gabon[8]	62	79	138	81	80
Germany, Federal Republic of:					
Western states[e]	r37	r26	r16	r16	18
Ghana	8,931	10,201	11,601	13,358	[3]16,840
Guinea	—	(9)	e [10]1,300	e [10]2,053	[10]2,600
Guyana	437	1,568	e2,330	e [3],200	3,500
Honduras	63	131	127	1,244	1,300
Hungary[e]	560	560	560	500	500
India[11]	r1,931	r1,864	1,942	1,827	1,850
Indonesia[12]	r3,304	r3,643	4,738	6,155	[3]11,158
Japan	10,280	8,590	7,310	6,098	[3]7,302
Kenya	73	278	17	15	[3]25
Korea, North[e]	5,000	5,000	5,000	5,000	5,000
Korea, Republic of[11]	4,648	7,600	11,121	14,270	[3]20,760
Liberia[e 13]	625	470	[3]677	700	700
Madagascar	e4	40	90	45	40
Malaysia	2,718	3,512	2,929	2,859	[3]2,594
Mali[e]	r725	r950	[14]2,650	[14]3,000	[14]5,200
Mexico	7,795	7,988	9,098	8,613	[3]8,338
Mozambique	—	—	—	—	[3]63
Namibia	184	172	195	336	1,700
New Zealand	1,265	1,148	2,404	4,963	5,000
Nicaragua	892	948	878	1,232	1,200
Papua New Guinea	35,075	33,250	38,129	27,538	[3]31,035
Peru	8,846	r8,486	9,164	10,555	8,500
Philippines	40,322	32,599	35,500	35,300	35,000

See footnotes at end of table.

TABLE 15—Continued

GOLD: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Portugal	191	248	267	295	350
Romania[e]	1,900	1,900	1,900	1,750	1,500
Rwanda[e]	6	r9	r15	r732	700
Saudi Arabia[e]	—	—	1,000	3,000	3,000
Sierra Leone[15]	373	467	404	400	400
Solomon Islands	98	e124	47	36	35
South Africa, Republic of	638,047	596,456	617,719	607,460	3602,789
Spain	r8,949	r7,752	8,034	8,200	8,400
Sudan	e70	85	500	50	75
Suriname[e]	r19	22	30	31	30
Sweden	4,514	4,108	3,590	5,120	5,000
Taiwan[11]	910	533	236	269	250
Tanzania	85	201	52	116	100
U.S.S.R.[e]	275,000	275,000	280,000	285,000	250,000
United States	r116,297	153,870	200,914	265,731	3290,202
Venezuela	r2,510	r3,416	3,502	3,867	37,700
Yugoslavia	3,583	5,348	4,620	4,700	4,500
Zaire	5,220	4,372	3,422	2,032	2,580
Zambia[16]	268	356	227	r e225	225
Zimbabwe	14,853	14,710	14,191	16,000	316,900
Total	r1,606,570	r1,660,529	1,848,237	1,999,648	2,049,946

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through June 21, 1991.

[2]Gold is also produced in Burma, Cuba, Czechoslovakia, the Eastern states of the Federal Republic of Germany, Norway, Senegal, Thailand, and several other countries. However, available data are insufficient to make reliable output estimates. Poland annually mines and processes copper ore estimated to contain about 31,000 kilograms of gold. Disposition of the gold byproduct is unknown.

[3]Reported figure.

[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 97% for 1986 and 98% for 1987-90.

[5]Officially reported figures are as follows, in kilograms: Major mines: 1986—9,348; 1987—13,120; 1988—24,012 (estimated); 1989—24,900 (estimated) and 1990—29,900 (estimated). Small mines (garimpos): 1986—14,776; 1987—22,660; 1988—55,053 (estimated); 1989—56,000 (estimated); and 1990—57,400 (estimated).

[6]Gold purchased by Banco Central from placer deposits and mines; actual production estimated to be at least twice this amount.

[7]Year ending June 30 of year listed.

[8]Does not include undocumented production from small artisanal production.

[9]Revised to zero.

[10]Figures include reported mine production of 320 kilograms in 1988; 1,059 kilograms in 1989; and 1,600 kilograms from SAG mine in 1990. Remainder represents approximate reported sales to Government of artisanal production. 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 1986-90, 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]Year beginning Apr. 1 of year listed.

variable fashion trends, and the continued success of industry product advertising to attract new jewelry buyers. The use of gold in electronic applications may experience moderate growth as the demand for sophisticated and more reliable electronic goods expands to match the anticipated growth of the gross national product. Gold has a number of unique characteristics that favor its continued usage in dental applications; its usage in dentistry should probably remain at or near the present level despite the continued impact of cheaper substitute materials.

[1]Ounce refers to troy ounce. One kilogram of gold weighs 32.1507 troy ounces.

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GRAPHITE

By Harold A. Taylor, Jr.

Mr. Taylor, a physical scientist with 25 years of industry, Federal Government, and U.S. Bureau of Mines experience, has been the commodity specialist for graphite since 1980. Domestic survey data were prepared by William Field, mineral data assistant; and international data tables were prepared by Audrey Wilkes, international data coordinator.

Amorphous graphite was not mined domestically in 1990. Graphite supplies caught up with industrial demand and then exceeded it to a minor degree. Some prices of the major imported graphite increased from those of 1989, and some were unchanged. Production of manufactured graphite and graphite fibers decreased 7% and increased by 29%, 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 5.

BACKGROUND

Definitions, Grades, and Specifications

Graphite, a soft crystalline form of carbon, has been called plumbago and black lead. It crystallizes in a lamellar hexagonal system, has a gray to black metallic luster, and is greasy to the feel. It is anisotropic in its physical properties and has a weak plane of cleavage parallel to the lamellae.

The term "amorphous" when applied to graphite is a misnomer. The term "microcrystalline" is more descriptive. The definition of amorphous, as applied to graphite, has been further complicated by longstanding industrial application of the term to very fine particles of crystalline flake graphite that can be sold only for low-value use such as foundry facings. Fine-grained varieties of lump graphite that are easily reduced to fine particle size by grinding are called amorphous lump to distinguish them from the tough, platy, and acicular varieties, known as crystalline lump, that can be reduced in particle size only with extreme difficulty.

Crystalline flake graphite is well defined in paragraph 214 of the Tariff Act of 1930 as follows:

"The term crystalline flake means graphite, or plumbago, which occurs disseminated as a relatively thin flake throughout its containing rock, decomposed or not, and which may or has been separated there from 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,

TABLE 1

SALIENT NATURAL GRAPHITE STATISTICS

		1986	1987	1988	1989	1990
United States:						
Production	metric tons	—	—	W	W	—
Apparent consumption	do.	31,784	31,634	42,799	50,867	W
Exports	do.	7,034	11,700	11,068	11,452	11,537
Value	thousands	$3,416	$6,218	$5,815	$7,421	$9,481
Imports for consumption	metric tons	38,818	43,334	53,867	62,319	50,213
Value	thousands	$15,758	$17,654	$23,238	$33,707	$35,222
World: Production	metric tons	624,718	648,156	r660,168	r648,827	e660,600

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

"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 graphite is 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 is 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 intrusive. 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 tons. Detailed breakouts are given in the 1988 Minerals Yearbook chapter.

Technology

Mining.—In Sri Lanka, lump graphite is mined underground from narrow, steeply dipping veins. The ore is mined principally by overhand stoping and filling, using temporary stulls when necessary to support the walls. Hand drilling is used in most stoping to achieve selective mining and to avoid unwanted fines and product contamination. Drills are used in developing headings. The ore is hauled by truck to the sorting and classification yard.

Amorphous graphite beds are usually mined underground. However, the beds are much thicker than those of amorphous lump and crystalline lump. The ore is drilled, blasted, hand loaded into cars, and hauled to the surface by conventional methods.

Flake graphite deposits have been mined by underground and surface methods. Underground deposits are usually unweathered and require drilling and blasting. Most surface mining is confined to the weathered part of the deposit, and normal excavating equipment such as power shovels, bulldozers, and rippers is used with a minimum of drilling and blasting. The ore is usually trucked to the mill.

Milling.—Sri Lankan amorphous and crystalline lump graphite is 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 stan-

dard market quotations. Prices quoted in trade journals are only a range negotiated between buyer and seller. Quotations are available in Industrial Minerals, Chemical Marketing Reporter, and the U.S. Bureau of Mines Minerals Yearbook. However, average declared import values per ton for amorphous and crystalline graphite have been available for years from the 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.

Employment and Productivity.—Production and marketable natural graphite requires little hand labor, except for the graphite mined in Sri Lanka. Even in areas of low-cost labor, mechanical methods are used to mine and concentrate flake graphite.

Because of the small size of the domestic natural graphite industry, no publishable employment data are available. Because there is only one small mine and the product is beneficiated and processed to a minimal extent, employment probably does not exceed 50. Much of the imported graphite requires grinding, perhaps further refining, mixing with other grades to meet consumer specifications, bagging, and shipping. The total number of persons engaged in these operations, including marketing, probably does not exceed 500.

Tariffs.—Duties on graphite items imported from most favored nations (MFN) are minimal. Graphite from the U.S.S.R. and certain other nations is subject to a higher duty.

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.

Operating Factors

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.

TABLE 2

U.S. IMPORT DUTIES

Tariff item	HTS No.	Most favored nation (MFN) Jan. 1, 1991	Non-MFN Jan. 1, 1991
Crystalline flake, (not including flake dust)	2504.10.10	0.7 cents per kilogram[1]	3.6 cents per kilogram.
Other powder	2504.10.50	Free	10% ad valorem.
Other	2504.90.00	Free	10% ad valorem.

[1] Duty temporarily suspended.

TABLE 3

U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND STOCKS OF NATURAL GRAPHITE IN 1990, BY TYPE

(Metric tons)

Type	Goal	National stockpile inventory
Madagascar crystalline flake	12,880	15,655
Sri Lanka amorphous lump	5,715	4,934
Crystalline, other than Madagascar and Sri Lanka	1,750	1,754
Nonstockpile-grade, all types	—	846

Source: General Services Administration, Inventory of Stockpile Materials as of Dec. 31, 1990.

ANNUAL REVIEW

Legislation and Government Programs

No acquisitions or disposal of graphite from the strategic and critical materials stockpile occurred in 1990. New, smaller goals were implemented by notice in the June 26, 1990, Federal Register, as follows: 12,880 metric tons for Madagascar crystalline flake and 1,750 tons for crystalline graphite from other than Madagascar and Sri Lanka.

Production

United Minerals Co. suspended production of its amorphous graphitic material from its Montana mine in 1990. Output of manufactured graphite decreased 7% to about 252,000 tons at 30 plants, with a likelihood of some unreported production for in-house use. Production of all kinds of graphite fiber and cloth increased 29% to 3,774 tons.

Union Carbide Corp. has sold one-half of its wholly owned graphite and carbon subsidiary to Mitsubishi Corp. of Japan for $232.5 million. the proceeds were used to retire part of the company's debt. Union Carbides's intention was to strengthen its role as a supplier to the metals industry. According to the firm, graphite-carbon sales totaled $802 million in 1989. The Mitsubishi sales force will be used to support the graphite and carbon business. This transaction involves four U.S. graphite electrode and product plants.

Consumption and Uses

Reported consumption of natural graphite decreased 8% to about 36,300 tons, according to a survey of more than 230 users. The three major uses of natural graphite were refractories, lubricants, and brakelinings, which together accounted for 67% of reported consumption.

Nonclay refractories represent two important uses categories of graphite. Standard refractory products, particularly gunning and ramming mixes, accounted for a sizable part of the demand in the past 5 years, mainly as amorphous graphite. Crucibles, shrouds, nozzles, stopper heads, and retorts, used in hot-metal processing operations such as the continuous casting of steel, use significant amounts of crystalline flake. Coarse flake graphite is preferred for crucibles and refractory associated items, but generally it is mixed with some fine crystalline material of lower

TABLE 4

PRINCIPAL PRODUCERS OF SYNTHETIC GRAPHITE IN 1990

Company	Plant location	Product[1]
Akzo Fortafil Fibers Inc.	Rockwood, TN	High-modulus Fibers.
Amoco Performance Products	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.
Courtaulds Grafil Co.	Sacramento, CA	Do.
Fiber Materials, Inc.	Biddeford, ME	Other.
Fiber Technology Corp.	Provo, UT	
BF Goodrich Co., Engineered Systems Div., Super Temp Operation	Santa Fe Springs, CA	Other.
Great Lakes Carbon Corp.	Morganton, NC	Electrodes, unmachined shapes, motor brushes, other.
Do.	Niagara Falls, NY	Do.
Do.	Ozark, AR	Do.
Hercules Inc.	Salt Lake City, UT	High-modulus fibers.
HITCO Materials Group, British Petroleum Co. Ltd.	Gardena, CA	Cloth and high-modulus fibers.
National Electrical Carbon Co.	Fostoria, OH	Motor brushes, unmachined shapes, cloth.
NAC Carbon Products, Inc.	Punxsutawney, PA	Other.
Pfizer Minerals, Pigments & Metals Div.	Easton, PA	Do.
Polycarbon, Inc.	Valencia, CA	Cloth.
Showa Denko Carbon Inc.	Ridgeville, SC	Electrodes, other.
Sigri Carbon Corp.	Hickman, KY	
Stackpole Fibers Co., Inc.	Lowell, MA	High-modulus fibers.
Superior Graphite Co.	Russellville, AR	Electrodes.
Do.	Hopkinsville, KY	Other.
Textron Corp., Avco Specialty Materials Div.	Lowell, MA	High-modulus fibers.
The Carbon/Graphite Group Inc.	Niagara Falls, NY	Anodes, electrodes, unmachined shapes, motor brushes, refractories.
Do.	St. Mary's, PA	Do.
The Carborundum Co., Metallics Systems Div.	Sanborn, NY	Motor brushes, unmachined shapes, cloth.
The Stackpole Corp., Carbon Div.	St. Mary's, PA	Motor brushes and unmachined shapes.
UCAR Carbon Co.	Clarksburg, WV	Anodes, electrodes, unmachined shapes, crucibles and vessels, other.
Do.	Clarksville, TN	Do.
Do.	Columbia, TN	Do.
Do.	Yabucoa, PR	Do.

[1] Cloth includes low-modulus fibers; motor brushes include machined shapes; crucibles include vessels.

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 and as an ingredient in special packings. 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.

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 ship-

ments 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—decreased slightly to $1,561 per ton from $1,574 (revised) in 1989. The price for amorphous graphite (including small amounts of amorphous-synthetic graphite mixtures) decreased by 12% to $684 per ton, from $780 (revised) in 1989.

Foreign Trade

The United States changed its tariff classification to the Harmonized Code on January 1, 1989. This has made the 1988 and 1990 import and export statistics somewhat noncomparable.

Total exports of natural graphite increased slightly. Exports of graphite electrodes totaled 84,602 tons valued at $144.3 million, of which 33,235 tons ($34.5 million) went to Canada, 7,552 tons ($12.5 million) to Brazil, 5,964 tons ($15.8 million) to Japan, 3,517 tons ($7.7 million) to Venezuela, and the balance to other destinations.

Imports of natural graphite decreased 20% from those of 1989. Imports of natural graphite from Canada and Madagascar rose substantially, while imports from Brazil, the Republic of Korea, and Mexico decreased significantly.

World Review

The current year has begun the sorting out of last year's confusion about whether or not the Chinese were really exporting less and about which Canadian deposits would actually be devel-

TABLE 5

U.S. PRODUCTION OF SYNTHETIC GRAPHITE, BY USE

Use	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Products:				
Anodes	6,196	$18,144	3,549	$11,259
Cloth and fibers (low-modulus)	377	34,846	380	29,232
Crucibles, vessels, refractories	W	W	(1)	(1)
Electric motor brushes and machined shapes	W	W	3,139	21,902
Electrodes	188,264	379,196	169,798	363,319
High-modulus fibers	2,538	128,603	3,394	181,138
Unmachined graphite shapes	4,584	27,297	4,413	33,622
Other	6,201	2 90,008	3,130	78,044
Total	208,160	678,094	187,803	718,516
Synthetic graphite powder and scrap	62,259	28,574	63,984	33,605
Grand total	270,419	706,668	251,787	752,121

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1] Crucibles, vessels, and refractories end products included in "Other" products category.

TABLE 6

U.S. PRODUCTION OF GRAPHITE FIBERS

Year	Cloth and low-modulus fibers		High-modulus fibers		Total	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1980	153	$11,254	278	$17,379	431	$28,633
1981	196	15,293	371	21,759	567	37,052
1982	192	17,706	549	30,091	741	47,797
1983	171	14,217	670	33,854	841	48,071
1984	202	17,979	1,052	56,436	1,254	74,415
1985	287	27,235	1,439	84,743	1,726	111,978
1986	149	17,895	1,373	76,622	1,522	94,517
1987	231	23,706	1,583	84,559	1,814	108,265
1988	239	28,228	2,176	117,754	2,415	145,982
1989	377	34,846	2,538	128,603	2,915	163,449
1990	380	29,232	3,394	181,138	3,774	210,370

TABLE 7

U.S. CONSUMPTION OF NATURAL GRAPHITE, BY USE

Use	Crystalline		Amorphous[1]		Total[2]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1988:[3]	r18,897	r$23,871	r17,708	r$12,978	r36,605	r$36,848
1989:						
Batteries	W	W	W	W	1,243	1,924
Brake linings	2,281	2,436	2,427	5,450	4,708	7,886
Carbon products[4]	340	886	167	242	507	1,128
Crucibles, retorts, stoppers, sleeves, nozzles	W	W	W	W	1,497	1,697
Foundries[5]	408	481	4,847	1,412	5,255	1,893
Lubricants[6]	3,391	5,033	3,125	1,068	6,516	6,101
Pencils	r1,510	1,876	248	150	r1,758	2,026
Powdered metals	1,401	2,551	58	111	1,459	2,662
Refractories	W	W	W	W	r12,599	r11,985
Rubber	72	108	406	314	478	422
Steelmaking	218	122	1,035	484	1,253	606
Other[7]	2,108	7,542	189	284	2,297	7,826
Withheld uses	r7,516	r9,260	7,823	6,346	—	—
Total	r19,245	30,295	r20,325	r15,861	r39,570	r46,156
1990:						
Batteries	W	W	W	W	319	505
Brake linings	1,520	2,195	3,808	4,331	5,328	6,526
Carbon products[4]	243	647	114	142	358	789
Crucibles, retorts, stoppers, sleeves, nozzles	W	W	W	W	1,391	1,716
Foundries[5]	825	878	3,348	1,024	4,174	1,902
Lubricants[6]	3,999	6,326	3,540	1,397	7,539	7,723
Pencils	964	1,339	237	128	1,201	1,467
Powdered metals	1,278	2,691	37	66	1,315	2,757
Refractories	4,024	5,823	7,610	5,594	11,634	11,417
Rubber	W	W	W	W	421	329
Steelmaking	W	W	W	W	1,174	657
Other[7]	736	1,845	744	740	1,480	2,585
Withheld uses	1,839	2,333	1,467	874	—	—
Total[2]	15,428	24,077	20,905	14,296	36,334	38,373

r Revised. 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] Revision reflects a data correction in the refractories and other use categories.

[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.

oped. Demand for graphite in the United States was only slightly changed from that of 1989. Graphite moved into worldwide oversupply about midyear, but not in a major way. Prices were generally little changed. Norwegian production reached a much higher level in 1990. The Brazilian producers shelved plans for a major expansion of output, as did the Mexican companies involved with crystalline flake. Mexican output of crystalline flake has not reflected even a previous doubling of capacity. The flurry of Canadian activity that continued to be reported seemed less likely to result in many new producers. The count of Canadian producers may level out at three or even fewer. China continues to be the major force in the market; its reported demise in the press has been much exaggerated. Graphite in small quantities began to appear from Eastern Europe, primarily in Western European markets. The oversupply seems likely to worsen in 1991 as many consumers draw down their inventories. These inventories are frequently huge. Imports of graphite will drop very significantly. The prices of graphite are likely to drop significantly in

TABLE 8

REPRESENTATIVE YEAREND GRAPHITE PRICES

(Per metric ton)

	1989	1990
Industrial Minerals:		
Crystalline large flake, 85% to 90% carbon	$820–$1,300	$820–$1,300
Crystalline medium flake, 85% to 90% carbon	770– 1,120	770– 1,120
Crystalline small flake, 80% to 90% carbon	540– 900	540– 900
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
Customs value, at foreign ports:		
Flake	r913	935
Lump and chip, Sri Lankan	1,027	1,216
Amorphous, Mexican	114	116

r Revised.

Source: Industrial Minerals, No. 267, Dec. 1989, p. 82, and No. 279, Dec. 1990, p. 78.

TABLE 9

INDEXES OF UNIT VALUE OF GRAPHITE FIBER PRODUCED IN THE UNITED STATES[1]

(1973 = 100)

Year	Cloth and low-modulus fibers	High-modulus fibers
1979	114	56
1980	125	50
1981	129	46
1982	146	48
1983	129	45
1984	146	43
1985	149	50
1986	176	51
1987	153	50
1988	179	57
1989	164	52
1990	166	50

[1] The indexes were calculated from company data most representative of the industry and are not based solely on data shown in table 5.

TABLE 10

U.S. EXPORTS OF NATURAL AND ARTIFICIAL GRAPHITE, BY COUNTRY

Country	Natural[1]		Artificial[2]		Total	
	Quantity (metric tons)	Value[3]	Quantity (metric tons)	Value[3]	Quantity (metric tons)	Value
1989:						
Brazil	8	$17,452	885	$1,324,786	893	$1,342,238
Canada	5,936	3,032,576	14,295	4,964,881	20,231	7,997,457
Germany, Federal Republic of	156	72,316	1,860	848,464	2,016	920,780
Italy	102	211,966	268	261,984	370	473,950
Japan	572	691,249	1,905	2,734,937	2,477	3,426,186
Mexico	2,382	1,203,060	1,176	656,173	3,558	1,859,233
United Kingdom	448	189,271	3,777	2,485,322	4,225	2,674,593
Venezuela	411	686,777	90	79,166	501	765,943
Other	1,437	1,316,130	13,021	12,610,802	14,458	13,926,932
Total	11,452	7,420,797	37,277	25,966,515	48,729	33,387,312
1990:						
Brazil	332	800,456	1,188	2,442,945	1,520	3,243,401
Canada	3,769	2,394,059	16,690	7,262,105	20,460	9,656,164
Germany, Federal Republic of	542	560,828	1,070	669,536	1,612	1,230,364
Italy	86	259,254	271	242,728	357	501,982
Japan	556	744,063	1,588	4,977,240	2,144	5,721,303
Mexico	2,566	1,542,476	1,528	793,269	4,094	2,335,745
United Kingdom	365	349,342	2,563	1,538,004	2,928	1,887,346
Venezuela	914	750,788	398	537,539	1,312	1,288,327
Other	2,407	2,080,067	7,789	13,161,557	10,195	15,241,624
Total	11,537	9,481,333	33,085	31,624,923	44,622	41,106,256

[1] Amorphous, crystalline flake, lump or chip, and natural, not elsewhere classified. HTS Nos. 2504.10.0000 and 2504.90.0000.
[2] Includes artificial graphite and colloidal or semi-colloidal graphite. HTS Nos. 3801.10.0000 and 3801.20.0000.
[3] Customs value.

Source: Bureau of the Census.

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF NATURAL GRAPHITE, BY COUNTRY

Country	Crystalline flake		Lump or chippy dust		Other natural crude and refined		Amorphous		Total	
	Quantity (metric tons)	Value[1] (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)
1988	8,249	$6,120	2,819	$2,376	23,676	$13,625	19,123	$1,117	53,867	$23,238
1989:										
Austria	—	—	—	—	—	—	—	—	-	—
Belgium-Luxembourg	—	—	—	—	50	12	—	—	50	12
Brazil	2,613	2,937	—	—	2,935	3,018	—	—	5,548	5,955
Canada	r3,144	r3,135	—	—	r2,261	r1,784	—	—	5,405	4,919
China	2,995	2,047	—	—	12,504	7,906	1,090	995	16,589	10,948
France	—	—	—	—	50	196	—	—	50	196
Germany, Federal Republic of	38	48	—	—	182	479	—	—	220	527
Hong Kong	—	—	—	—	—	—	220	43	220	43
India	36	45	—	—	431	417	—	—	467	462
Japan	46	161	—	—	411	1,646	—	—	457	1,807
Korea, Republic of	—	—	—	—	—	—	7,275	380	7,275	380
Madagascar	r2,294	r1,822	—	—	r2,368	r1,818	—	—	4,662	3,640
Mexico	71	43	—	—	1,704	229	17,073	1,939	18,848	2,211
Netherlands	—	—	—	—	22	404	—	—	22	404
South Africa, Republic of	—	—	—	—	58	66	—	—	58	66
Sri Lanka	—	—	675	693	-	—	—	—	675	693
Switzerland	—	—	—	—	66	75	—	—	66	75
United Kingdom	—	—	—	—	1	6	—	—	1	6
Zimbabwe	685	643	—	—	1,018	697	—	—	1,703	1,340
Other	—	—	—	—	3	23	—	—	3	23
Total	r11,922	r10,881	675	693	r24,064	r18,776	25,658	3,357	62,319	33,707
1990:										
Austria	40	20	—	—	—	—	—	—	40	20
Belgium-Luxembourg	—	—	—	—	2	41	—	—	2	41
Brazil	1,455	1,996	—	—	213	307	—	—	1,668	2,303
Canada	5,162	5,038	—	—	4,449	4,068	—	—	9,611	9,106
China	10,047	6,628	—	—	5,036	3,409	1,615	264	16,698	10,301
France	—	—	—	—	15	147	—	—	15	147
Germany, Federal Republic of	276	721	—	—	7	65	—	—	283	786
Hong Kong	—	—	—	—	—	—	732	69	732	69
India	117	102	—	—	180	213	—	—	297	315
Japan	884	1,120	—	—	20	177	—	—	904	1,297
Madagascar	2,763	2,965	—	—	2,536	2,517	—	—	5,299	5,482
Mexico	40	10	—	—	1,567	997	10,570	1,224	12,177	2,231
South Africa, Republic of	100	59	—	—	—	—	—	—	100	59
Sri Lanka	—	—	565	687	—	—	—	—	565	687
Switzerland	—	—	—	—	289	50	—	—	289	50
United Kingdom	102	43	—	—	—	—	—	—	102	43
Zimbabwe	1,281	1,111	—	—	—	—	—	—	1,281	1,111
Other	141	1,143	—	—	9	31	—	—	150	1,174
Total	22,408	20,956	565	687	14,323	12,022	12,917	1,557	50,213	35,222

r Revised.
[1] Customs values.

Source: Bureau of the Census.

almost all instances.

Canada.—Mineraux Industrielle de Refractaire et Ceramique, a subsidiary of Imetal S.A., acquired a 25% share, worth $5 million, of Stratmin Inc., Canada's principal producer of graphite.

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF GRAPHITE ELECTRODES, BY COUNTRY[1]

Country	Graphite electrodes[2]	
	Quantity (metric tons)	Value[3] (thousands)
1989:		
Belgium	306	$542
Brazil	1,289	503
Canada	6,130	6,277
China	526	831
France	1,387	1,367
Germany, Federal Republic of	2,758	4,082
Italy	5,931	9,747
Japan	4,889	7,807
Mexico	11,333	14,122
Spain	525	985
Sweden	—	5
Switzerland	55	105
Taiwan	4	14
United Kingdom	588	928
Other	669	874
Total	36,390	48,189
1990:		
Belgium	1,096	2,226
Canada	1,975	2,422
China	217	328
France	331	863
Germany, Federal Republic of	5,558	9,177
Italy	8,316	15,016
Japan	6,817	13,966
Mexico	12,298	16,132
Spain	626	1,228
Sweden	1	65
Switzerland	72	135
United Kingdom	537	992
Other	473	949
Total	38,317	63,499

[1] The artificial graphite imports category was reported through 1989. However, the category has been excluded from this table due to substantial delays in obtaining complete data for accurate comparison and reporting in the current period.
[2] Electric furnace electrodes; HTS No. 8545.11.0000.
[3] Customs values.

Source: Bureau of the Census.

This firm will become the exclusive agent for Stratmin's graphite product in Europe. The graphite will complement its present product line of refractory-related minerals such as andalusite and various clays.

A paper describing the Lac Knife graphite deposit of Societe d'Exploration Miniere Mazaring Inc. in detail was presented at the Ninth Industrial Minerals International Congress and later published in a journal. The paper covers the history, regional geology, geology and mineralogy of the deposit, reserves, proposed mining method, mine planning, ore beneficiation, environmental aspects, and the volume and specifications of the product.[1] Cambior Inc. intended to sign a joint-venture agreement with Mazarin to bring the deposit into production.

Cal Graphite Corp. operated at a very low level after a delayed fall start-up. The schedule was delayed by a waste disposal permit problem and by a decision to change the size of some major equipment items.

Global Graphite Group Ltd. has opened a high-purity and exfoliated graphite production facility in Anjou, Province of Quebec. The final capacity of the production line will be about 3,000 tons per year. The high-purity product was expected to contain 99% plus graphite and was to be made by acid leaching from Canadian and Brazilian feedstock. The exfoliated graphite was to be converted into graphite sheet, which can be sold for use in high-performance gaskets and seals. The high-purity product can be used in lubricants, batteries, ceramics, and certain refractories. Almost all of the product will be exported.

China.—According to the Yearbook of Iron and Steel Industry of China, Chinese production of graphite electrodes was 191,100 tons in 1988, 124,300 tons in 1987, and 99,800 tons in 1986. Production was 95,800 tons in 1985, 76,200 tons in 1980, 68,400 tons in 1975, and 32,800 tons in 1970.

Sweden.—The state mining Property Commission ordered the exploration of a crystalline flake graphite deposit at Kringeltjarn Lake, near Edsbyn, about 100 kilometers northwest of Gavle. After some graphite-rich boulders were found, detailed geophysical surveys and trenching began in 1985. Ore reserves were delineated by extensive diamond drilling. Beneficiation studies and some pilot plant recovery have been done. Proven ore reserves are stated to be 1 million tons averaging 11% C plus 0.6 million tons of finer flake averaging 6% C on the eastern side of the deposit. The beneficiation studies indicated it would be possible to get a 90% recovery of two products, about one-half the tonnage a fine crystalline flake running 98% C and 40% of the tonnage a medium crystalline flake running 87% C. A joint-venture partner is now being sought to participate in a feasibility study.[2]

Vietnam.—A review of the current Vietnamese industrial mineral situation in a prominent Western publication comprehensively covered graphite. The size of Vietnamese graphite production is only moderate and comes from two areas. The northernmost and larger is north of Hanoi near Lao Cai and the Chinese border, and the other is 80 kilometers south of Danang. All of the graphite deposits seem to be distributed along the Red River Thrust Belt and found in schist or gneisses. The great majority of the graphite, if not all, is crystalline flake or crystalline dust. The largest and best known ore thickness is up to 35 meters and content ranging from 5% to 12% C. Vietnamese sources estimate that the six main ore bodies may contain a total of 2.5 million tons of graphite.[3]

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 relatively slow growth rate reflects the maturity of the market, mostly in refractories, and particularly in carbon-magnesite brick. Supply is likely to be abundant as the oversupply worsens.

[1] Bonneau, J., and R. Raby. The Lac Knife Graphite Deposit. Min. Mag., v. 163, No. 1, July 1990, pp. 12–18.
[2] Russell, A. The Swedish Minerals Industry. Ind. Miner. (London), No. 271, Apr. 1990, p. 51.
[3] Premoli, C. Industrial Minerals of Vietnam. Ind. Miner. (London), No. 274, July 1990, p. 65.

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European Chemical News.

Industrial Minerals (London).

Materials Engineering.

Wall Street Journal.

TABLE 13

GRAPHITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989	1990[e]
Argentina	40	216	24	[r]100	100
Austria	36,167	39,391	7,577	[r]15,307	17,500
Brazil (marketable)[3]	28,586	31,404	[r]34,520	[r]31,700	32,000
Burma[4]	722	—	—	—	—
China[e]	185,000	185,000	200,000	200,000	200,000
Czechoslovakia[e]	[5]25,254	[r]25,000	25,000	25,000	25,000
Germany, Federal Republic of	13,233	9,891	[r]9,666	7,000	8,000
India (mine)[6]	38,412	42,589	[r]57,325	[r]47,731	50,000
Korea, North[e]	25,000	25,000	25,000	[r]35,000	35,000
Korea, Republic of:					
Amorphous	96,577	106,507	107,767	[r]100,282	100,000
Crystalline flake	641	838	678	[r]1,186	1,000
Madagascar	16,187	13,169	14,106	[r]15,863	16,000
Mexico:					
Amorphous	[r]36,018	36,674	[r]47,871	[r]38,304	35,000
Crystalline flake	1,838	1,787	1,735	[r]1,942	2,000
Norway	—	—	—	[r]1,800	5,000
Romania[e]	12,000	12,000	12,000	10,000	20,000
Sri Lanka	7,453	9,400	8,547	4,163	4,000
Turkey (mine)	3,586	11,760	[r]12,911	[r]11,302	12,000
U.S.S.R.[e]	83,000	84,000	84,000	84,000	80,000
United States	—	—	W	W	—
Zimbabwe	15,004	13,530	11,441	[r]18,147	18,000
Total	624,718	648,156	[r]660,168	[r]648,827	660,600

[e] Estimated. [r] Revised. W Withheld to avoid disclosing company proprietary data.

[1] Table includes data available through May 9, 1991.

[2] In addition to the countries listed, Canada produced graphite during the period covered by this table but output is unreported.

[3] Does not include the following quantities sold directly without benefication, in metric tons: 1985—16,425; 1986—19,074; 1987—10,505; 1988—18,269 (revised estimated); and 1989—20,000 (estimated).

[4] Data are for fiscal year beginning Apr.1 of that stated.

[5] Reported figure.

[6] Indian marketable production is 10% to 20% of mine production.

GYPSUM

By Lawrence L. Davis

Mr. Davis, a physical scientist with 35 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 Virginia Harper, mineral data assistant; and international data tables were prepared by William L. Zajac, Chief, Section of International Data.

Demand for gypsum products decreased in 1990, a result of decreased construction activity, especially in new housing starts that decreased 13% to 1.2 million units. Crude gypsum mined, calcined gypsum produced, and shipments of wallboard products were all lower than the record highs set in 1989.

Sales of gypsum products decreased slightly to 26 million short tons, and value decreased 11% to $1.7 billion. Increased competition caused lower prices for gypsum products. Imports for consumption of crude gypsum decreased 6% to about 8.7 million tons. Total value of gypsum product exports increased 40% to $84 million.

DOMESTIC DATA COVERAGE

Domestic production data for gypsum are developed by the U.S. Bureau of Mines from a survey of U.S. gypsum operations. Of the 132 operations to which the annual survey request was sent, 100 responded, representing 96% 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.

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 often associated with gypsum. When gypsum is calcined at high temperatures, it is converted to anhydrite.

Commercially calcined gypsum, $CaSO_4 \cdot \frac{1}{2}H_2O$, is a manufactured hemihydrate product produced by partial calcination of gypsum. It is produced by heating gypsum at temperatures to 350° F. Commonly called plaster of paris, when water is added to form a paste, it quickly sets and hardens to form gypsum again.

Byproduct gypsum is a chemical product of manufacturing processes such as phosphoric acid, hydrofluoric acid, citric acid, and titanium dioxide from ilmenite, consisting essentially of $CaSO_4 \cdot 2H_2O$. 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; 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 frequently 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,

TABLE 1

SALIENT GYPSUM STATISTICS

(Thousand short tons and thousand dollars)

	1986	1987	1988	1989	1990
United States:					
Active mines and plants[1]	113	109	112	112	106
Crude:					
Mined	15,403	15,612	16,390	17,624	16,406
Value	$99,570	$106,977	$109,205	$128,448	$99,567
Imports for consumption	9,559	9,717	9,679	9,304	8,726
Byproduct gypsum sales	653	688	733	725	735
Calcined:					
Produced	17,061	17,592	17,274	17,893	17,553
Value	$310,353	$321,645	$313,251	$285,659	$278,607
Products sold (value)	$2,514,432	$2,278,822	$2,090,786	[2]$1,926,676	[2]$1,712,848
Exports (value)	$28,805	$32,061	$42,789	$60,311	$84,452
Imports for consumption (value)	$181,168	$163,581	$158,169	$111,012	$110,205
World: Production	[r]97,256	[r]102,154	103,499	[p]109,023	[e]107,671

[e] Estimated. [p] Preliminary. [r] Revised.

[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.

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 diving adits, with mining development and production by the room-and-pillar system.

Most domestic gypsum is produced from surface mines using standard open pit mining methods. In a typical domestic mine, the gypsum is drilled and blasted as needed, probably every week or two. Broken gypsum rock, loaded with hydraulic shovel or front-end loader, is hauled to the primary crusher by a fleet of three or four 35-ton handtrucks. All material removed from the mines is crude gypsum. All waste is left in the mine.

The processing of crude gypsum depends on the end use. Gypsum for use in cement is crushed to minus 1½ inch plus ⅜ 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, $CaSO_4 \cdot \frac{1}{2}H_2O$. 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 29 companies at 58 mines in 20 States. Production decreased 7%. Leading producing States, in descending order, were Iowa, Oklahoma, Michigan, Texas, 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 Alabaster Mine, Iosco County, MI; USG's Shoals Mine, Martin County, IN; USG's Sperry Mine, Des Moines County, IA; Harrison's Cement Mine, Caddo County, OK; National Gypsum's Tawas Mine, Iosco County, MI; Temple-Inlands's Fletcher Mine, Comanche County, OK; Pacific Coast Building Products Inc.'s (PABCO), Las Vegas Mine, Clark County, NV; and H. M. Holloway Inc.'s Lost Hills Mine, Kern County, CA. These 10 mines accounted for 43% of the national total. Average output for the 58 mines increased 4% to 283,000 tons.

Gypsum was calcined by 13 companies at 71 plants in 28 States, principally for the manufacture of gypsum wallboard and plaster. Calcined output decreased slightly in tonnage and value. Leading States, in descending order, were California, Iowa, Texas, Florida, Nevada, and New York. These 6 States, with 29 plants, accounted for 48% of the national output.

Leading companies were USG, 20 plants; National Gypsum, 18 plants; Georgia-Pacific, 10 plants; Domtar, 8 plants; and Celotex, 4 plants. These 5 companies, operating 60 plants, accounted for 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 Baltimore plant, Baltimore County, MD; Briar Gypsum Co.'s Briar plant, Howard County, AR; National Gypsum's Tampa plant, Hillsborough County, FL; USG's Shoals plant, Martin County, IN; PABCO's Las Vegas Plant, Clark County, NV; and USG's Stony Point plant, Rockland County, NY. These 10 plants accounted for 29% of the national production. Average calcine production for the 71 U.S. plants was 247,000 tons, a slight decrease.

A total of 735,000 tons of byproduct gypsum, valued at $3.1 million, was used, principally in agriculture, but some for gypsum wallboard manufacturing. Approximately 69% was of nonphosphogypsum origin compared with 76% in 1989.

According to the Gypsum Association, yearend gypsum wallboard plant capacity for producing ½-inch regular wallboard decreased slightly to 24.65 billion square feet per year. Total wallboard shipments were 20.9 billion square feet, 81% of capacity.

Improvements to existing plants and construction of new plants continued during the year. At the same time, some plants were closed. Domtar completed construction and began operating its Newington, NH, wallboard plant. The plant uses crude gypsum imported from Domtar's Flat Bay quarry in Newfoundland. Domtar closed, at least temporarily, its Florence wallboard plant in Fremont County, CO.

Eagle Gypsum Products began operation of its new wallboard plant in Eagle County, CO. Highland-American Corp. completed construction of its new gypsum fiberboard plant in East Providence, RI, and was expecting to begin full-scale production in early 1991. Centex American continued construction of its new wallboard plant in Bernalillo, NM. Windsor Gypsum Co.'s board plant at Tatum, TX, was closed during 1990.

Consumption and Uses

Apparent consumption, defined as production plus net imports plus industry stock changes, of crude gypsum, including byproduct gypsum, remained about the same at 26.8 million tons. Net imports provided 32% of the crude gypsum consumed. Apparent consumption of calcined gypsum decreased slightly to 17.5 million tons.

Yearend stocks of crude gypsum at mines and calcining plants were 2.0 million tons. Of this, 44% was at calcining plants

TABLE 2

CRUDE GYPSUM MINED IN THE UNITED STATES, BY STATE

State	1989			1990		
	Active mines	Quantity (thousand short tons)	Value (thousands)	Active mines	Quantity (thousand short tons)	Value (thousands)
Arizona, New Mexico	6	561	$3,132	6	778	$5,658
Arkansas, Kansas, Louisiana	5	1,836	13,097	5	1,608	11,413
California, Nevada, Utah	14	3,526	26,905	11	3,209	16,955
Colorado, Montana,[1] South Dakota, Washington, Wyoming	10	673	5,202	7	522	3,751
Indiana, New York, Ohio, Virginia	5	2,149	16,226	5	2,046	14,715
Iowa	6	2,273	16,884	6	2,192	14,243
Michigan	5	2,089	15,589	5	2,000	11,511
Oklahoma	8	2,523	14,369	7	2,184	11,154
Texas	6	1,993	17,044	6	1,868	10,166
Total[2]	65	17,624	128,448	58	16,406	99,567

[1]1989 only.

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

TABLE 3

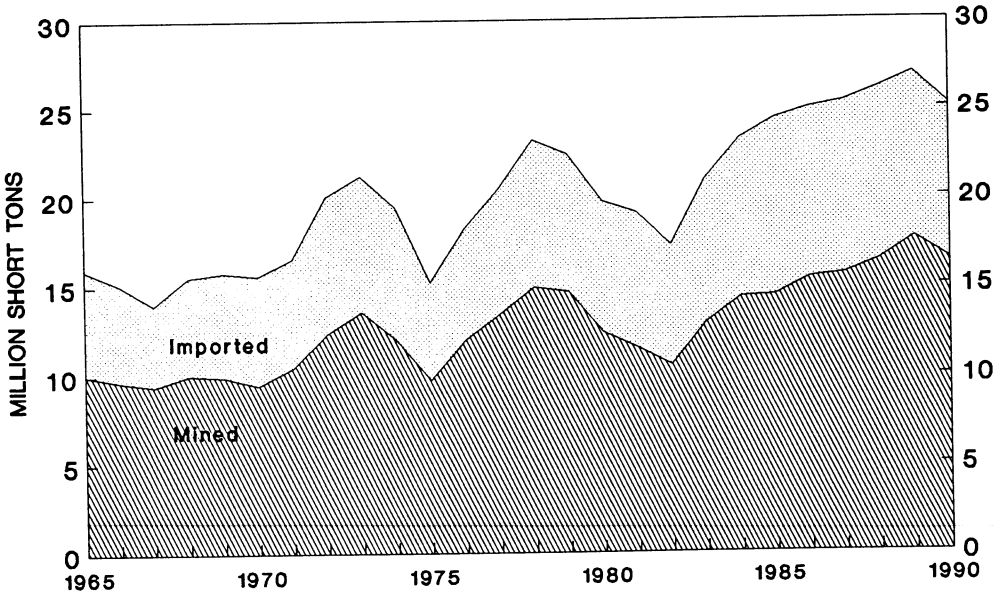
CALCINED GYPSUM MINED IN THE UNITED STATES, BY STATE

State	1989			1990		
	Active plants	Quantity (thousand short tons)	Value (thousands)	Active plants	Quantity (thousand short tons)	Value (thousands)
Arizona and New Mexico	5	651	$7,831	5	661	$5,689
Arkansas, Louisiana, Oklahoma	7	1,982	25,741	7	1,958	23,263
California	6	1,958	32,401	6	2,031	32,225
Delaware, Maryland, North Carolina, Virginia	6	1,708	28,155	6	1,688	33,174
Florida	3	1,303	21,066	3	1,264	25,474
Georgia	3	724	12,022	3	694	10,692
Illinois, Indiana, Kansas	6	1,513	24,721	6	1,467	22,242
Iowa	5	1,490	24,575	5	1,506	20,351
Massachusetts, New Hampshire, New Jersey	4	832	14,410	5	984	18,951
Michigan	4	650	10,677	4	637	11,809
Nevada	4	1,186	19,075	4	1,191	15,360
New York	4	1,093	15,646	4	1,053	19,787
Ohio	3	458	7,405	3	415	7,716
Texas	7	1,584	23,918	6	1,311	15,466
Washington and Wyoming	4	761	18,016	4	694	16,408
Total[1]	71	17,893	285,659	71	17,553	278,607

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

FIGURE 1

SUPPLY OF CRUDE GYPSUM IN THE UNITED STATES



in coastal States.

Of the total gypsum products sold or used, 6.5 million tons, about 34%, 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 1990, 67% of the uncalcined gypsum products 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, 62% was regular wallboard; 28% was fire-resistant type X wallboard; 3% 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, 85% was ½ inch and 11% was ⅝ inch.

In descending order, the leading sales regions for prefabricated products were the South Atlantic, Pacific, East North-Central, and Middle Atlantic. Together they accounted for 68% of the total.

TABLE 4

GYPSUM PRODUCTS (MADE FROM DOMESTIC, IMPORTED, AND BYPRODUCT GYPSUM) SOLD OR USED IN THE UNITED STATES, BY USE

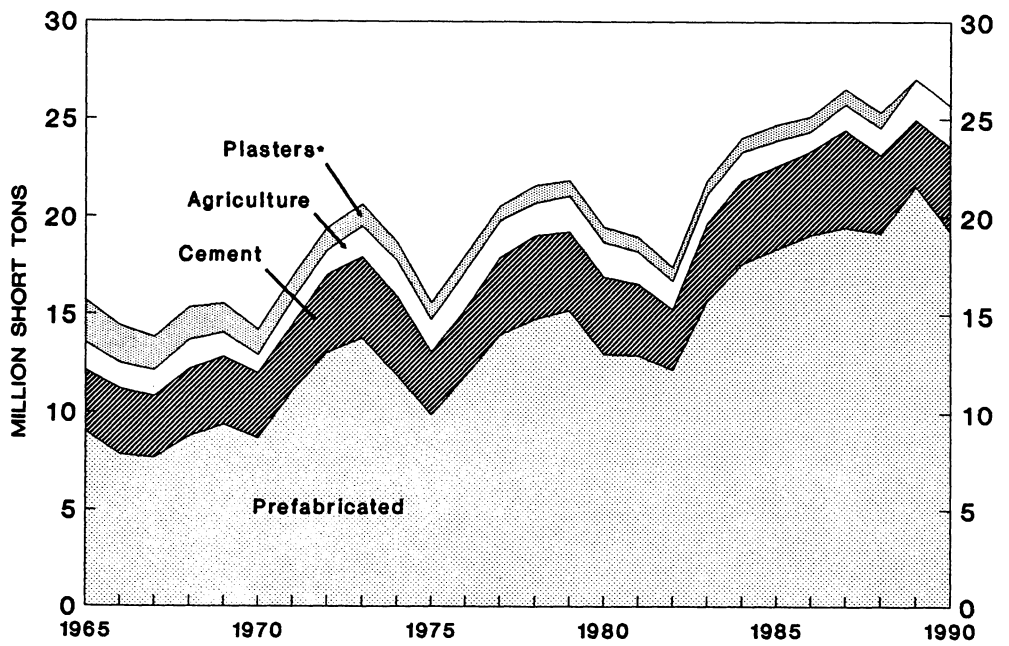
(Thousand short tons and thousand dollars)

Use	1989		1990	
	Quantity	Value	Quantity	Value
Uncalcined:				
Portland cement	3,422	41,834	4,355	46,660
Agriculture and miscellaneous[1]	2,094	32,310	2,099	39,143
Total[2]	5,516	74,145	6,454	85,803
Calcined:				
Plasters	W	W	W	W
Prefabricated products[3]	21,552	1,852,531	19,237	1,627,045
Total calcined[2 4]	21,552	1,852,531	19,237	1,627,045
Grand total[2 4]	27,068	1,926,676	25,691	1,712,848

W Withheld to avoid disclosing company proprietary data.
[1]Includes byproduct gypsum.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes weight of paper, metal, or other materials and some byproduct gypsum.
[4]Data does not include plasters.

FIGURE 2

SALES OF GYPSUM PRODUCTS BY USE



•Data withheld in 1989 and 1990

TABLE 5

PREFABRICATED GYPSUM PRODUCTS SOLD OR USED IN THE UNITED STATES

Product	1989			1990		
	Thousand square feet	Thousand short tons[1]	Value (thousands)	Thousand square feet	Thousand short tons[1]	Value (thousands)
Lath:						
⅜ inch	15,319	11	$2,747	14,700	11	$2,563
½ inch	460	(2)	61	300	(2)	46
Other	3,480	3	532	—	—	—
Total[3]	19,259	15	3,339	15,000	11	2,608
Veneer base	476,330	478	40,810	440,040	453	34,940
Sheathing	310,880	301	36,543	253,044	245	33,126
Regular gypsumboard:						
⅜ inch	891,365	819	100,335	433,512	348	41,299
½ inch	11,187,062	9,830	802,976	10,454,624	9,448	750,560
⅝ inch	1,303,673	2,244	101,706	1,319,403	1,354	62,438
1 inch	76,604	94	16,712	47,780	56	10,439
Other[4]	80,820	62	8,834	113,079	75	25,624
Total[3]	13,539,524	13,050	1,030,564	12,368,398	11,280	890,360
Type X gypsumboard	6,027,090	6,398	537,116	5,513,055	5,977	485,342
Predecorated wallboard	129,341	122	41,427	106,550	103	33,316
5/16-inch mobile home board	725,283	549	67,049	646,631	516	57,938
Water/moisture-resistant board	587,830	557	77,385	543,184	527	69,516
Other	83,561	83	18,297	114,240	125	19,900
Grand total[3]	21,899,098	21,552	1,852,531	20,000,142	19,237	1,627,045

[1]Includes weight of paper, metal, or other material.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.
[4]Includes 1/4-, 7/16-, and 3/4-inch gypsumboard.

Markets and Prices

On an average value-per-ton basis, f.o.b. mine or plant, crude gypsum decreased 17% to $6.07, calcined gypsum decreased slightly to $15.87, and byproduct gypsum increased 6% to $4.27. Prefabricated products were valued at $84.58 per ton, plasters at $128.42 per ton, and uncalcined products at $13.29 per ton.

According to the Department of Commerce, the average producer price of regular ½-inch wallboard was 6% lower in 1990 than in 1989, and type X board was 4% lower.[1]

Lower demand and lower prices, especially for gypsum wallboard products, have caused difficult times for much of the industry. Two companies, Celotex and National, filed for bankruptcy protection under chapter 11, and USG, the country's largest producer, was struggling to restructure its debt load.

Foreign Trade

Imports for consumption of crude gypsum decreased 6% to 8.7 million tons and 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, decreased 23% to 272 million square feet. The decrease is a reflection of fewer housing starts in the United States.

World Review

Estimated world production of crude gypsum decreased slightly to 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.

Canada.—Louisiana-Pacific Panel Products Ltd. completed construction of its new fiber gypsum board plant in Sydney, Nova Scotia. Commercial production was to begin in 1991.

The Gypsum Association in the United States, of which all Canadian wallboard producers were members, reported that yearend capacity of ½-inch regular wallboard in Canada was 3.92 billion square feet, an increase of 5% compared with that of the previous year.

France.—BPB Industries PLC of the United Kingdom acquired the plaster and gypsum operations of Poliet Group. The

operations included six plaster mills, seven gypsum block factories, and one plasterboard plant in various locations throughout France and several mines near Paris.[2]

Germany, Federal Republic of.—Harzer Gipswerke Rottleberode GmbH, the major producer in Eastern Germany, was purchased by Gebr. Knauf Westdeutsche Gipswerke, Germany's largest producer.[3]

Ireland.—North West Exploration PLC awarded a contract to Ortech MCS Ltd. for a feasibility study on its Glangevlin deposit in County Cavan. The study will be a detailed assessment of the mining and processing of the gypsum and the manufacturing and marketing of gypsum products.[4]

Netherlands.—Novem BV, the Dutch agency for energy and the environment, was supporting a Dutch-German joint venture to demonstrate a novel process for using gypsum from flue gas desulfurization for making self-leveling mortars and as a setting time regulator in cement.[5]

Spain.—Controlling interest in Spain's largest plaster producer, Inveryeso S.A., was acquired by BPB Industries PLC of the United Kingdom. Inveryeso, with 20 plaster mills, had about 50% of the plaster market.[6]

United Kingdom.—LaFarge Coppee of France and Redland PLC of the United

TABLE 6

IMPORTS FOR COMSUMPTION OF CRUDE GYPSUM, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1989		1990	
	Quantity	Value	Quantity	Value
Australia	23	201	20	172
Canada[1]	6,285	41,964	6,349	45,314
China	13	95	35	421
Jamaica	—	—	24	163
Mexico	2,353	11,606	1,698	8,741
Morocco	12	60	49	269
Spain	618	5,142	550	5,696
Other	(2)	40	1	232
Total[3]	9,304	59,107	8,726	61,009

[1]Includes anhydrite.
[2]Less than 1/2 unit.
[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:								
1986	15	1,056	141	14,425	NA	9,299	4,025	28,805
1987	4	696	123	14,933	NA	11,444	4,988	32,061
1988	5	668	266	18,694	NA	16,531	6,896	42,789
1989	108	2,286	106	15,914	97	25,140	16,972	60,311
1990	129	5,056	94	18,381	69	30,959	30,056	84,452
Imports for consumption:								
1986	9,559	64,996	3	436	811	99,089	16,646	181,168
1987	9,717	59,171	2	384	715	82,220	21,806	163,581
1988	9,679	59,166	2	670	637	70,866	27,467	158,169
1989	9,304	59,107	3	270	355	29,355	22,280	111,012
1990	8,726	61,009	1	236	272	22,786	26,174	110,205

NA Not available.
[1]Import and export data for 1989 and 1990 are for "Gypsum; anhydrite," Harmonized Tariff Schedule 2520.10. Data for 1986-88 are for "Plaster rock or gypsum: Not ground and not wholly or partly calcined," TSUS 512.21. The two categories might not be comparable.
[2]Import and export data for 1989 and 1990 are for "Plasters," Harmonized Tariff Schedule 2520.20. Data for 1986-88 are for "Plaster rock or gypsum: Ground, wholly or partly calcined, or both," TSUS512.24. The two categories might not be comparable.
[3]Import and export data for 1989 amd 1990 are for "Boards, sheets, panels, tiles and similar articles, not ornamented: Faced or reinforced with paper or paperboard only," Harmonized Tariff Schedule 6809.11. Data for 1986-88 are for "Gypsum or plaster building boards and lath" TSUS 245.70. The two categories might not be comparable.
[4]Import and export data for 1989 and 1990 are for "Boards, sheets panels, tiles and similar articles, not ornamented: other," Harmonized Tariff Schedule 6809.19 and "Other articles," Harmonized Tariff Schedule 6809.90. Data for 1986-88 are for "Cement of gypsum," TSUS 512.31and 512.35, "Articles n.s.p.f. of Plaster of Paris," TSUS 512.41, and "Alabaster articles, n.s.p.f.," TSUS 513.94. Data for 1989 and 1990 might not be comparable to those of previous years.
[5]Data may not add to totals shown because of independent rounding.
Source: Bureau of the Census.

Kingdom entered into a joint venture that became Europe's second largest gypsum wallboard producer. LaFarge bought the interests of CSR Ltd. of Australia in a previous joint venture with Redland.[7]

British Gypsum Ltd., subsidiary of BPB Industries PLC, contracted for the purchase of up to 1 million tons per year of flue gas desulfurization gypsum from the Drax powerplant in Yorkshire. Delivery was expected to begin in 1993 with 200,000 tons and then increase in later years.[8]

Knauf UK signed a long-term contract with Tioxide UK for byproduct gypsum to be produced at Tioxide's Grimsby facility. Knauf will use the gypsum at this Immingham board plant beginning in 1992.[9]

TABLE 8

GYPSUM: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country	1986	1987	1988	1989[p]	1990[e]
Afghanistan[e]	3	3	3	3	3
Algeria[e 2]	303	303	303	303	303
Angola[e]	22	22	r63	r63	63
Argentina	509	682	573	444	440
Australia	1,842	1,742	1,801	e1,980	1,980
Austria[3]	774	732	796	689	700
Bolivia[e]	r1	r1	r1	r1	1
Brazil (direct sales plus beneficiated)	693	727	715	e720	720
Bulgaria	435	337	442	497	4545
Burma[5]	r29	r25	35	35	434
Canada (shipments)[3]	9,704	9,980	10,485	9,035	49,041
Chile	213	259	348	306	4278
China[e]	7,200	7,900	8,900	8,900	8,800
Colombia	325	333	338	610	550
Cuba[e]	145	145	145	145	145
Cyprus	33	50	36	12	12
Czechoslovakia	819	r850	853	877	875
Dominican Republic	146	65	169	188	165
Ecuador	320	r32	r e55	53	55
Egypt	998	1,200	e1,200	1,443	1,440
El Salvador[e]	5	5	5	5	5
Ethiopia[e 6]	1	2	2	2	2
France[3]	5,797	5,962	6,204	6,266	6,200
Germany, Federal Republic of:					
Eastern states[e]	375	353	353	342	330
Western states (marketable)[3]	2,090	1,882	1,921	e2,040	1,980
Greece[e]	r550	550	550	r500	500
Guatemala	31	26	38	31	33
Honduras[e]	25	25	25	25	25
Hungary[e 3]	20	111	4130	127	127
India	r1,808	r1,911	1,570	1,697	1,760
Iran[2 7]	8,942	8,430	8,662	r e8,800	8,800
Iraq[e]	330	390	390	500	520
Ireland	318	313	359	346	350
Israel	51	39	34	33	42
Italy	1,372	1,339	e1,430	e1,380	1,380
Jamaica	129	194	160	86	491
Japan[e]	7,000	6,600	6,900	6,900	7,000
Jordan	77	126	94	146	145
Kenya[3]	12	43	42	40	40
Laos[e]	r33	77	88	115	125
Lebanon[e]	3	2	2	2	2

See footnotes at end of table.

TABLE 8—Continued

GYPSUM: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country	1986	1987	1988	1989[p]	1990[e]
Libya[e]	200	200	200	200	200
Luxembourg[e]	(8)	(8)	(8)	(8)	(8)
Mauritania	20	21	[r e]22	11	11
Mexico	4,666	5,044	5,269	5,942	[4]6,615
Mongolia[e]	35	35	35	35	35
Morocco[e]	500	500	500	500	500
Nicaragua	[e]9	8	[e]8	13	13
Niger[e]	3	—	3	3	3
Pakistan	411	495	413	515	520
Paraguay	3	3	4	5	5
Peru	189	252	[e]165	[e]176	165
Philippines	138	138	[e]141	[e]132	132
Poland[3]	1,220	1,242	1,224	[e]1,220	1,220
Portugal	292	356	373	[e]330	330
Romania[e]	1,760	1,650	1,760	1,760	1,650
Saudi Arabia[e]	[4]411	411	413	413	413
Sierra Leone[e]	4	4	4	4	4
South Africa, Republic of	446	385	410	448	[4]424
Spain	5,581	7,369	6,062	[e]6,060	5,500
Sudan[3]	[e]8	[e]8	6	11	11
Switzerland[e]	220	250	250	[r]250	250
Syria	[e]176	273	197	[e]198	198
Taiwan	2	2	3	4	4
Tanzania[3]	16	27	22	6	6
Thailand	1,836	3,341	5,014	6,038	[4]6,342
Tunisia[e]	110	110	110	110	110
Turkey	141	333	255	246	250
U.S.S.R.	5,070	5,270	5,404	5,401	5,200
United Kingdom[e 3]	[4]3,765	3,860	4,080	4,400	4,400
United States[9]	15,403	15,612	16,390	17,624	[4]16,406
Uruguay[e]	110	110	110	110	110
Venezuela	284	272	244	366	[4]222
Vietnam[e]	30	30	30	30	30
Yemen, Republic of	58	165	176	[e]175	175
Yugoslavia	656	610	612	600	610
Total	[r]97,256	[r]102,154	103,499	109,023	107,671

[e]Estimated. [p]Preliminary. [r]Revised.
[1]Table includes data available through June 28, 1991.
[2]Includes approximately 55,000 short tons of plaster a year.
[3]Includes anhydrite.
[4]Reported figure.
[5]Data are for years beginning Apr. 1 of that stated.
[6]Data are for years ending July 7 of that stated. Reported in cubic meters and estimated at 2.2 short tons per cubic yard.
[7]Data are for years beginning Mar. 21 of that stated.
[8]Less than 1/2 unit.
[9]Excludes byproduct gypsum.

OUTLOOK

More than 90% of the gypsum consumed annually in the United States is used in construction, mainly in gypsum wallboard products, building plasters, and in the manufacture of portland cement. With new housing starts decreasing each year since 1986 and an oversupply of office space, demand for gypsum products is expected to decrease slightly in 1991, then slowly increase for the next several years as the economy improves and construction activity increases.

[1]International Trade Administration (Dep. of Commerce). Construction Review. V. 37, No. 2, Mar.-Apr. 1991, p. 41.
[2]Industrial Minerals (London). No. 276, Sept. 1990, p. 15
[3] Falk, L., and D. Hausser. The Eastern German Industrial Minerals Contribution. Ind. Miner. (London), No. 279, Dec. 1990, pp. 24-49
[4]Industrial Minerals. No. 271, Apr. 1990, p. 13.
[5]———. No. 278, Nov. 1990, p. 18.
[6]———. No. 275, Aug. 1990, p. 15-17.
[7]Rock Products. V. 93, No. 11, Nov. 1990, p. 70.
[8]Industrial Minerals (London). No. 273, June 1990, pp. 9-11.
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HELIUM

By William D. Leachman

Mr. Leachman, a chemical engineer with 37 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for helium since 1983. He also prepared the domestic survey data and the 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 2,167 million cubic feet (MMcf) in 1990.[1] Grade-A helium exports by private producers were 892 MMcf, for total sales of 3,059 MMcf of U.S. helium. The price of Grade-A helium, f.o.b. plant, was about $37.50 per thousand cubic feet (Mcf) for both the Bureau and private industry. The Bureau price for bulk liquid helium was $45.00 per Mcf, with additional costs for container services and rent. The liquid helium price for private industry was also about $45.00 per Mcf, with some producers posting surcharges to this price.

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 seven 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. The purposes of the act were to provide for conservation of helium for essential Government activities and to promote development of a private helium industry. 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 the conservation program were made under 22-year contracts with private natural gas companies, which added crude helium extraction capabilities to their existing gas processing facilities. Four companies built five crude helium plants. The Bureau constructed a high-pressure pipeline to transport the helium from Bushton, KS, and intermediate points to the Bureau-owned Cliffside Field for storage.

Helium needs of the Federal agencies, particularly the U.S. Department of Defense, the National Aeronautics and Space Administration (NASA), and the U.S. Department of Energy (DOE), have been met, and there is enough helium in storage to meet their foreseeable needs for up to 100 years, depending on how much helium will be needed by future Government programs. The entire Federal helium demand is now supplied by the Exell Helium Plant.

In the mid-1970's, the Bureau began accepting privately owned crude helium for storage in Cliffside under long-term contracts. Private industry currently has about a 6-month supply of helium in Government storage, assuming all private market requirements would come from storage.

Geology-Resources

Domestic measured and indicated helium resources as of January 1, 1990, the latest figures available, are estimated to be 541 billion cubic feet (Bcf). The total identified helium resources are about 6 Bcf more than reported in 1989. The increase is attributed to the reevaluation of the helium reserves of several fields in Texas. The resources include measured reserves and indicated resources estimated at 256 and 32 Bcf, respectively, in natural gas with a minimum helium content of 0.3%. The measured reserves included 35 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 40 Bcf. Indicated helium resources in natural gas with a helium content of less than 0.3% are estimated to be 213 Bcf. Approximately 165 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 95 gasfields in 11 States. About 83% of these reserves is

contained in the Hugoton Field in Kansas, Oklahoma, and Texas; the Keyes Field in Oklahoma; the Panhandle and Cliffside Fields in Texas; and the Riley Ridge area in Wyoming. The U.S. Bureau of Mines analyzed a total of 184 natural gas samples from 21 States during 1990 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 operated. 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 highest-energy particle accelerator in the world (1.6 trillion electron volts). In addition, the DOE has already selected the magnets it proposes to use in the Superconducting Supercollider (SSC). The SSC magnets will be similar to those used at Fermi, which are liquid helium-cooled, because they have been proved and tested in operation. When completed, the SSC will have about 20 times the power of the Tevatron (40 trillion electron volts). The proposed Texas site for the SSC was selected by DOE in January 1989.

Argonne National Laboratory is developing a magnetohydrodynamic (MHD) propulsion system for military and commercial use. The MHD propulsion system has no moving parts, but uses magnetic fields and electricity to pump water through a tube. Researchers at Argonne will use the world's largest helium-cooled superconducting dipole magnet to study the propulsion system. Development of this technology could lead to a new generation of water transportation vessels that would travel more quickly, quietly, and efficiently than present ships.

Testing of the six liquid helium-cooled electromagnets supplied for the Large Coil Task was completed at Oak Ridge National Laboratory last year. These six magnets each incorporated slightly different designs, which were tested to determine the best configuration for the confinement of fusion systems in the production of "clean" nuclear energy. Although these magnets are the largest ever tested (8 tesla, or 160,000 times as strong as the magnetic field of the Earth), they are only one-third to one-half the size of those needed for proposed fusion reactors. Successful operation of these magnets gives researchers more confidence in the use of superconducting magnets for fusion containment.

Liquid helium use in magnetic resonance imaging (MRI) continues to increase as the medical profession accepts and develops new uses for this equipment. MRI equipment is providing accurate diagnosis of medical problems where exploratory surgery was required previously. Another medical application being developed uses MRI to determine by blood analysis if a patient has any form of cancer. Most researchers seem to think it will be at least 5 to 10 years before the new high-temperature (about −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, many companies besides Goodyear are now using "blimps" for advertising.

Helium is being used to develop several Strategic Defense Initiative (SDI) applications such as the antisatellite (ASAT) rocket, chemical laser, and rail gun. 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. This telescope is 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 1,100 miles per hour. Electromagnetic energy applied along the bore accelerates the projectile to a final velocity of about 9,000 miles per hour.

Superconducting magnetic energy storage (SMES) is also being investigated to provide power for Defense laser systems. SMES allows the accumulation and storage of electrical energy over the long term (hours) and discharges it in minutes.

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 atmosphere is required; (3) helium-filled plastic pillows, where low density is required to simulate a precursor wave from a nuclear blast; (4) helium ion tumor treatment, where large inert particles are required; (5) liquid helium-cooled superconducting microswitches, called Josephson junctions, which are much faster than conventional semiconductors and use less power; (6) "Aneutronic" nuclear fusion where nuclear energy is produced by fusion of deuterium and helium-3, which produces few or no neutrons; and (7) new helium-hydrogen breathing mixtures that enable deep-sea divers to reach depths below 1,700 feet.

ANNUAL REVIEW

Legislation and Government Programs

The Government's program for storage of private crude helium in the Government's helium storage facilities at the Cliffside Field near Amarillo, TX, was vital in supplying helium for the private helium market. Excess helium production of private industry obtained from natural gas supplying fuel markets in the winter is stored by the Government under contract. This privately owned crude helium is returned to the owners for purification as needed to provide for private industry demand. Privatization of all the Government's helium program, except the conservation storage operation, is under consideration.

Production

In 1990, 12 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. Both private and Bureau plants use cryogenic extraction processes. The volume of helium recovered from natural gas decreased 3%, while sales increased about 6% in 1990. A shortage of private helium production was prevented by purifying crude helium that had been stored in the Government's Cliffside Field. All natural gas processed for helium recovery came from gasfields in Colorado, Kansas, New Mexico, 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 five of the private helium plants and at the Bureau's plant. Cryogenic purification is used by the other producers and provides backup at the Bureau's plant. 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; Navajo Refined Helium Co., Shiprock, NM; Kansas Refined Helium Co., Otis, KS; Exxon Co., U.S.A., Shute Creek, WY; and Union Carbide Corp., Linde Div., Bushton and Ulysses, KS. Nitrotec's new helium plant near Burlington, CO, produces Grade-A helium but does not liquefy helium. Linde's helium plant at Elkhart, KS, was shut down in 1988.

Consumption and Uses

The major domestic end uses of helium were cryogenics, welding, and pressurizing and purging. Minor uses included synthetic breathing mixtures, chromatography, leak detection, lifting gas, heat transfer, and controlled atmospheres. The Pacific and Gulf Coast States were the principal areas of helium consumption.

Bureau sales to Federal agencies and their contractors totaled 403 MMcf in 1990, an increase of about 15% when compared with last year's sales. This increase was due largely to NASA's resumption of space shuttle flights, which include associated projects that use large volumes of helium. Sales to DOE continue to decline.

The Federal agencies purchase their major helium requirements from the

TABLE 1

OWNERSHIP AND LOCATION OF HELIUM EXTRACTION PLANTS IN THE UNITED STATES IN 1990

Category and owner or operator	Location	Product purity
Government-owned:		
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]
KN Energy Inc.	Scott City, KS	Crude helium.[2]
Nitrotec	Burlington, CO	Grade-A helium.
Oxy NGL Inc.	Ulysses, KS	Crude helium.
Exxon Co. U.S.A.	Shute Creek, WY	Grade-A helium.[1]
Kansas Refined Helium Co.	Otis, KS	Do.
Navajo Refined Helium Co.	Shiprock, NM	Do.
Enron Helium Co.	Bushton, KS	Crude helium.
Phillips Petroleum Co.	Dumas, TX	Do.
Do.	Hansford County, TX	Do.
Union Carbide Corp., Linde Div.	Bushton, KS	Grade-A helium.[1]
Do.	Elkhart, KS	Deactivated.
Do.	Ulysses, KS	Grade-A helium.[1]

[1] Including liquefaction.
[2] Output is piped to Ulysses, KS, for purification.

TABLE 2

HELIUM RECOVERY IN THE UNITED STATES[1]

(Thousand cubic feet)

	1986	1987	1988	1989	1990
Crude helium:					
Bureau of Mines total storage	−379,827	−289,085	−359,409	−377,508	−462,812
Private industry:					
Stored by Bureau of Mines	431,917	730,360	630,748	547,158	507,057
Withdrawn	−980,209	−697,266	−551,997	−653,263	−766,684
Total private industry storage	−548,292	33,094	78,751	−106,105	−259,627
Total crude helium	−928,119	−255,991	−280,658	−483,613	−722,439
Stored private crude helium withdrawn from storage and purified by the Bureau of Mines for redelivery to industry	−18,658	−6,765	−11,920	−5,482	−6,401
Grade-A helium:					
Bureau of Mines sold	333,447	266,594	316,954	350,154	402,706
Private industry sold	1,607,963	1,963,750	2,256,997	2,529,226	2,655,848
Total sold	1,941,410	2,230,344	2,573,951	2,879,380	3,058,554
Total stored	−946,777	−262,756	−292,578	−489,095	−728,840
Grand total recovery	994,633	1,967,588	2,281,373	2,390,285	2,329,714

[1] Negative numbers (−) denote net withdrawal from the Government's underground helium storage facility, a partially depleted natural gas reservoir in Cliffside Field near Amarillo, TX.

FIGURE 1

HELIUM RECOVERY IN THE UNITED STATES

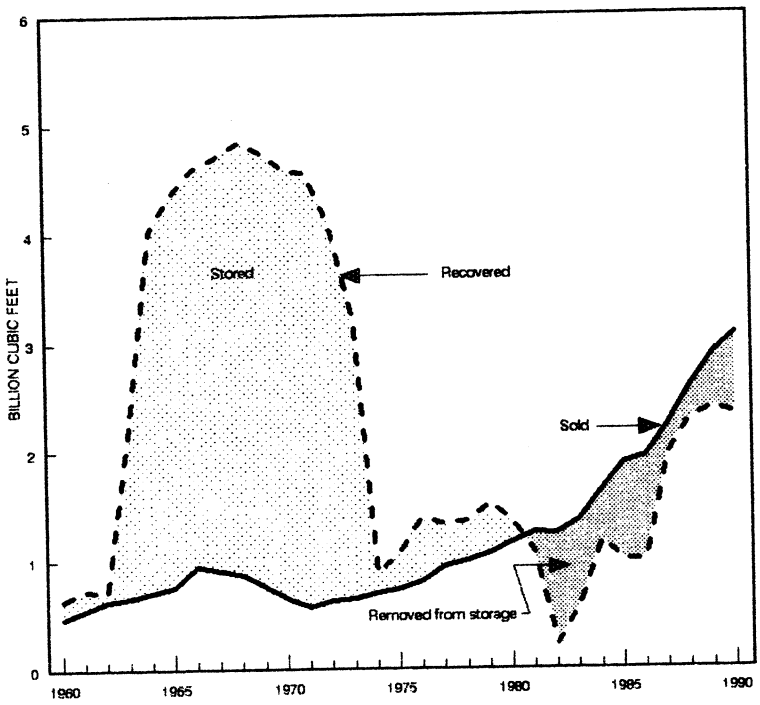


FIGURE 2

MAJOR U.S. HELIUM-BEARING NATURAL GASFIELDS

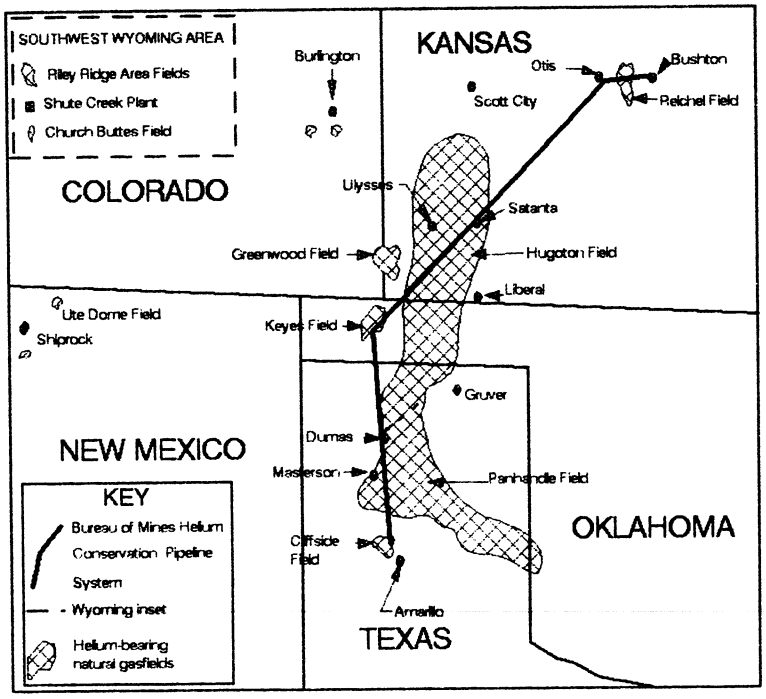


TABLE 3

TOTAL SALES OF GRADE-A HELIUM PRODUCED IN THE UNITED STATES

(Million cubic feet)

Year	Volume		
	Domestic sales	Exports[1]	Total sales
1986	1,509	432	1,941
1987	1,736	494	2,230
1988	1,911	663	2,574
1989	2,083	796	2,879
1990	2,167	892	3,059

[1] Source: Bureau of the Census.

U.S. Bureau of Mines. Direct helium purchases by the Department of Defense, NASA, DOE, and the National Weather Service constituted most of the Bureau's Grade-A helium sales. All 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 for future use in the U.S. Bureau of Mines helium conservation storage system, which includes the conservation pipeline network and the Cliffside Field near Amarillo, TX, totaled 34.4 Bcf at yearend. The conservation storage system contains crude helium purchased by the Bureau under contract, Bureau helium extracted in excess of sales, and privately owned helium stored under contract. During 1990, 507 MMcf of private helium was delivered to the Bureau's helium conservation storage system and 773 MMcf was withdrawn for a net decrease of 266 MMcf of private helium in storage.

Transportation

All Grade-A gaseous helium sold by the Bureau was shipped in cylinders, modules (large gas cylinders), special railway tankcars, or highway tube semi-

TABLE 4

SUMMARY OF BUREAU OF MINES HELIUM CONSERVATION STORAGE SYSTEM OPERATIONS[1]

(Thousand cubic feet)

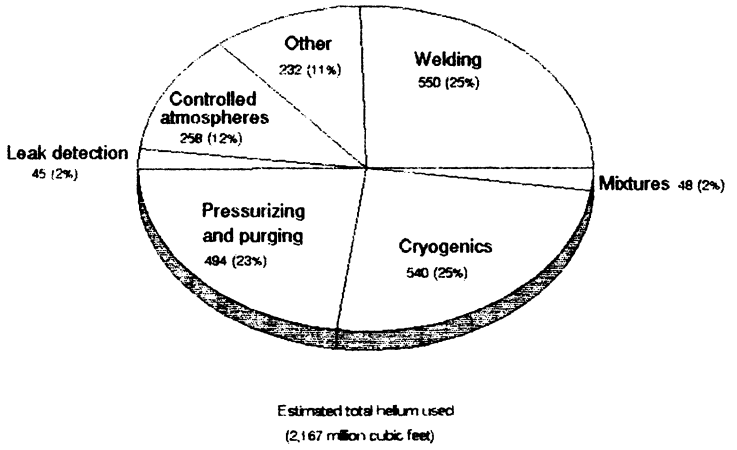
	1988	1989	1990
Helium in conservation storage system at beginning of period:			
Stored under Bureau of Mines conservation program	34,116,084	33,756,675	33,379,167
Stored for private producers under contract	1,799,774	1,866,605	1,755,018
Total	35,915,858	35,623,280	35,134,185
Input to system:			
Net deliveries from Bureau of Mines plants[2]	−359,409	−377,508	−462,812
Stored for private producers under contract	630,748	547,158	507,057
Total	271,339	169,650	44,245
Redelivery of helium stored for private producers under contract[2]	−563,917	−658,745	−773,085
Net addition to system[2]	−292,578	−489,095	−728,840
Helium in conservation storage system at end of period:			
Stored under Bureau of Mines conservation program	33,756,675	33,379,167	32,916,355
Stored for private producers under contract	1,866,605	1,755,018	1,488,990
Total	35,623,280	35,134,185	34,405,345

[1] Crude helium is injected into or withdrawn (−) from the Government's underground helium storage facility, a partially depleted natural gas reservoir in Cliffside Field near Amarillo, TX.
[2] Negative numbers denote net withdrawal from storage.

FIGURE 3

ESTIMATED HELIUM CONSUMPTION, BY END USE, IN THE UNITED STATES IN 1990

(Million cubic feet)



trailers. Small gas cylinders are filled at the Amarillo plant, and railway tankcars are filled at the Exell plant. Other shipping containers for gaseous helium may 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 primarily as a liquid in semitrailers. These semitrailers delivered the liquid helium to distribution centers where some of it was gasified and compressed into trailers and small cylinders for delivery to the end user. The remaining liquid helium was sold as bulk liquid or repackaged in dewars of various sizes for delivery.

Prices

The U.S. Bureau of Mines price, f.o.b. plant, for Grade-A helium has been maintained at $37.50 per Mcf since October 1, 1982, when it was raised from the $35.00 per Mcf price established in 1961. The price for Grade-A helium from private producers is also about $37.50 per Mcf. The Bureau trailer-load liquid helium price was $45 per Mcf during all of 1990, with additional charges for container services and rent. The typical private industry price for liquid helium was also $45 per Mcf gaseous equivalent plus surcharges. The Bureau has submitted a report to Congress on options for the routine adjustment of helium prices.

Foreign Trade

Exports of Grade-A helium, all by private industry, increased by 12% in 1990 to 892 MMcf (table 3). About 52% 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 33% of the U.S. helium exports went to Asia, with Japan taking about 87% of this helium. Other exports were as follows: more than 7% to North America; about 2% each to Australia-New Zealand, Middle East, and South America; and less than 1% each to Africa, the Caribbean, and Central America. The shipments of large volumes of helium to Western Europe were attributed to helium use in cryogenic research and superconducting equipment. Significant volumes were also being used in breathing mixtures for diving, welding, and as a lifting gas. Although no helium was imported in

1990, import tariffs on helium remained at the 3.7% rate established on January 1, 1987. No further decreases in import tariffs are scheduled.

World Review

World production of helium, excluding the United States, was estimated to be 300 MMcf, most of which was extracted in Poland and the U.S.S.R. The remainder was produced in small plants in China and India.

OUTLOOK

Until recently, all superconductors required liquid helium (−452 °F) to reach superconducting temperatures. Current research on superconductors has resulted in the discovery of superconducting materials that operate above liquid nitrogen temperatures (−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 problems are solved, the new materials could replace liquid helium-cooled superconductors.

Since 1986, the market for U.S. produced helium has grown at an average annual rate of 12%. Private industry's market has been growing at 13.4% per year, while the Federal market has grown at 4.9%. The Federal market has reached its highest volume in more than 20 years. At the present time, private industry is supplying about 87% of the demand for U.S. produced helium, while the Bureau is supplying the remaining 13%. Private industry supplies all of the U.S. helium exports. The foreign market made up about 26% of U.S. helium sales in 1990 and has grown at an average rate of approximately 20% per year since 1986.

At the present time, the outlook for helium looks good, with growth continuing in new technologies that use helium. The adverse impact of high-temperature superconductors, if any, is not expected for several years.

TABLE 5

WORLD GRADE-A HELIUM PRODUCTION CAPACITY, DECEMBER 31, 1990

(Million cubic feet)

	Capacity
United States	[1] 3,400
Rest of world[e]	300
Total[e]	3,700

[e] Estimated.
[1] Includes capacity of plants on standby as well as operating plants.

[1] All helium volumes herein reported are at 14.7 pounds per square inch absolute and 70° F.

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INDIUM

By Stephen M. Jasinski

Mr. Jasinski, a physical scientist with 4 years of U.S. Bureau of Mines experience, has been the commodity specialist for indium since 1988. Domestic survey data were prepared by Eraina Dixon, mineral data assistant.

Domestic indium production was derived from the upgrading of crude indium metal and residues generated in the refining of zinc and other base metals. Two companies accounted for all refined indium produced in the United States. Domestic production data for 1990 were unavailable. Falconbridge Ltd. began production of indium at its Kidd Creek Mine in Ontario, Canada. The indium was to be sold through Indium Corp. of America, as part of a joint-venture agreement. The main uses of indium were for solder, alloys, coatings, plating, and semiconductor compounds. Domestic consumption grew slightly owing to increased usage in coatings.

DOMESTIC DATA COVERAGE

The two refiners of indium in 1990 chose not to respond to the voluntary survey of indium produced from primary sources. Domestic consumption estimates were based on discussions with the major refiners and consumers and analysis of trade data.

BACKGROUND

Definitions, Grades, and Specifications

Indium is silvery-white in color and has a brilliant metallic luster. It is softer than lead, very ductile and malleable, and has a very low melting point; therefore, it is well suited for use in solders and low-melting alloys. It retains these plastic-like properties to temperatures near absolute zero. Indium can endure considerable deformation through compression and cold-welds easily.

Some physical constants of pure indium are chemical symbol In; atomic number, 49; atomic weight, 114.82; melting point, 156.61° C; boiling point, 2,080° C; and density, 7.31 grams per cubic centimeter at 20° C. Standard grade is 99.97% purity, and high grades are available from 99.99% (4N) to 99.99999% (7N) purity.

Industry Structure

Arconium Specialty Alloys, Providence, RI, and Indium Corp., Utica, NY, the only refiners of indium in the United States, produce indium primarily from imported zinc residues, low-grade indium bullion, and indium scrap. Arconium, Indium Corp., and Johnson Matthey Electronics, Spokane, WA, produce high-purity indium shapes, ingots, and foil. Metalspecialties Inc., Fairfield, CT, intermittently recovers indium from old scrap. New scrap is usually returned to the supplier for reprocessing.

In 1990, Arconium was acquired by Alpha Metals Inc. of New Jersey, a producer of solder and plating materials for electronic uses. Both companies are part of Cookson Group PLC of the United Kingdom. The move was made primarily to consolidate the Cookson sales and distribution departments; little change was expected in the operations at either company.

Because indium is primarily recovered from residues, slags, flue dusts, and intermediate compounds resulting from zinc smelting, world mine production is inferred from the average indium content of zinc ore mined. Canada is the largest producer of zinc in the world; therefore, its mine production is believed to contain the largest quantity of indium.

Historically, most of the world's refining capacity has been in Europe. However, recently, most capacity has increased in Asia and North America because new refineries have opened in Canada and Japan in the past several years.

Geology-Resources

Indium occurs predominantly in solid solution in sphalerite, an ore of zinc, but it has been reported in ores of copper, lead, and tin. It does not occur in the native state. The average indium content of the Earth's crust is estimated at 0.1 part per million, about the same as that of silver.[1] The indium content of mined zinc deposits ranges from 0 to 100 parts per million. The highest known indium concentrations are in vein, replacement, and contact metasomatic sulfide deposits, especially those containing tin minerals. The indium contents of these deposits typically range from 100 to 21,000 parts per million. Deposits of this type include those in the Central City district in Colorado, the Argentine Andes, the Cornwall tin district in England, and the Mount Pleasant tin deposit in New Brunswick, Canada.

Because indium is usually recovered as a byproduct of zinc, world indium reserves are based on weighted estimates of the average indium contents of regional zinc ores.

Technology

A variety of methods are employed to recover indium, depending on the source material and indium content. Indium is primarily recovered as a byproduct of zinc processing. Among the more common methods of recovery are leaching the indium-containing material with sulfuric or hydrochloric acid and extracting the crude indium from solution by cementation on aluminum or zinc sheets. Solvent extraction with organic solutions is used to recover indium from dilute solutions. Another method involves the precipitation of indium phosphate selectively from slightly acidic solutions and conversion to oxide by leaching in a strong caustic soda solution, followed by reduction of the oxide to metal.

During the smelting of zinc, the indium concentrates in the zinc-lead bottom metal and is separated from that portion by chlorination under molten salt, forming an indium-rich slag. Indium is recovered from the slag by leaching and cementation on zinc or aluminum sheets. The indium deposits on the sheets as a low-density, sponge-like mass, which breaks away and floats to the surface of the solution. The indium sponge is washed, briquetted, melted, and cast into anodes for electrolytic refining.[2]

Byproducts and Coproducts

Indium is a minor byproduct of processing base metal ores or zinc residues. The value of recovered indium is negligible in relation to the value of zinc production. Coproducts include molybdenum, silver, tin, and tungsten.

Substitutes

In solder and fusible alloys, bismuth can substitute for indium, but only for certain applications because some bismuth-base solders are prone to brittleness. Hafnium can replace silver-indium-cadmium in nuclear control rods.

Economic Factors

Indium, which is classified under Harmonized Code 8112.91.3000 as unwrought, waste and scrap, and powders of indium, was imported free from most favored nations (MFN) and subject to a 25% ad valorem duty from non-MFN.

ANNUAL REVIEW

Legislation and Government Programs

The Defense Logistics Agency, which maintains the National Defense Stockpile, was authorized to procure 2,488 kilograms of indium in 1990, but delayed purchasing indium until a new stockpile acquisition plan is announced in 1991. The inventory on December 31, 1990, was zero, with a goal of 41,990 kilograms.

Consumption and Uses

Domestic consumption was estimated at 30,000 kilograms, a slight increase from that of 1989. The estimated usage pattern was as follows: solders and alloys, 40%; coatings, 35%; electronic and semiconductor uses, 15%; and research and other, 10%.

Indium was available in various forms, such as ingot, foil, shot, ribbon, wire, and powder. Standard-grade indium was generally used in solders, chemical compounds, plating solutions, and fusible alloys. High-purity indium was used for semiconductors, coatings, and solar cells.

Thin film coatings on glass, which included indium oxide and indium tin oxide (ITO), constituted 35% of total domestic indium usage in 1990. Coatings have been the largest area of growth for indium consumption in the past 5 years. Applications involving thin coatings on glass can be divided into two categories, electrically conductive and infrared reflecting. Electrically conductive coatings, the largest group, were used primarily in liquid crystal displays (LCD) for watches, television screens, portable computer screens, video monitors, and other related display devices.

Aircraft and locomotive windshields used a transparent, electrically conductive ITO film as a defroster or defogger. In this application, the electric current heats the film quickly to clear the glass. Indium coatings are more effective than other types of materials, but the use of indium was limited because of its higher cost and limited supply. Several automobile manufacturers have also experimented with indium, but because of the cost and availability factors, most have opted for a zinc-silver oxide coating for quick defrosting windshields. In a similar use, glass doors on commercial refrigerators and freezers are kept free of condensation and frost by a heated thin film of indium oxide.

Another group of films includes visually transparent infrared reflecting coatings on window glass used to control energy losses by reflecting heat inward in winter and outward in summer. For residential windows, the coating is usually applied to a plastic sheet and encased between two panes of glass. This prevents erosion of the coating and reduces the cost of production. Because the expense of refitting a commercial building remains high, other less expensive metals, such as silver, were used as a replacement for indium coatings on commercial windows.

A major use of indium in Europe, and a growing application in the United States, was in the manufacturing of low-pressure sodium vapor street lamps. An indium oxide coating was used on the inside surface of the outer glass cover of the lamp. The indium oxide acts as an infrared reflector, which allows the bulb to operate at a high temperature for improved efficiency. These lights can be recognized by their pink-orange tint.

Electroluminescent (E-L) lamps are thin, flat, flexible light sources used to backlight LCD screens, display panels, and switches for military and civilian applications. An E-L lamp consists of a layer of light-emitting phosphor material on an aluminum foil substrate. A transparent film of ITO, which acts as an electrode, is placed on the phosphor. E-L lighting can penetrate fog, smoke, and haze, making these lights essential in military and commercial aircraft. Tactical military aircraft used E-L lamps for instrument panels and marker lights, and commercial planes used the lamps primarily in safety lighting for aisles and doors.

High-purity indium was an important element for semiconductor materials. Indium phosphide (InP) has become the leading substrate material for optical integrated circuits, fiber optics, laser diodes, optical computers, and signal processing. Indium antimonide and indium arsenide were used in infrared detectors for missile-guidance systems, night-vision instruments, and medical devices.

The use of indium in solar cells has grown during the past several years. Copper-indium-diselenide (CIS) and InP were used to produce cells with some of the highest energy conversion ratios. CIS cells have attained ratios close to 15% for small cells and about 10% for large panels. For the cells to be economically viable, the cost must drop from the current cost of $240 per square meter to $50 per square meter, and the cells must have at least a 30-year lifespan. Gallium can be added to CIS cells to increase the efficiency rating, but it raises the cost of production.

InP cells were used primarily in applications related to space exploration because its resistance to solar radiation is greater than that of gallium arsenide or silicon. An energy conversion factor of 19.1% was achieved in a simulated space environment with an InP cell in 1990.[3] The Japan Space Agency used InP solar cells on the lunar orbiter that it launched in 1990.

A major domestic use for indium has been as an addition to bismuth, cadmium, lead, or tin alloys to lower the melting point. These alloys can be used in

such applications as electrical fuses, fusible links, or as holding material for the grinding of optical glass. Pure indium and several indium alloys will wet glass and were used for glass-to-metal and glass-to-glass seals.

Indium was used as a strengthening agent for lead solder and as the base material for a variety of low-melting-temperature solders. Many indium-base solders have a melting point below 183° C, the melting point of conventional 63% Sn-37% Pb solder used in electronic applications. This makes indium solder useful for components that would be damaged by a high soldering temperature. Indium-base alloys also remain flexible over a greater temperature range than tin-lead solder. Indium solders reduce the possibility of gold scavenging, a problem that occurs when tin-lead solder is used to join gold components. The solder will gradually leach gold from the contact surface, thus weakening or damaging the soldering joint. The Department of Defense approved the use of indium-base solders for certain military equipment in 1990.

Several manufacturers of pressurized water reactors used an alloy consisting of 80% silver, 15% indium, and 5% cadmium for nuclear control rods. The manufacture of these rods declined in the United States in the early 1970's when orders for new nuclear powerplants began to drop. Following the Three Mile Island nuclear accident in 1979, all orders for new nuclear powerplants in the United States ceased, and subsequent consumption has been only for replacement rods, which must be changed every 15 years.

Minor uses of indium included indium-palladium and indium-gold alloys in dentistry, use as a surface lubricant for abrasive compounds, and as an additive to lubricating oil to prevent corrosion. Certain radiation-detection badges used indium foil because low-energy neutrons easily induce radioactivity in indium.

Markets and Prices

Indium demand and production both increased slightly from 1989, and as a result, producers held the price steady. The price of standard-grade, 99.97%-purity indium in the United States gradually decreased from $251 per kilogram ($7.80 per troy ounce) in January to $225 per kilogram ($7.00 per troy ounce) in April, where it remained until the end of the year.

Foreign Trade

The United Kingdom, France, and Belgium were the largest suppliers of indium to the United States in 1990. Data on U.S. exports of indium were not available.

World Review

World refinery production in 1990 was about 118 metric tons. Belgium, Canada, France, Italy, and Japan were the largest producers. World consumption was about 110 tons. Japan and the United States were the largest consumers.

Canada.—Johnson Matthey PLC, United Kingdom, closed its Trail, British Columbia, high-purity metals plant in December. The closing was part of a company restructuring plan. The high-purity metals production was moved to the firm's plants in Spokane, WA, and Vancouver, British Columbia. Johnson Matthey produced high-purity germanium, indium, and other metals in 1990.

Falconbridge Ltd. began production of indium at the Kidd Creek Mine at Timmons, Ontario, in November 1990. The indium was recovered from waste material from the copper-zinc mining operation. The plant had a refinery production capacity of 30 tons per year, but the output was to be adjusted to market conditions. Indium Corp. was to be the sole marketing agent for all indium produced at Kidd Creek. Indium Corp. also planned to upgrade some 99.99% indium from Kidd Creek to 99.999% (5N) and above purity at its Utica, NY, facility.

Canada now has the largest refinery production capacity for indium in the world. Cominco Ltd., which produced indium at Trail, British Columbia, and Falconbridge Ltd., each have the ability to recover up to 30 tons per year.

Japan.—Japan was the largest producer of refined indium in 1990. It produced 48 tons, but only about 25 to 30 tons was estimated to have been derived from Japanese ores. The remainder was derived from upgrading indium-bearing material imported mainly from China and Europe. The leading uses of indium in Japan were for transparent,

TABLE 1

MAJOR WORLD INDIUM PRODUCERS IN 1990

Country	Company
Belgium	Metallurgie Hoboken-Overpelt.
Canada	Cominco Ltd. Falconbridge Ltd. and Indium Corp. of America (joint venture).
China	Several Government metallurgical plants.
France	Metaleurop S.A.
Germany, Federal Republic of	Do.
Italy	Do.
Japan	Nippon Mining Co. Ltd.
Netherlands	Billiton Metaalundustrie NV.
Peru	Empresa Minera del Centro del Peru S.A. (Centromin Peru).
U.S.S.R.	Several Government metallurgical plants.
United Kingdom	Capper Pass Ltd. Mining and Chemical Products Ltd.

TABLE 2

U.S. IMPORTS FOR CONSUMPTION OF INDIUM,[1] BY CLASS AND COUNTRY

Class and country	1988		1989[2]		1990	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Unwrought and waste and scrap:						
Belgium	8,957	$2,855	6,035	$2,544	5,470	$1,146
Bulgaria	17	76	—	—	—	—
Canada	1,685	619	357	105	3,398	788
China	3,378	542	2,444	629	3,390	734
France	4,729	1,576	4,629	1,324	5,675	1,080
Germany, Federal Republic of	439	111	2,931	485	110	33
Hong Kong	—	—	44	12	—	—
Italy	7,490	2,553	2,150	604	3,347	717
Japan	351	416	659	500	380	197
Netherlands	1,771	182	1,109	313	299	80
Peru	1,698	487	914	492	1,927	392
U.S.S.R.	—	—	529	135	—	—
United Kingdom	6,460	3,452	5,012	1,801	6,162	1,387
Total	36,975	[3]12,870	26,813	8,944	30,158	[3]6,555
Wrought:						
China	3	11	—	—	—	—
Japan	79	34	—	—	—	—
United Kingdom	171	401	—	—	—	—
Other	822	69	—	—	—	—
Total	1,075	[3]516	NA	NA	NA	NA

NA Not available.
[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 and 1990 are not necessarily comparable with those in 1988.
[2]Beginning in 1989, only data for unwrought and waste and scrap are available.
[3]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 3

ESTIMATED WORLD INDIUM REFINERY PRODUCTION AND CAPACITY, 1990

(Metric tons)

	Production	Capacity
North America:		
Canada	15	60
United States	NA	30
Total[1]	15	90
South America:		
Peru	4	6
Europe:		
Belgium	18	25
France	18	20
Germany, Federal Republic of	2	10
Italy	9	12
Netherlands	1	3
U.S.S.R.	5	15
United Kingdom	6	6
Total	59	91
Asia:		
China	13	15
Japan	27	50
Total	40	65
World total[1]	118	252

NA Not available.
[1]Excludes U.S. production.

electrically conductive coatings on glass, E-L lamps, and semiconductors.

Current Research

A lead-indium glass was developed at the Oak Ridge National Laboratory for use in optical mirrors, lenses, prisms, windows, and optical fibers. The glass melts at a low temperature, allowing it to be cast into complex shapes, thus reducing the amount of grinding and polishing required. The high lead content makes the glass resistant to gamma radiation, making it suitable for use in nuclear applications.[4]

OUTLOOK

World reserves and increases in production capacity are sufficient to meet expected demand for indium through the year 2000. Consumption of indium is expected to increase gradually in this period, especially for LCD's, semiconductor materials, and in low-temperature solder for military and commercial electronics. Other uses, such as nuclear control rods, which have a lifespan of 15 years, and fusible alloys should remain steady.

[1]Hurlbut, C. S., Jr., and C. Klein. Manual of Mineralogy. Wiley, 19th ed., 1977, pp. 123-124.
[2]Stevens, L. G., and C. E. T. White. Indium and Bismuth. Ch. in Metals Handbook, ASM Int. 10th ed., v. 2, 1990, p. 750.
[3]Lasers & Optronics. Record Efficiency for Space Solar Cell. V. 9, No. 12, p. 12.
[4]Photonics Spectra. Cast-Glass Optics Minimize Grinding. V. 24, No. 6, June 1990, p. 68.

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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 12 years. Domestic survey data were prepared by Blanche Hughes, mineral data assistant; and international data tables were prepared by William L. Zajac, Chief, Section of International Minerals.

Three producers of crude iodine supplied approximately one-half 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 table 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 in 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 to 1,200 ppm. In Woodward County, OK, the iodine occurs in the Morrowan Formation of Pennsylvania age.

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 the Japan and United States, iodine is removed from brines by processes that separate the brines from any associated hydrocarbons. In the blowing-out process, brine is acidified and iodine is liberated by reducing the pH to about 3. A countercurrent stream of air transports the liberated iodine to a second tower in which the iodine is absorbed by a solution of hydriodic acid. The iodine settles, is filtered, and melted under concentrated acid. Brine stripped of iodine is treated and then reinjected into its subsurface formation of origin.

In the absorption process, brine is passed through an absorber and the waste brine is neutralized and sent to a disposal well. The absorbent laden with iodine is treated with an alkaline solution to regenerate the absorbent and eluted 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. Absorbents 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.[1]

Economic Factors

Prices.—In the past, changes in the official price of crude iodine have been initiated during shortages. Because iodine cannot be substituted in radiopaque, animal feeds, catalysts, and stabilizers readily, shortages tend to cause the accumulation of inventories to ensure an adequate supply. An adequate supply tends to lower and stabilize the price.

Costs.—Electrical costs for maintaining the pumps to bring the brine to the surface, for air-blowing the iodine, and for reinjecting the brine are major components of maintenance costs. Capital costs have been estimated at $20 per pound of annual iodine production. These costs include high-quality stainless steels because iodine is highly corrosive. In addition, the brine must be leased from private landowners over large acreage for many years. The principal material cost is for chlorine because 1 pound is required for every 1.4 to 1.8 pounds of iodine produced.

Tariffs.—Crude and resublimed iodine enter the United States duty free. Calcium and cuprous iodine has a 25% ad valorem for non-most-favored-nation status. Potassium iodide has a 2.8% ad valorem for most-favored-nation status and 7.5% ad valorem for non-most-favored-nation status.

Depletion Provisions.—The domestic and foreign depletion allowances for mined iodine are 14% of gross income, and they may not exceed 50% of net income without the depletion deduction. The domestic and foreign depletion allowances for minerals from brine wells are 5%.

Operating Factors

Environmental Requirements.—The reinjection of waste brine is a limiting factor to the production of iodine. During 1982, the Environmental Protection Agency (EPA) 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 prior or shortly after exposure of radioactive iodine can block the intake of radiation to the thyroid. The dosage must be repeated if exposure continues. Replenishing the thyroid with KI prevents the thyroid from using radioactive I^{131} for normal metabolic needs.

TABLE 1

TIME-PRICE RELATIONSHIPS FOR CRUDE IODINE

Year	Average annual c.i.f. value, dollars per pound		Average annual c.i.f. value, dollars per kilogram	
	Actual price	Based on constant 1990 dollars	Actual price	Based on constant 1990 dollars
1970	$1.15	$3.60	$5.59	$17.50
1971	1.58	4.68	3.48	10.32
1972	1.64	4.64	3.62	10.22
1973	1.72	4.57	3.79	10.07
1974	1.86	4.53	4.10	9.99
1975	2.21	4.90	4.87	10.80
1976	2.13	4.44	4.70	9.79
1977	1.05	2.05	2.31	4.52
1978	2.21	4.03	4.87	8.87
1979	3.37	5.64	7.43	12.43
1980	4.72	7.24	10.41	15.97
1981	6.03	8.44	13.29	18.60
1982	5.97	7.85	13.16	17.31
1983	5.57	7.05	12.28	15.54
1984	4.90	5.98	10.80	13.19
1985	5.38	6.38	11.86	14.06
1986	5.68	6.56	12.52	14.47
1987	6.92	7.75	15.26	17.09
1988	7.92	8.59	17.46	18.93
1989	7.70	8.02	16.98	17.67
1990	6.26	6.26	13.80	13.80

Source: Bureau of the Census.

ANNUAL REVIEW

Legislation and Government Programs

The June 21 Federal Register announced an ad hoc meeting of experts in the field of nuclear medicine and potassium iodide issues to solicit relevant scientific and medical information. The meeting was sponsored by the Center for Environmental Health and Injury Control of the Centers for Disease Control, U.S. Department of Health and Human Services.

The State of Oklahoma passed a bill to empower the Oklahoma Corp. Commission (OCC) to regulate individuals or companies that produce iodine from underground saltwater. Oklahoma is the only state where iodine is produced. The bill is expected to simplify the producers' obligations by requiring OCC approval for all iodine production. The courts have held that brine in the ground belongs to the surface owner, while associated natural gas belongs to the mineral owner. The bill puts natural gas produced with iodine-bearing brine water in a high-priority production classification.

Strategic Considerations

The National Defense Stockpile contained 6.1 million pounds of crude iodine. The stockpile goal remained at 2.6 million kilograms (kg) (5.8 million pounds). The Defense Logistics Agency of the U.S. Department of Defense disposed of 5,000 kg of excess material during fiscal year 1990.

Production

IoChem Corp., 2 miles east of Vici, Dewey County, OK, produced iodine by the blowing-out process. The majority of production was shipped to Schering AG, Federal Republic of Germany, under a long-term contract. IoChem was reported to have nine production wells and four injection wells with a total production capacity of 1,200 kilograms. North American Brine Resources operated miniplants at Dover in Kingfisher County, OK. The plant is at an oilfield reinjection disposal site. Iodine concentrations ranged up to 1,200 ppm. The company also operated a plant at the border of Woodward and Harper Counties. Woodward Iodine Corp., a subsidiary of Asahi Glass Co. of Japan, operated a plant in Woodward County that produced iodine from brines using the blowing-out process.

Consumption and Uses

Iodine was used primarily in animal feed supplements, catalysts, inks and colorants, pharmaceutics, photographic equipment, sanitary and industrial disinfectants, stabilizers, and radiopaque medium. Other smaller uses included production of batteries, high-purity metals, motor fuels, iodized salt, and lubricants.

The lithium-iodine battery was the first commercially successful lithium battery and is unusual because of its in situ growth of electrolytes. Superior charge transfer is achieved using an iodine compound with powdered iodine. Layers of lithium iodide act as both electrolyte and separator and are self-sealing in the event of a crack. Thus, the batteries are intrinsically reliable and withstand abuse.[2]

TABLE 2

U.S. CONSUMPTION OF CRUDE IODINE, BY PRODUCT

Product	1989		1990	
	Number of plants	Consumption (thousand kilograms)	Number of plants	Consumption (thousand kilograms)
Reported consumption:				
Resublimed iodine	7	143	7	143
Hydriodic acid	3	49	2	W
Calcium iodate	(1)	(1)	(1)	(1)
Calcium iodide	3	119	3	110
Cuprous iodide	3	15	3	17
Potassium iodide	6	829	5	627
Potassium iodate	5	56	4	62
Sodium iodide	4	46	4	81
Other inorganic compounds	14	821	15	1,133
Ethylenediamine dihydroiodide	4	398	4	433
Other organic compounds	8	426	8	448
Total	[2]31	2,902	[2]30	3,054
Apparent consumption	XX	4.8	XX	5.3

W Withheld to avoid disclosing individual 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.

Prices

The average declared c.i.f. value for imported crude iodine was $15.19 per kg ($6.90 per pound). The average declared c.i.f. value for imported crude iodine from Japan averaged $14.90 per kg ($6.76 per pound). The average declared c.i.f. value for iodine imported from Chile was $15.51 per kg ($7.04 per pound).

Quoted yearend U.S. prices for iodine and its primary compounds are shown in 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. During 1989 and 1990, exports to Santa Domingo were incorrectly placed into the iodine category. A test of correct reporting is to calculate price per kilogram and compare this value with the prices shown above. Values that differ significaly could be a result of being placed in the wrong category.

World Review

Capacity.—The data in table 4 are rated capacity for plants as of December 31, 1990. Mine capacity for iodine is based on rated capacity as reported by the company, another government agency, or another published source.

Chile.—Sociedad Química y Minera de Chile (SOQUIMICH) was the largest producer of iodine in Chile. The María Elena and Pedro de Valdivia plants

TABLE 3

YEAREND 1990 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
Eythlenediamine dihydriodide	16.64- 20.39	7.55- 9.25
Hydrodic acid, f.o.b. works	18.19- 19.95	8.25- 9.05
Iodine, crude, drums	13.00- 14.00	5.89- 6.34
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. 238, No. 27, Dec. 31, 1990, pp. 36-38.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF CRUDE IODINE, BY TYPE AND COUNTRY

(Thousand kilograms and thousand dollars)

Country	1989		1990	
	Quantity	Value[1]	Quantity	Value[1]
Iodine, crude:				
Belgium	30	545	—	—
Canada	(2)	9	—	—
Chile	1,014	18,298	1,321	18,598
Germany, Federal Republic of	(2)	1	—	—
Japan	2,251	39,751	(2)	53
Mexico	13	178	1,798	24,295
Sweden	(2)	13	20	307
United Kingdom	—	—	(2)	2
Total[3]	3,309	58,795	3,139	43,256
Iodide, potassium:				
Germany, Federal Republic of	1	28	(2)	4
India	7	121	17	215
Italy	9	31	9	23
Japan	—	—	1	18
United Kingdom	(2)	5	2	37
Total	17	185	29	297
Grand total[3]	3,326	58,980	3,168	43,553

[1]Declared c.i.f. valuation.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 5

WORLD IODINE ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1990, RATED CAPACITY[2]

(Thousand kilograms)

Country	Capacity
North America: United States	1,200
South America: Chile	3,800
Europe: U.S.S.R.	2,000
Asia:	
China	500
Indonesia	4
Japan	7,000
Total	7,600
World total	[3]15,000

[1]Actual capacity limited by brine supply.
[2]Includes capacity at operating plants as well as at plants on stand-by basis.
[3]Data do not add to total shown because of independent rounding.

produced iodine, sodium nitrate, potassium nitrate, and sodium sulfate. SOQUIMICH continued to operate a plant at Puelma. Installed capacity was reported at 6,000 tons per year.

SOQUIMICH had a joint venture with Israel Chemicals Ltd. named Compania Quimica Internacional de Desarrollo (IDC Co.). In March, Israeli Chemicals of Israel purchased 10.5% of SOQUIMICH's shares valued at $30 million from the Bankers Trust New York Corp. of the United States.[3]

Other companies active in iodine production were Amsterdam Chemical Pharmaceutical Minera (ACF Minera), a joint venture of the Sociedad Contractual Minera Lagunas and the Amsterdam Pharmaceutical Co. of the Netherlands. ACF Minera operated a plant using nitrate tailings as the iodine source.

Also actively producing iodine from nitrate tailings was Compania de Salitre y Yodo de Chile (Cosayach), a subsidiary of Cia. Minera del Norte. Cosayach inaugurated a plant in November. A feasibility study completed by Davy McKee Worldwide Corp. established that the Yolanda nitrate and iodine project near Taltal was both financially viable and technically feasible. The study suggests an annual output of 1,360 metric tons of iodine and 250,000 metric tons of potassium nitrate. Recoverable resources are

reported at 40,500 tons of iodine. North Lily Mining is operator of the company and will receive a 10% net profit interest. Kap Resources, the owner of the property, merged with its joint-venture partner Atacama Resources.[4] A second location was being studied at Yumbes Pampa south of the Yolanda site.

In May, Chile Hunt Oil Co. reported the discovery of gas in the Salar de Atacama at a depth of 4,500 meters. The availability of gas for the generation of low-cost electric power could increase the economic viability of other projects in the region.[5]

Indonesia.—The only producer of crude iodine was the state-owned pharmaceutical firm, P. T. Kimia Farma, that operated a plant at Watudakon near Mojokerto, East Java.

Japan.—Production of iodine was from underground brines associated with natural gas. Japan was the world's leading producer of iodine in 1989. Six companies operated 17 plants with a total production capacity of 9 million kilograms per year.

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 has remained stable.

TABLE 6

CRUDE IODINE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Chile	3,076	[r]3,181	3,967	[re]3,845	5,029
China[e]	500	500	500	500	500
Indonesia	6	8	10	14	15
Japan	7,389	7,014	7,451	7,592	7,500
U.S.S.R.[r]	2,000	2,000	2,000	2,000	2,000
United States	W	W	998	1,508	[3]1,973
Total	[4]12,971	[r4]12,703	14,926	15,459	17,017

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Table includes data available through May 31, 1991.
[2]In addition to the countries listed, New Zealand also produces elemental iodine, but data are not available and available information is inadequate for formulation of reliable estimates of output levels.
[3]Reported figure.
[4]Excludes U.S. production.

[1]Rosene, M. R. Silver Removal With Halogen Impregnated Non-carbon Adsorbents. U.S. Pat. 4,396,585, Aug. 2, 1983.

[2]Hunt, M. Beat the Drums Faster. Materials Eng., v. 107, No. 7, 1990, pp. 31–35.

[3]U.S. Embassy, Santiago, Chile. Israel's Growing Investment in Chile's Mining Sector. State Dep. Telegram 2612, Mar. 30, 1990, 4 pp.

[4]Mining Journal (London). Yolanda Debate. V. 315, No. 8102, 1990, p. 472.

[5]U.S. Embassy, Santiago, Chile. Chile-Hunt Oil Company Finds Gas in the Salar de Atacama. State Dep. Telegram 3439, May 3, 1990, 2 pp.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Mineral Facts and Problems.
Iodine. Ch. in Minerals Yearbook, annual.

IRON ORE

By Peter H. Kuck

Dr. Kuck has been the commodity specialist for iron ore since 1986 and was previously responsible for vanadium and silicon. The domestic survey data were compiled and analyzed by Sarah P. Guerrino, Chief of the Ferrous Data Section (now retired), and Henry F. Sattlethight, management analyst. The world production table was prepared by William L. Zajac, Chief, International Data Section.

World demand for iron ore has continued to grow over the long term. In 1990, the iron content of the ore produced throughout the world was estimated to be 543 million metric tons (Mmt) compared with 521 Mmt in 1975 at the end of the Vietnam conflict. An estimated 98% of the ore shipped in the world is used for the manufacture of iron and steel. The remaining 2% is used in the manufacture of cement, heavy-medium materials, pigments, ballast, agricultural products, or specialty chemicals. As a result, demand for iron ore is tied directly to the production of raw steel and the availability of high-quality ferrous scrap. Although world iron ore production slipped slightly in 1990 from the record high of 1989 because of adverse events in the U.S.S.R., North America, and Liberia, production is expected to reach new highs in the near future because of escalating demand for steel in the developing and newly industrialized countries.

The majority of U.S. iron ore producers had a relatively good year in 1990, defying pessimistic forecasts made by some industry analysts in 1989. The United States produced 56.41 Mmt of usable ore. Although the tonnage was slightly less than that of 1989, significant progress was made in improving pellet quality. Pellets constituted 97% of the total figure, the remainder being a near-equal mix of concentrates and direct-shipping ore. The pellets were made from low-grade Precambrian ores mined in Michigan, Minnesota, and Missouri. The bulk of the direct-shipping ore was produced in California and Utah for local consumption. Mine shipments of pellets, concentrates, and direct-shipping ore totaled 57.01 Mmt, again an amount only slightly lower than that of 1989. Michigan production was down 39% from that of 1989 because of a 4-month labor dispute, but the slack was picked up by mines in Minnesota. Cyprus Northshore Mining Corp. overcame a number of refurbishing obstacles at the beginning of 1990 and shipped 2.23 Mmt of pellets during the 1990-91 navigation season. Competition within the U.S. iron ore industry intensified because of the startup of Cyprus Northshore and the ongoing drive by domestic steel producers to cut their raw material costs and other production expenses.

Competition between U.S. and Canadian mines also stiffened because of (1) strikes against two integrated steel companies in Canada and (2) the impending shutdown of older ironmaking operations in eastern Pennsylvania. Steelworks in eastern Pennsylvania and Maryland purchased more than 2 Mmt of Canadian pellets in 1990. The Canadian strikes, which disrupted operations at The Algoma Steel Corp. Ltd. and Stelco Inc., began at the same time as the one in Michigan, but were settled 1 month earlier. U.S. exports of ore and agglomerates dropped 40% because of the Canadian strikes. As in past years, most of the 3.20 Mmt exported went to Algoma and Stelco, which hold equities in U.S. taconite projects.

The iron and steel industry accounts for 99% of the iron ore and agglomerates consumed in the United States. Published prices for Lake Superior pellets do not necessarily reflect the existing supply-demand situation because domestic steel companies directly control 77% of mine production. Canadian steel companies control an additional 7%. Changes in the level of blast furnace production are almost immediately transmitted back up the supply line to the mines.

Consumption of ore and agglomerates by the domestic iron and steel industry rose slightly between 1989 and 1990 to 73.69 Mmt. Combined U.S. imports of ore, concentrates, and agglomerates decreased 8% to 18.05 Mmt, with Canada regaining market share at the expense of Brazil and Venezuela. There were no imports from Liberia for the first time since 1950 because of the civil war in that country. Domestic hot-metal and pig iron production was 49.67 Mmt, 2% less than that of 1989. A total of 60.51 Mmt of pellets was consumed—an amount only slightly lower on a gross weight basis than that of 1 year ago.

Pellet consumption did not drop as much as hot-metal production. The slight discrepancy is explained in part by the growing use of fluxed pellets in the United States and their substitution for sinter. Fluxed pellets contain 3% to 9% less iron than traditional standard pellets, but significantly more calcium and magnesium. As a result, a greater tonnage of the fluxed variety is needed to produce a given amount of hot metal. Fluxed pellets accounted for 39% of domestic mine shipments in 1990. Fluxed or partially fluxed pellets were routinely being made at 6 of the Nation's 10 active taconite plants. The new pellets are in demand because they improve blast furnace productivity by decreasing smelting time. The decrease in smelting time can reduce coke consumption significantly. Besides lowering coke costs, the shorter smelting time also reduces wear on the blast furnace lining, cutting refractory replacement costs.

Ore consumption was relatively stable until the fourth quarter of the year, when concerns of an impending recession and the deteriorating situation in the Persian Gulf region caused consumer confidence to drop off and sales of products incorporating steel to weaken. Because of these signs of slowing demand, blast furnace operators cut back hot-metal production more than normal during the yearend holiday season. On December 31, 46 blast furnaces were in operation, 2 fewer than at the end of 1989. Monthly output of hot metal averaged 4.14 Mmt during 1990.

Ore consumption for all of 1990 was slightly higher than that of the previous year for two reasons. First, domestic raw steel production did not collapse as some

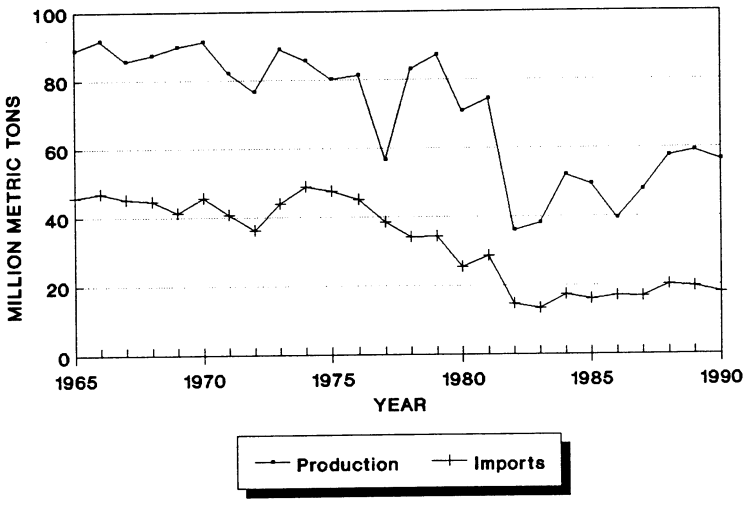
industry analysts had forecasted in 1989. Raw steel production, which had been relatively stable since March, slackened in early December. However, the December downturn was not large enough to offset earlier gains made in the spring. Second, blast furnaces at integrated mills were able to compete with electric arc furnace operations because of (1) improvements in hot-metal practices and (2) growing demand for higher quality steels free of tramp elements.

Wheeling-Pittsburgh Steel Corp. and Sharon Steel Corp., two steel companies, which had filed for protection under chapter 11 of the Federal Bankruptcy Code during the turbulent 1980's, emerged from court protection. A third, LTV Corp., was in the final stages of being reorganized. A number of claims involving joint mining ventures were settled in conjunction with the chapter 11 reorganizations. The settlement of these claims and other court-approved actions removed the cloud of uncertainty hanging over four North American mines and allowed their mine managers to resume long-range planning.

In late November, Cleveland-Cliffs Inc. (CCI) and the United Steelworkers of America (USWA) finally agreed on a new labor contract that runs for 31 months. The 1,800 union members at the Empire and Tilden Mines began returning to work on December 1. The two mines had been shut down since August 1 by a dispute over wages, pension rights, and cost-of-living escalators. According to some industry analysts, the 4-month-long dispute hurt both sides. Little was gained in the near term by the local membership in Michigan because the strike settlement came at the beginning of a major downturn in the iron and steel sector and was followed by temporary layoffs at the two mines. In early February 1991, the USWA negotiated a new 3-year labor contract with USX Corp., narrowly avoiding a second costly and damaging strike. In the summer of 1986, the entire USS segment of USX Corp. was shut down for 184 days. The 1986 shutdown was the longest work stoppage in the history of the domestic steel industry.

FIGURE 1

U.S. IRON ORE PRODUCTION AND IMPORTS FOR CONSUMPTION



DOMESTIC DATA COVERAGE

U.S. production data for iron ore are developed by the U.S. Bureau of Mines from two separate, voluntary surveys of domestic operations. The annual "Iron Ore" survey (1066-A) provides the basic data used in this report. Of 46 addressees to whom the 1066-A form was sent, 46 responded, representing 100% of total production shown in tables 1 through 4. In past years, production for nonrespondents to the annual survey was estimated from monthly surveys (1066-M), from railroad reports, or from reported production levels in prior years. This information may be supplemented by employment data, mine-inspection reports, and information from consumers.

Data on consumption and stocks of iron ore and agglomerates at iron and steel plants were provided by the American Iron Ore Association (AIOA). AIOA also provided data on ore shipments from loading docks on the upper Great Lakes as well as receipts at transfer docks and furnace yards nationwide. The dock and steel plant data were compiled jointly by AIOA and the American Iron and Steel Institute (AISI). Data on consumption of iron ore for non-steel end uses were compiled from information gathered from other Bureau surveys.

BACKGROUND

Industry Structure

History.—The history of iron mining in early America has already been reviewed in several other publications of the U.S. Bureau of Mines and its predecessor.[1] For additional information on the economic history of the entire U.S. iron and steel sector, the reader should refer to the comprehensive works of Father Hogan of Fordham University.[2]

The history of the iron ore industry as it currently exists began in 1844 with the discovery of "hard" magnetite-hematite ores on the Marquette Range of Michigan and the subsequent founding of the Jackson Mining Co.[3] At first, lack of transportation facilities prevented rapid development. However, completion of a shipping canal at Sault Ste. Marie in 1855 opened the way for further development of mining in the Lake Superior region. By 1885, ore had been discovered in the Gogebic and Menominee Ranges of Michigan and Wisconsin, and annual production of ore had climbed to more than 2 Mmt, 20 times the volume in 1860. The high grade of these ores, combined with the low cost of water transportation, made them increasingly competitive at Eastern furnaces and forced many small mines in New York, Tennessee, and the Mid-Atlantic States to close. This trend was accelerated in the 1880's by production from the Vermilion Range and the discovery of the great Mesabi ore bodies in the 1890's. By the

turn of the century, most of the Eastern mines had closed. In Alabama, production of iron ore increased nearly tenfold between 1880 and 1890, and Birmingham was established as a major ironmaking center. During this period, many steel companies acquired iron ore properties in the Lake Superior District, and the production of many smaller mines was consolidated by the formation of large mining companies. The mergers that took place in the steel industry between 1893 and 1905 basically organized the iron ore industry into the structure that exists today.

Hundreds of mines closed during the 1950's following the depletion of higher grade ores, rapidly rising imports, and the subsequent growth of the taconite industry in the Lake Superior District. By 1981, 15 mines accounted for 90% of the Nation's production of iron ore. By 1986, the 15 mines had been reduced to 10 because of increasing imports of steel and 2 deep recessions from which the iron ore and steel industries have not yet fully recovered.

Size and Organization.—In 1990, iron ore was produced by 20 companies operating 22 mines, 16 concentration plants, and 10 pelletizing plants. The mines included 21 open pits and 1 underground operation. However, only 10 mines accounted for 98% of the output. Virtually all ore was concentrated before shipment, and about 97% was pelletized. Most of the ore was produced by, or for the account of, nine U.S. companies and two Canadian companies engaged in production of iron and steel. Domestic steel companies directly controlled about 77% of production; Canadian steel companies, about 7% of production. Consumption of iron ore and agglomerates was distributed approximately as follows: blast furnaces, 97.9%; direct-reduction plant, 0.7%; steel furnaces, 0.2%; and manufacture of cement, heavy-medium materials, and other products, 1.2%.

During the 1980's, a quasi-symbiotic relationship existed between several iron ore operations in Canada and the United States because of ownership ties. In 1982, U.S. companies owned about 70% of Canadian production capacity for iron ore and held significant minority interests in iron ore mines in Australia, Brazil, Liberia, and New Zealand. Since then, Japanese interests have acquired part of the Canadian and overseas holdings previously owned by companies in the U.S. iron and steel sector.

The iron ore industry of the United States and Canada 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. Ownership shares and installed production capacity of United States and Canadian producers of iron ore in 1991 are shown in figure 2. This diagram, when compared with the one previously published by the Bureau for 1984,[4] illustrates how pervasive the restructuring has been since then.

The breadth and intensity of the restructuring is illustrated by USX Corp., the largest steel producer in the United States. The existing company was formed in 1986 after U.S. Steel Corp. acquired the Texas Oil and Gas Corp. USX is now a diversified company with interests in energy, steel, mineral resources, real estate, and engineering services. Its energy segment includes the Marathon Oil Co. in addition to Texas Oil and Gas Corp. U.S. Steel paid $6.5 billion for Marathon in 1982. The former U.S. Steel Corp. had been a leader in domestic steelmaking and iron ore mining for about 85 years prior to the 1986 restructuring.

USX owns and operates the Minntac Mine at Mountain Iron, MN. Minntac is the largest iron mine in the United States and supplies fluxed pellets to USX's blast furnaces at Gary, IN, and Dravosburg, PA. In 1990, pellets were also shipped to Geneva Steel at Provo, UT; the USS-Kobe Steel Co. joint venture at Lorain, OH; and the Weirton Steel Corp. at Weirton, WV.

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 sale of QCM was a somewhat complicated affair. 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%).

At the beginning of 1991, USX announced plans to divide its common stock into separate steel and energy issues. The company's U.S. Diversified Group (real estate, engineering services, timber, and certain coal interests) was to be included with the steel group. Stockholders approved the stock restructuring proposal at their annual meeting on May 6, 1991. Approval of the May stock proposal facilitates further restructuring of the corporation and requires the steel group to fund capital expenditures from its own internally generated cash-flow. It is not known at this time what effect the stock separation and accompanying corporate changes will have on the Minntac operation.

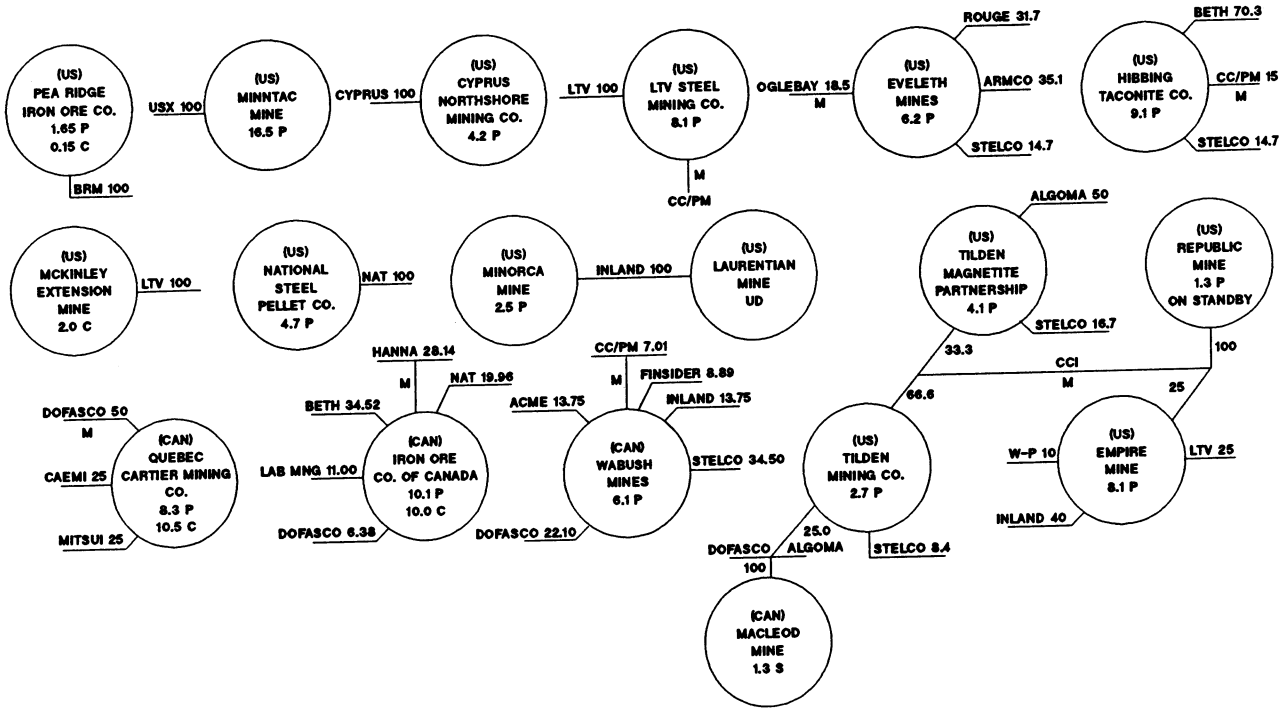
Recent technological advances have affected not only day-to-day operations, but also the structure of the industry. An increasing number of integrated steelworks in North America are using fluxed pellets. This newer, more easily reducible type of pellet is created by adding limestone ($CaCO_3$) and/or dolomite [$(Ca,Mg)CO_3$] 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 39% of total U.S. production in 1990. Idle capacity was brought on-stream at three mining complexes on the Mesabi Range during 1989 to meet increased pellet demand. The idled complex of the Reserve Mining Co. at Silver Bay, MN, was renovated by Cyprus during the last quarter of 1989. Cyprus shipped a trial batch of fluxed pellets in April 1990.

Combined United States and Canadian production represented only about 11% of the world output of usable ore in 1989. At least 45 other countries mined crude ore during the year. The leading producer was the U.S.S.R., which accounted for about 25% of world output in terms of metal content, followed by Brazil with 19% and Australia with 12%. Trends in world mine production since 1986 are shown on a country basis in table 24. Major mines are listed individually in table 23.

In 1989, the U.S.S.R. produced 241.0 Mmt of direct-shipping ore and concentrate. A large part of the concentrate was consumed to make 68.7 Mmt of pellets. The bulk of the iron ore produced in Australia, Brazil, India, and the Republic of South Africa consisted of

FIGURE 2

PRODUCTION CAPACITY AND OWNERSHIP OF PRINCIPAL IRON MINES, UNITED STATES AND CANADA, 1991



ACME:	ACME STEEL CO.
ALGOMA:	ALGOMA STEEL CORP. LTD.
ARMCO:	ARMCO INC.
BETH:	BETHLEHEM STEEL CORP.
BRM:	BIG RIVER MINERALS CO.
BSC:	BRITISH STEEL CORP.
CAEMI:	CIA. AUXILIAR DE EMPRESAS DE MINERACAO
CCI:	CLEVELAND-CLIFFS IRON CO.
CC\PM:	CLEVELAND-CLIFFS INC/PICKANDS MATHER
CYPRUS:	CYPRUS MINERALS CO.
DOFASCO:	DOFASCO INC.
FINSIDER:	FINANZIARIA SIDERURGICA S.P.A.
HANNA:	M.A. HANNA CO.
INLAND:	INLAND STEEL CO.
LAB MNG:	LABRADOR MINING & EXPLORATION CO. LTD.
LTV:	LTV STEEL CO. *
MITSUI:	MITSUI & CO. LTD.
NAT:	NATIONAL STEEL CORP.
OGLEBAY:	OGLEBAY NORTON CO.
ROUGE:	ROUGE STEEL CO.
STELCO:	STELCO INC.
USX:	USX CORP.
W-P:	WHEELING-PITTSBURGH STEEL CORP.

NUMBERS IN CIRCLES: INSTALLED PRODUCTION CAPACITY FOR IRON ORE PRODUCTS. MILLION METRIC TONS PER YEAR.
NUMBERS ON BARS: APPROXIMATE OWNERSHIP SHARE, IN PERCENT, OF INDICATED COMPANY.

P PELLETS C CONCENTRATES, UNAGGLOMERATED S SINTER UD UNDER DEVELOPMENT (US) UNITED STATES (CAN) CANADA M MANAGING CO.

*Successor to Jones & Laughlin Steel Corp. and Republic Steel Corp.

high-grade direct-shipping ore or products derived from much higher grade crude ores than those mined in the United States.

Geology-Resources

Iron is the fourth most abundant rock-forming element, comprising about 5% of the Earth's crust. Astrophysical and seismic evidence suggest that the element has also combined with nickel to make up the bulk of the Earth's core. A small part of the crustal iron has been concentrated by sedimentary, igneous, or metamorphic processes into deposits containing up to 70% of the element.

The largest concentrations of iron are found in banded sedimentary iron formations of Precambrian age. (See figure 3.) These formations currently supply most of the world's iron ore and constitute the bulk of the world's iron resources. Precambrian ores are mined extensively in Africa, Australia, Canada, China, India, South America, the United States, and the U.S.S.R. Individual banded iron formations (BIF's) can vary from 30 to 600 meters (m) in thickness. Some are relatively flat-lying, while others have been complexly folded by subsequent regional metamorphism. 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 carbonate, and contain 20% to 40% iron. These rocks comprise ores of the taconite type mined in Canada, China, Norway, the United States, and the U.S.S.R.

Locally, the BIF's have been concentrated by natural processes to form high-grade deposits of hematite or goethite by leaching of silica and oxidation of ferrous minerals. The high-grade ores are classed as residual or replacement deposits, depending on whether removal of silica was accompanied by introduction of additional iron oxide. The residual ores are usually earthy, porous, and contain 50% to 60% iron in their natural state. Examples are the soft ores of the Lake Superior District, the Schefferville District of Labrador, and the Krivoy Rog District of the Ukrainian S.S.R. Some soft ores appear to be merely decomposed bodies of BIF, containing 20% to 40% iron in the form of martite, hematite, or goethite. Examples of the latter are bodies of "wash ore" in the western Mesabi Range, which are highly siliceous but easily concentrated by gravity methods.

Replacement ores in the Precambrian BIF's are usually dense, massive, and contain 64% to 68% iron. Often, the ores retain banded structures of the original sedimentary rock. Examples are the hard ores of the Vermilion Range, MN; Steep Rock and Michipicoten Districts of Ontario; Minas Gerais, Brazil; Fort Gouraud, Mauritania; and Sishen, Republic of South Africa.

Another class of sedimentary iron deposits, of regional importance in the southeastern United States and Western Europe, is oolitic ironstone of Paleozoic to Cretaceous age. The formations are extensive laterally and contain 20% to 40% iron, but they differ from the Precambrian BIF's in several important respects. They are usually less than 15 m thick, and minable layers are commonly less than 6 m thick. The deposits rarely contain more than 48% iron, and most contain only 25% to 35% iron. The ore consists of very fine-grained hematite, quartz, chamosite,[5] and siderite in varying proportions; sometimes enough calcite is present to make self-fluxing ore. The ore is usually high in phosphorus and difficult to beneficiate. Oolitic ironstones were mined until recently in Alabama, Newfoundland, and the United Kingdom and are still mined extensively in France and to a lesser extent in central Europe. They are also mined in Egypt and comprise most of the iron resources of Pakistan.

A third type of sedimentary ore, consisting of siderite or limonite in flat-lying lenses up to 6 m thick, is mined in east Texas from the Weches Formation of Eocene age. The ore is associated with glauconitic sand and clay and contains up to 35% iron.

Massive deposits of magnetite, sometimes with hematite, thought to be of igneous origin, are important sources of iron ore in many parts of the world. These deposits can contain as much as 65% iron and are often rich in titanium and vanadium, as at Lake Sanford, NY. There are two principal types of these igneous deposits: magmatic segregations and 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 alternating seams 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.

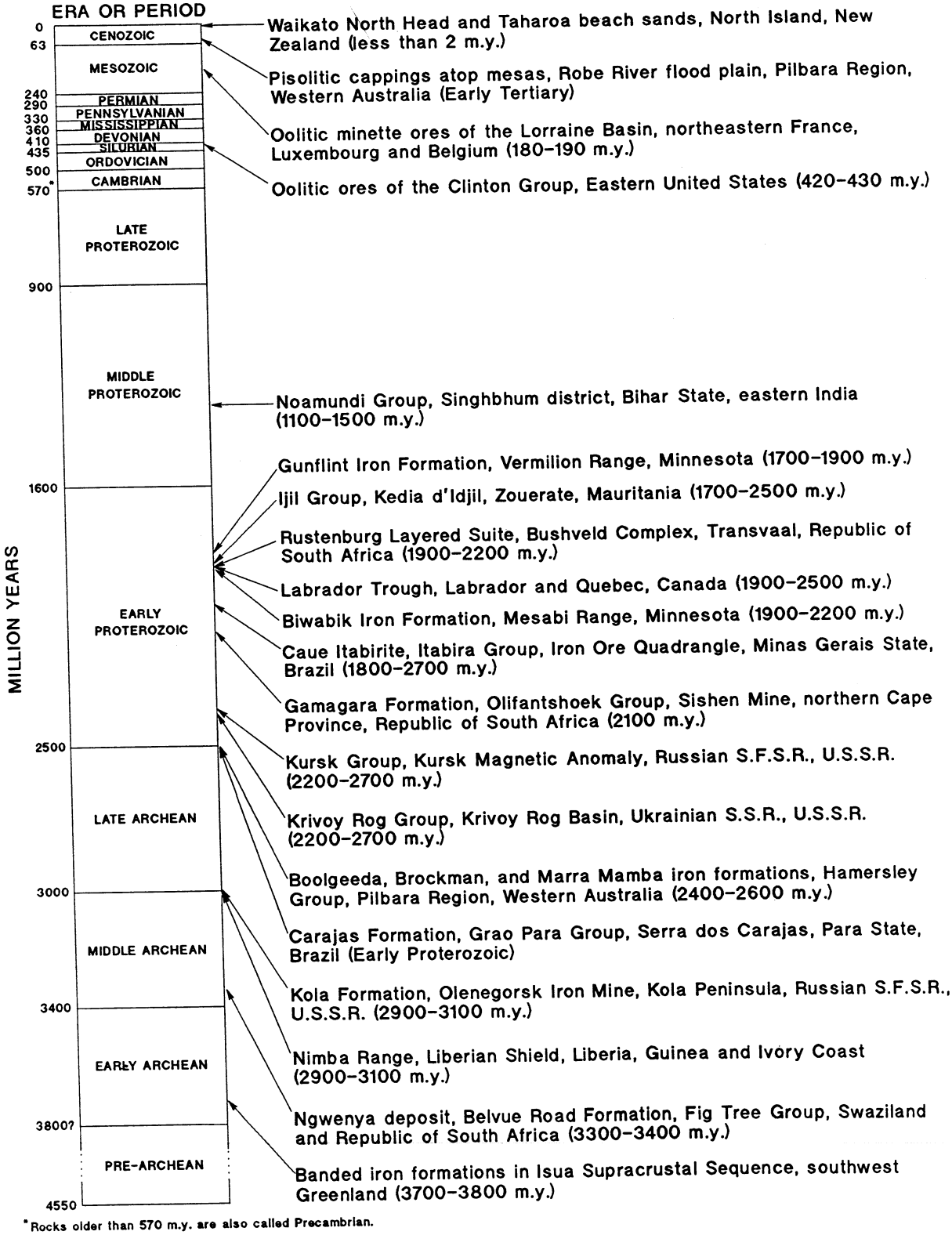
Pyrometasomatic deposits are concentrations of magnetite that have replaced portions of the limestone or volcanic country rock at or near the contact of an igneous intrusion. These deposits may be partly altered to hematite and contain up to 65% iron, depending on the extent of replacement. Garnet, epidote, 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 of pyrometasomatism include Iron Springs, UT; Eagle Mountain, CA; Hanover, NM; Cornwall and Morgantown, PA; El Romeral, Chile; and Marcona, Peru.

Technology

The technology of iron ore beneficiation, agglomeration, and smelting has changed significantly over the past 20 years. With the depletion of higher grade natural ores in the United States, the subsequent development of the North American taconite industry, and recent advances in steelmaking, beneficiation and agglomeration have become more complicated for domestic mine operators. Today, steelmakers both in North America and abroad need pellets that are much more uniform in chemical composition and meet tighter physical specifications. All of this has led to larger investments in processing equipment by domestic mine owners, driving their production costs upward. At the same time, ore grades have been declining in the United States. In addition, competition between major U.S. and Canadian producers has stiffened because of continuing weak demand for raw steel in the United States, keeping iron ore prices relatively low. North American producers, shippers, and consumers are all under increasing pressure to reduce unit costs and have only survived the latest series of economic downturns by making technological improvements that increased productivity.

FIGURE 3

IRON DEPOSITION THROUGHOUT GEOLOGIC TIME



*Rocks older than 570 m.y. are also called Precambrian.

Significant progress has been made at a number of critical points along the supply chain. Older model power shovels and haulage trucks are continually being replaced by more efficient and increasingly larger units. Mini- and microcomputers are being used to improve mining and process control. Advances have been made in the fine-screening of concentrates and the use of wet, high-intensity magnetic separators (WHIMS). New flotation processes have been developed to lower phosphorus and silicate levels in concentrates. Organic binders are being used to further reduce the silicate content. Several steelmakers have reduced coke consumption at their blast furnaces by switching from standard acid pellets to fluxed pellets.

Exploration.—The principal methods of exploration for iron ore are magnetometer surveys, geological mapping, and drilling. Aerial photography, and occasionally gravimetric surveys, are used to supplement the information gained from the magnetic and geological data. But, regardless of how promising the results of geophysical and geological mapping may be, the deposit must be drilled to determine the quantity, quality, and spatial distribution of ore present.

Magnetometer surveys are useful because deposits of iron ore are commonly associated with local anomalies in the Earth's magnetic field. In poorly explored or remote regions, airborne magnetometer surveys can quickly and economically pinpoint the more favorable areas for surface investigation. Such a survey may employ a low-sensitivity magnetometer, capable of measuring magnetic intensity to 0.5 gamma, or high-sensitivity instruments measuring to 0.02 gamma.[6] Flux-gate or proton-precession magnetometers are usually used in aerial work. Surface magnetometer surveys may be used to add detail to results of aerial surveys or where extensive overburden prevents adequate geological mapping. The newer types of magnetometers can be used in drill holes or underwater because their sensitive elements are separated from the recording systems by long coaxial cables. In some cases, advances in telemetry have made even the coaxial cables obsolete.

Surface magnetometer surveys have been extremely valuable in guiding exploration and development drilling on the Cuyuna and Mesabi Ranges, where the iron formations are buried under as much as 60 m (200 ft) of glacial drift. Discovery of the Cuyuna Range was made possible by early dip-needle surveys. On the Mesabi, magnetometer surveys have outlined areas of low magnetic intensity that are typically associated with the presence of hematite deposits. The correlation with hematite has also helped outline the oxidized portions of buried formations of magnetic taconite. Balance-type magnetometers were once used widely in ground surveys, but have been largely replaced by proton-precession instruments, which do not require leveling and permit faster and more accurate readings.

Geological mapping in remote areas can be expedited by employing helicopters and conventional aircraft. Aerial and satellite photographs may also be used to advantage, since iron-rich rocks often form topographic features such as ridges, mesas, or hills. These features help to guide ground survey teams and may be aerially traceable into districts that are unmapped or have been mapped only by reconnaissance teams. Aerial photography has been especially valuable in exploring the tundra of Alaska and northern Canada. There has been little exploration for iron ore in the United States in recent years because of weak demand and the existence of large reserves in the Lake Superior District and Alaska.

The exploration geologist is now able to accurately pinpoint his or her location in the field with the help of the Global Positioning System (GPS) set up by the U.S. Department of Defense. Handheld receivers are commercially available for use with the GPS to determine latitude, longitude, Universal Transverse Mercator Coordinates, and altitude. The GPS is composed of a network of more than 20 satellites that circle the Earth at an altitude of about 18,000 kilometers (km) (11,000 miles).[7] The handheld receiver is able to determine its location by monitoring identically coded radio signals broadcasted simultaneously by the different satellites and then triangulating on four of the satellites. Most of the cheaper receivers can pinpoint a location anywhere on Earth to within 15 m, while more advanced receivers are accurate to within 1 cm.

Exploration drilling for iron ore is usually done with diamond-surface-set coring bits. Core samples are desired because they provide "undisturbed" samples yielding information on geologic structure and physical properties that would not be available from ordinary drill cuttings. Bit sizes commonly used are B, N, and H, which cut cores approximately 1.7, 2.1, and 3.0 inches in diameter, respectively. Either hard or soft ores can be cored. Core recoveries of 75% or better are common. Diamond drilling is expensive, however, and other methods such as rotary or churn drilling may be used if cuttings constitute an acceptable sample. The spacing of exploration drill holes depends on the size, structure, and continuity of a deposit and may range between 150 and 1,500 m (500 and 5,000 ft). Spacing of development drill holes in taconite deposits on the Mesabi Range is about 60 to 120 m (200 to 400 ft). Most diamond drilling at U.S. iron ore mines is now done by contractors rather than by the mining companies. Wire-line methods are often used and may permit extraction of cores without removing the entire drill string from the hole.

Mining.—About 90% of the world's output of iron ore comes from open pits; most of the rest is produced from underground mines. Only a small percentage is derived from beach sands and placers. In the United States and Canada, open pit operations accounted for 98% of usable production in 1990. Approximately 14% of the ore mined in the U.S.S.R. is produced underground, about 30% in Spain, and 100% in France and Sweden.

The choice of mining method depends on the size, structure, and accessibility of the ore body. Most iron ore is mined in open pits because of the ore's low unit value and the large tonnages that must be moved to obtain economy of scale. To be commercially viable, an ore body generally has to lie close to the surface and have large lateral dimensions. Narrow, steeply dipping, or buried ore bodies are normally mined by underground methods, but the relatively high cost and limited production capacity of underground mines has steadily reduced their ability to compete with open pit operations. The number of underground iron mines in the United States has declined from more than 30 in 1951 to only 1 in 1991.

At U.S. taconite mines, 5 to 6 mt of material must be mined for each mt of usable product produced. This is due to the relatively low magnetic iron content of the crude taconite, which typically ranges from 20% to 24% Fe. About 3 mt of crude taconite has to be processed to produce 1 mt of pellets. In addition, large quantities of waste rock and surface overburden must be stripped. At most mines in Australia and Brazil, where the ore is of much higher

grade, only 1.5 to 2 mt of material is mined for each mt of product produced.

Mining in most open pits is done with large power shovels and trucks. Blasthole drilling is mainly done by rotary drills with 12¼-inch to 16-inch diameter bits; 17½-inch bits have been used at some mines. Down-the-hole percussion drills using 6½-inch bits are used at Pea Ridge's underground mine in Missouri. A few "jet-piercing" machines, which bore a 9-inch hole by a continuous process of heating and spalling, were employed in Michigan and Minnesota during the late 1950's and 1960's, but are no longer in use.

Ammonium nitrate, in prilled form or slurries with fuel oil, is the most widely used blasting agent. Blasting efficiency has been increased by using emulsions or metallized slurries and by increasing the quantity of explosive in individual blastholes. The 12¼-inch to 17½-inch blastholes now drilled in taconite permit wider spacing of holes and larger explosive charges while maintaining adequate fragmentation. The quantity of taconite broken by individual blasts usually ranges from about 0.4 to 1.5 Mmt. Consumption of explosives ranges from about 0.18 to 0.45 kilograms (0.4 to 1.0 pound) per mt of rock broken. In natural ore mines, drilling and blasting requirements are less than in taconite. Some natural ores can be dug without blasting, as is the case in Goa.

Most power shovels at taconite mines have dipper or bucket capacities of 9 to 18 cubic yards and are designed to dig ore and waste rock as well as surface overburden. One of the first of a new generation of electric shovels equipped with a 33-cubic-yard bucket was delivered to the Empire Mine in 1990. The unit was employed in stripping operations in the main pit. Shovels with even larger capacities are used in the Pilbara mines of Western Australia. The first diesel-powered shovel in the U.S. industry was put into operation at the Tilden Mine in January 1991. The unit had a 12-cubic-yard bucket and was being used to strip overburden at the new Cliffs Drive III pit.

At large taconite mining operations, where as many as 14 shovels may be working in different materials over a distance of several miles, daily scheduling of shovel operations is assisted by computers. At most taconite mines, there is considerable variation in the physical properties and mineralogical composition of the ore. These variations make it difficult to schedule digging, loading, and haulage operations, while simultaneously delivering crude ore of relatively uniform grade to the crushing and concentrating plants. To accomplish this, daily operations require experienced visual judgment and frequent supplemental sampling by mine personnel.

Ore haulage from the pit to the crusher has been made more efficient by computerized truck dispatching. A new generation of haulage trucks is also helping to lower mining costs. At least three open pit operations in the Lake Superior District have begun replacing the older 120-short-ton and 170-short-ton trucks in their fleets with new 240-ton units. Most trucks at U.S. iron mines now have haulage capacities of at least 100 short tons. However, some 85-ton units are still used. Trucks of 180- to 225-short-ton capacity have been employed in Australia for more than a decade. In the mid-1970's, a 312-ton unit was tested successfully for a year at a California mine, but trucks larger than 240 tons have not yet proved to be practical at most U.S. iron mines. Minntac and the LTV Steel Mining Co., 2 of the larger U.S. taconite operations, prefer to use trains to haul ore to the crushers; the trains consist of 9 to 18 cars of 80- or 85-short-ton capacity each and are automated to allow operation by 1 worker.

At many mines, front-end loaders have replaced shovels in secondary ore loading, cleanup, and stockpile operations. The load-ers are more mobile than the shovels and have bucket capacities of up to 13 cubic yards.

In underground mining, the most noticeable technological changes have been in development of improved drilling and blasting operations and in mechanization of loading and transport. At Pea Ridge, 6½-inch-diameter percussion drills are used for 75% of all production drilling. The blastholes can be drilled at any angle, up or down, to depths up to 300 feet. These drills have improved blasting efficiency and have made possible the fragmentation of up to 3 Mmt of ore at one time. Similar drills are used at the Kiruna Mine of Luossavaara Kiirunavaara AB (LKAB) in Sweden, but some have been modified so that they can be operated by remote control. Load-haul-dump (LHD) vehicles are extensively used to move the ore from the face to the ore pass. Most of these vehicles have electric-wheel drive and bucket capacities of 5 to 8 cubic yards. At the MacLeod siderite mine in Ontario, Canada, a 10° 15,000-foot conveyor incline was driven to carry ore directly from the lower levels of the mine to a sinter plant on the surface, and a parallel incline of the same length was driven for the use of mobile equipment.

LKAB has automated most of the ore loading and transport operations at Kiruna.[8] The company even has a prototype LHD that can be operated remotely from a control room. After blasting, the ore and waste is mucked out with an LHD and hauled to the nearest ore pass. The ore is then loaded from the ore pass into an 18-car train powered by an electric locomotive, again operated by remote control. Each of the ore cars can hold 22 mt, for a total haul to the crusher of 400 mt. At Malmberget, LKAB's other underground mine, LHD's are also employed to get the ore to the ore passes.[9] However, at the haulage level, the ore is loaded into 65-mt trucks for the 2-km trip to the underground crushing station. A new 120-mt truck made in Finland was to be delivered for evaluation in late 1991. The mines of Arbed SA in eastern France have also been extensively mechanized with LHD vehicles, gathering-arm loaders, and trucks.

Beneficiation.—Crude iron ore is beneficiated to raise its iron content, reduce the content of impurities, or to improve its physical structure. Beneficiation processes include simple crushing, screening, drying, washing, as well as complex methods that separate ore minerals from gangue using differences in physical or chemical properties. The type of beneficiation required depends on the mineralogical and physical characteristics of the crude ore and the type of ore product desired.

Almost all iron ore mined today is beneficiated before shipment. Consumer requirements are strict, not only for content of iron, silica, phosphorus, alkali, and other constituents but also for particle size, compressive strength, reducibility, and other properties. High-grade ores are beneficiated to obtain closely sized products or to reduce content of minor but objectionable impurities such as phosphorus and alkali. Low-grade ores are beneficiated primarily to obtain concentrates that can compete in the market with high-grade natural ores.

In March 1982, a centralized computer system was commissioned at Reserve Mining Co.'s taconite concentrator to monitor and control a variety of processing operations.[10] This system was upgraded after Cyprus Northshore took over the operation

in 1989. The process controls are designed to maintain the iron content of final concentrate to within +0.25%.

During the Vietnam conflict, soft hematite ores of the Mesabi Range were beneficiated by gravity methods, using screw-type or spiral classifiers and heavy-medium separators. Beneficiation of these ores yielded more than 15 Mmt of concentrates in 1973, but by 1990, production had declined to less than 1 Mmt because of a shift in demand to less expensive material with a higher iron content. All but one of the larger hematite concentrators have since been dismantled. The hematite concentrates currently being marketed contain 52% to 57% iron, but are not normally produced or shipped during the winter months. The fines fraction has to be agglomerated by sintering before being charged to the blast furnace. In contrast, pellets made from taconite contain 62% to 65% iron are produced and shipped by rail year-round. All of the pellets, except for small quantities of fines generated during transport, are charged directly to the furnace.

Fine grinding is necessary to produce acceptable concentrates from crude ores of the taconite type, to prepare ore for flotation, and to prepare concentrates for pelletizing. In most ores mined in Michigan and Minnesota, mineral particles are so small that adequate separations cannot be made unless the ore is ground to about 90% minus-325 mesh. Ore at one mine is ground to 95% minus-500 mesh. Most of the taconite concentrators use steel rods or balls for grinding, but several plants also use autogenous or semiautogenous mills in which particles of crude ore constitute all or most of the grinding media. Less grinding is needed to concentrate the low-grade hematite ores of eastern Canada, as the ore particles are liberated at about minus-28 mesh, but fine grinding is necessary for concentrates that are further processed to pellets. In Missouri, relatively high-grade magnetite ore is finely ground to permit removal of mineral impurities such as apatite, feldspar, and sulfides by flotation as well as to prepare the concentrate for pelletizing.

Low-grade magnetite ores such as those in the Lake Superior District and in some districts of Norway and Sweden are concentrated (after grinding) by low-intensity magnetic separators. The concentrates may be beneficiated further by ultrafine (minus-150 mesh/0.004-inch) screening, as in most Minnesota plants, or by flotation, which is used at three plants in the Lake Superior District as well as in Norway and Sweden.

Low-grade hematite ores may be concentrated by gravity methods, as in eastern Canada where Humphreys spirals are used. Others are concentrated by high-intensity magnetic separators, as at the Caue and Conceicao plants in Brazil. Still others are concentrated by flotation, as at the Tilden Mine in Michigan and the Germano Mine in Brazil. Several processes may be used in one plant if the ore is mineralogically complex.

At the pelletizing plants, improved flotation techniques are being used to lower both phosphorus and silica levels in the concentrate. Considerable success has been achieved in lowering silica levels with the aid of either amines or diamines and similar cationic flotation reagents. Recent advances in the flotation of apatite [$Ca_5(PO_4)_3(F,OH,Cl)$] should help reduce the problem with phosphorus that has been plaguing steelmakers for more than a century. Control of phosphorus and arsenic is critical in the making of quality steels. The ideal situation is to reduce the phosphorus to as low a level as possible in the ore, coke, and other raw materials. As the phosphorus content of the steel increases, the steel becomes stronger but loses its ductility and drawability (i.e., formability). For this reason, the phosphorus level in deep-drawing sheet and strip normally cannot exceed 0.01%, or in rare instances 0.02%. The phosphorus problem cannot be entirely solved at the concentrator because significant amounts of the element are also present in the coke, some of the fluxes, and recycled slag. Arsenic acts similarly to phosphorus, although less strongly, and cannot be refined out of the steel bath. Both phosphorus and arsenic are completely reduced in the blast furnace and report to the iron.

In taconite ores from the Lake Superior District, about one-half of the phosphorus occurs as finely disseminated grains of apatite and can be partially removed by careful flotation. The rest of the phosphorus apparently substitutes for oxygen in the hematite or magnetite, making its removal by physical separation nearly impossible. Amphoteric flotation reagents, which have both anionic and cationic collector groups, can reduce the phosphorus content of the final concentrate by as much as 40%. Long-chain polyphosphate dispersants can improve the rejection of apatite during the desliming stage.

The situation is much more serious for oolitic iron ores. Recent studies using cathodoluminescence microscopy have revealed that the phosphorus in these types of ores occurs not only as collophane grains[11] and granular apatite, but also as phosphate-rich fossil fragments that have been partially replaced by hematite.[12] The ores near Birmingham, AL, typify these high-phosphorus oolitic and fossiliferous ores. The Lorraine minette ores of Belgium, France, and Luxembourg are a second example. The marketability of these two types of ore has fallen sharply over the past 20 years because of tightened specifications for phosphorus. In some of the Birmingham ores, hematite ooids are cemented together by a hematite matrix that contains disseminated, micron-size grains of carbonate-fluorapatite. Separation of these minute apatite grains would be extremely costly using existing beneficiation technology.

The Pea Ridge Iron Ore Co. of Missouri has had considerable success in lowering the phosphorus content of the magnetite concentrate it uses as pellet feed. In 1979, pellets from Pea Ridge averaged 0.080% P. At that time, the ore feeding the concentrator typically ran 0.60% P. Since then, the company has been able to gradually reduce the pellet phosphorus content to 0.020%.[13] The improved liberation of phosphate minerals was achieved by installing additional magnetic separators between 1981 and 1985 and by switching over to a larger and more sophisticated flotation circuit. The new phosphate flotation circuit became fully operational in September 1988. Amine, fatty-acid, and fatty-alcohol collectors all were tried and eventually discarded. A suite of proprietary collectors developed specifically for Pea Ridge concentrates was being used in 1990. Preliminary tests suggested that the pellet phosphorus content could be reduced even further to 0.015% by finer grinding.

Since 1982, flotation plants have been built in Brazil, Mexico, and Norway to produce special high-grade concentrates of magnetite or hematite for direct reduction. WHIMS equipment has also been installed at beneficiating plants in several countries, including Mexico, Norway, and Spain. The process is used at one Spanish plant for concentration of siderite. A WHIMS unit has been installed at a hematite concentrator in eastern Canada. The WHIMS process is not used commercially in the United States, although a commercial-scale unit was installed at the

Sunrise Mine in Wyoming in 1976. The Wyoming operation ceased production in 1980.

U.S. Bureau of Mines research has contributed significantly to flotation of low-grade hematite ores, especially the very fine grained or "earthy" type. A method of selective flocculation and desliming of pulp, prior to flotation, was developed jointly with the Cleveland-Cliffs Iron Co.[14] and led to commercial development of the Tilden Mine in 1974 and its expansion 5 years later. The process, or variations of it, has been used in other countries (e.g., at the Sawawin Mine and pilot plant in Saudi Arabia).

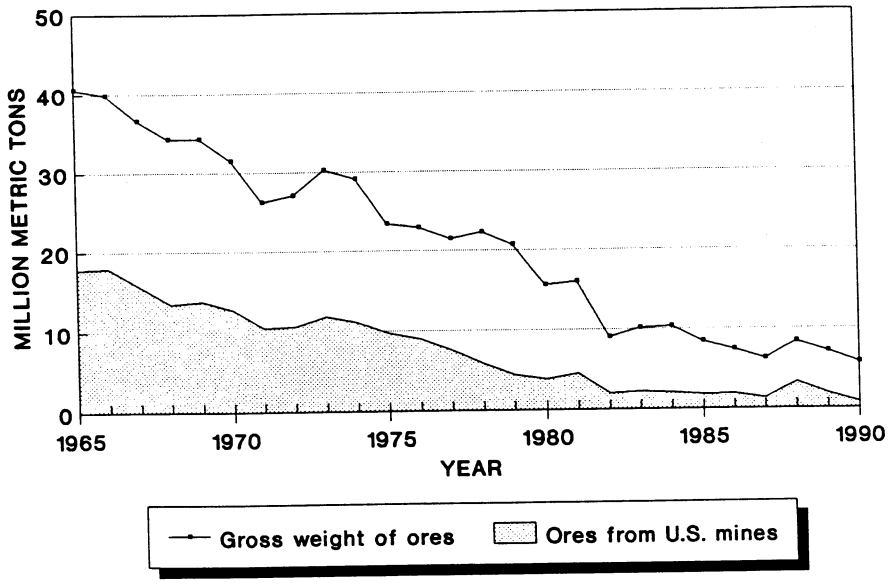
Agglomeration.—Iron ores consisting of particles less than ¼ inch in size are usually agglomerated by sintering or pelletizing before being charged to the blast furnace. This is done primarily to improve permeability of the furnace burden and to prevent loss of fines up the stack. Fine concentrates are also agglomerated to facilitate transportation and handling.

Ore particles ranging in size between ¼ inch and 100 mesh are usually sintered at the blast furnace site. Finer material such as taconite concentrates is pelletized at or near the mine site. Owing to the increased use of pellets in the United States, sinter production has been declining over the past 25 years, and many sinter plants have been closed. (See figure 4.) Consumption of sinter in 1990 was 12.23 Mmt, about 73% of active domestic sinter plant production capacity. No new sinter plants have been built in the United States since 1976, but several have been completely refurbished. The U.S. industry had only 11 operable plants in 1991. The decline in U.S. sintering operations contrasts with developments abroad. In Japan and Western Europe, sinter is still the principal feed to blast furnaces. In India, the sintering capacity of the Steel Authority of India Ltd. (SAIL) has grown almost sixfold since 1965 to 13.2 Mmt of sinter per year.[15]

Sinter is made by spreading a mixture of ore fines and coke breeze on a moving horizontal grate, igniting the surface of the bed by a gas or oil burner, and drawing combustion downward by suction. The temperature of combustion, which ranges from about 1,204° to 1,427° C (2,200° to 2,600° F), causes the ore particles to fuse together. Self-fluxing sinter is made by adding powders of lime, limestone, and/or dolomite to the mix. Iron-bearing materials such as flue dust, mill scale, and steel-furnace slag recovered from metallurgical plants are commonly recirculated to the blast furnace through sintering plants. If many types of ore and recirculated materials are used, careful blending is required; this is usually accomplished by bedding piles, with computer control of ingredients.

FIGURE 4

CONSUMPTION OF IRON ORE IN U.S. SINTERING PLANTS



Pellets are made by mixing a small quantity of binder (usually bentonite, but sometimes hydrated lime at foreign operations) with finely ground concentrate and balling the mixture in rotating drums or saucerlike disks. The moisture content of the mix must be closely controlled and is usually between 9% and 10%. The "green pellets," usually ⅝ inch to ¼ inch in diameter, are then hardened in furnaces fired by natural gas, fuel oil, or pulverized coal at about 1,315° C (2,400° F). Finished pellets usually contain 60% to 66% iron, have relatively high compressive strength (400 pounds or more), and withstand the abrasion of handling and transport better than sinter.

Pellets used in U.S. furnaces contain about 63% iron and, in 1990, made up about 81% of all iron ore and agglomerates consumed in the United States. U.S. production of pellets in 1990 was 54.82 Mmt, about 84% of installed capacity at the end of the year. Pellets accounted for 98% of all usable ore produced in the United States. Production of pellets for the entire world was reported to be 222.5 Mmt, also about 84% of installed capacity.

Consumption of bentonite in production of pellets at the Tilden plant in Michigan has been sharply reduced by using a different variety of bentonite having greater capacity to absorb water. Consumption per ton of concentrates was 3.6 kg (8 pounds) in 1983 compared with 11 kg (24 pounds) in 1975. In addition to the cost savings for bentonite, alkali content of the pellets was also reduced.[16]

The sharp price increases for natural gas and fuel oil, which occurred in 1973 and 1979, led to commercial-scale tests of the suitability of pulverized coal as a substitute fuel for pelletizing plants. The tests indicated that grate-kiln systems could run on bituminous coal from eastern Kentucky without major modifications or serious operating problems. Western subbituminous coals, though, were not satisfactory and caused kiln ringing problems. The coal should have a high ash-softening temperature (greater than 1,480° C or 2,700° F). The testing was accelerated after the Northern Natural Gas Co., the principal supplier of natural gas to Minnesota, began curtailing supplies to the pelletizing plants in 1976. By 1981, coal was

the principal fuel at Minntac and Eveleth Mines. The expected gas shortage forecast in 1976 for the mid-1980's did not materialize, and one plant switched back to gas in 1982. A number of research projects were launched at the peak of the second energy crisis in 1980. The U.S. Bureau of Mines, in cooperation with the U.S. Department of Energy (DOE) and a large group of companies that included all major pellet producers, studied the feasibility of producing low-heat-content coal gas [150 British thermal units (Btu)/cubic foot] for pelletizing fuel, using Western subbituminous and lignite coals.[17] The research indicated that the low-Btu coal gas would be suitable for indurating iron ore pellets, but would require some furnace modifications. Between 1979 and 1983, most pelletizing plants in the Lake Superior District installed heat-recuperation systems that reduced fuel requirements by 25% to 40%. Today, most of the pelletizing plants in the district are still dependent on natural gas, but some are able to switch between gas, pulverized coal, or fuel oil, depending upon energy prices. The Minntac plant is also set up to burn dried wood fibers.[18]

Fluxed Pellets.—The Pea Ridge Iron Ore Co. first began producing "olivine pellets" at its complex in Missouri in 1983. This type of pellet, in which magnesian olivine is substituted for silica, was developed 2 years earlier in Sweden after a decade of research by LKAB and others. Subsequent tests in European blast furnaces indicated reduced coke rates and increased pig iron productivity at some furnaces, while others experienced no change and one reported an increase in coke rates. The results were sufficiently favorable, however, to cause LKAB, the principal Swedish producer, to convert all of its standard lines to the production of olivine pellets. The Pea Ridge pellets were extensively tested in National Steel's blast furnaces at Granite City, IL, from 1983 to 1985, and served as standard feed for the Illinois steelworks until 1991.[19] The addition of olivine to concentrates in the Lake Superior District is not feasible because their silica contents are much higher than that of the Pea Ridge concentrates. Instead, a number of producers have begun adding dolomite with the bentonite to obtain the required magnesia units. In 1984, fluxed pellet production began in earnest when Hibbing Taconite shipped 200,000 mt of fluxed material to Dofasco's Hamilton works in Ontario for blast furnace tests.[20]

Since 1987, many blast furnace operators in North America have switched from the traditional standard "acid" pellet to some variation of the fluxed pellet. The flux—a mixture of limestone and dolomite—is ground at the concentrator to between minus-325 mesh and minus-500 mesh, slurried, and blended with the slurry of iron oxide concentrate in a mixing tank. The slurry mix is then filtered and sent to the balling drum for rolling into green balls, which are later fired at 1,315° C (2,400° F) in the furnace. The fluxed pellet is more expensive to produce, but leads to significant savings at the blast furnace. The switchover to a fluxed pellet improves productivity by decreasing smelting time, leading to reduced coke consumption. Experiments were underway to determine the limits of possible savings. Additional coke savings in the blast furnace are possible with fluxed pellets because calcination of the fluxstone is completed beforehand in the pelletizing furnace. Also, the temperature of the tuyere zone can now be raised because the fluxed pellet does not soften as readily as the acid pellet. (See figure 5.) As a result, the fluxed burden offers less resistance to wind flow, allowing the blast volume to be raised. (See figure 6.)

The kinetics of fluxed pellet reduction are poorly understood. At 1,100° C (2,010° F), the silica and flux inside the pellet react with one another to form a high-melting calcium-magnesium-silicate slag. This situation is quite different from an acid pellet where the silica is free to react with the wustite (FeO) to form a significantly lower melting fayalite slag. At temperatures between 1,100° C and 1,400° C (2,010° F and 2,550° F), the flux keeps the metallic iron disseminated throughout the pellet and prevents formation of an iron shell (i.e., rind) around the pellet. An acid pellet, in contrast, readily forms an iron shell at 1,150° C (2,100° F), making it more difficult for carbon monoxide to permeate into the unreduced core of the pellet. Because of these differences, an acid pellet will undergo a meltdown between 1,300° C (2,370° F) and 1,450° C (2,640° F). A fluxed pellet, on the other hand, retains its spherical shape at 1,300° C and uniformly liquifies suddenly at 1,400° C.

Organic Binders.—The North American iron ore industry has been looking for ways to reduce the silica, alumina, and alkali contents of its pellets. The substitution of an organic binder for the bentonite used in conventional pelletizing offers one way to achieve this reduction. The typical organic binder being marketed is more expensive than bentonite, but can improve the reducibility of the pellet, cutting coke usage at the blast furnace.

FIGURE 5

MELTING CHARACTERISTICS UNDER LOAD OF FLUXED PELLETS VS. STANDARD (ACID) PELLETS

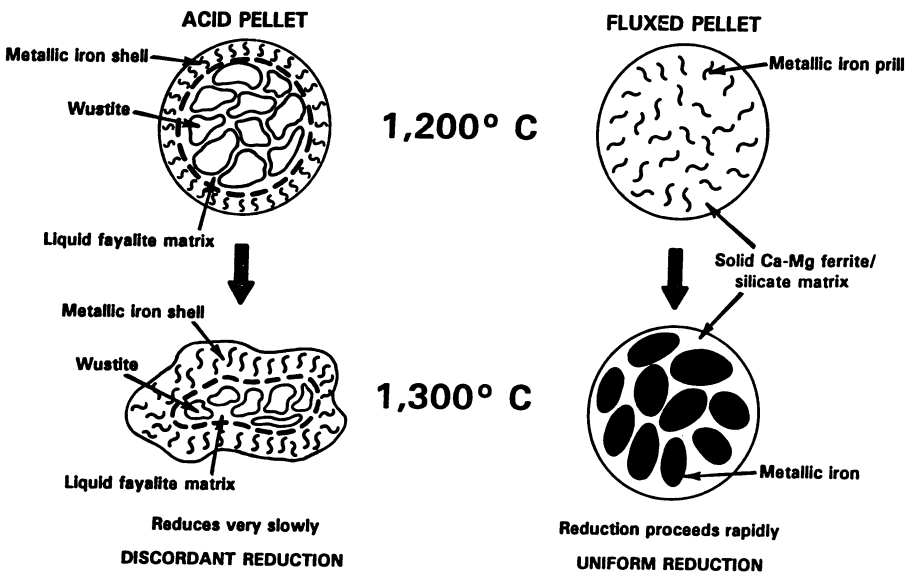
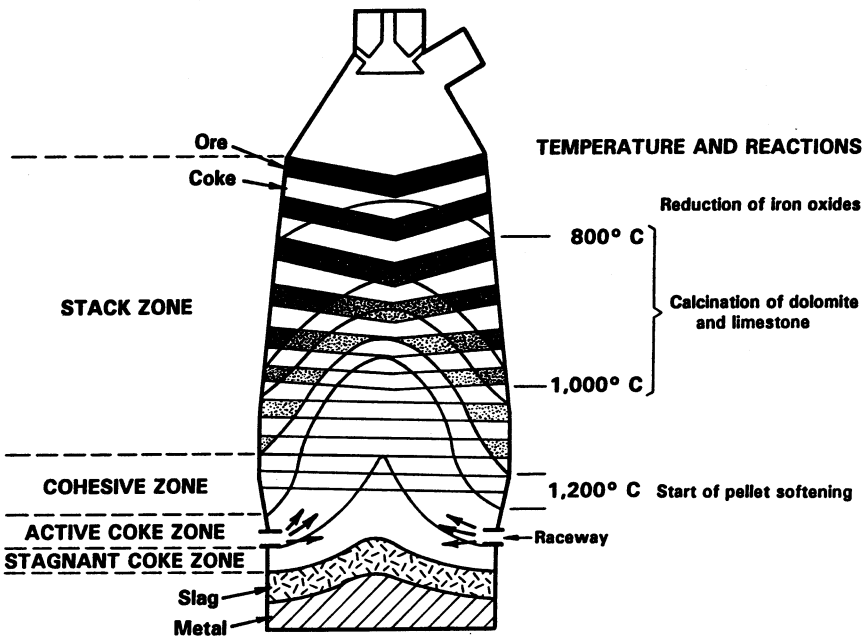


FIGURE 6

BEHAVIOR OF FLUXED PELLETS IN THE BLAST FURNACE



Another advantage of an organic binder is that most of the binder burns off during the firing of the pellet, leaving a pellet with a lower alumino-silicate content, a higher iron content, and reduced contamination. Several commercially available organic binders are variants of carboxymethyl cellulose (CMC), a polysaccharide derived from wood pulp or cotton. Others are derived from starches. Commercial binders are sold under a variety of brand names or trademarks, such as Oriox and Peridur.

One of the first organic binders to be considered commercially viable was a water-soluble cellulose derivative called Peridur. The binder was tested by CVRD in Brazil from 1976 to 1982 with favorable results.[21] Plant tests were also conducted concurrently by LKAB in Sweden at Malmberget and Svappavaara. The manufacturer claimed that the cellulose-based binder was equal to bentonite in handling and binding properties, increased pellet reducibility, and permitted savings of up to 14 kg (30 pounds) of blast furnace coke per short ton of hot metal produced. As little as 0.45 kg (1 pound) of the binder was required per ton of concentrates, although its cost was considerably higher than bentonite. Improved versions of this binder are still being tested by several U.S. pellet producers.

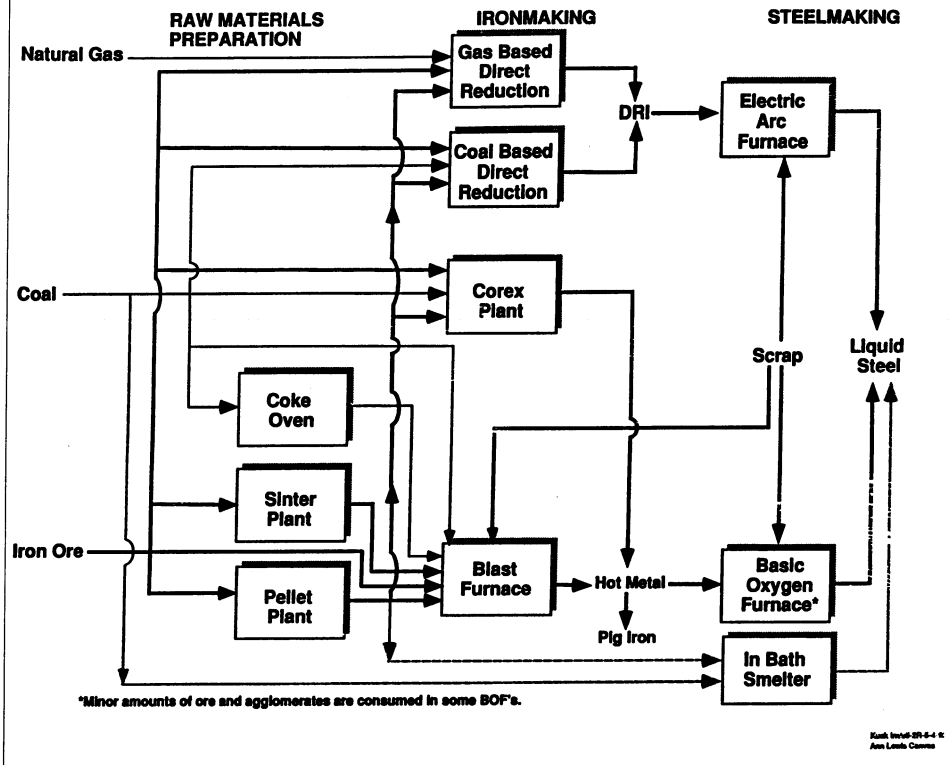
The U.S. Bureau of Mines has evaluated more than 30 different organic binders from commercial suppliers.[22] The binders came from six groups: celluloses, dairy wastes, natural gums, starches, starch acrylic copolymers, and wood-related products. Pellets made with natural gum (guar) had the best green pellet physical properties. CMC and gelled starch were less effective. However, after firing, pellets made with guar gum tended to have marginal compressive strengths. The most promising binder appears to be gelled starch. Pellets made with gelled starch have metallurgical properties that are superior to those made with bentonite. At the same time, the price of the starch is lower than that of CMC. The Bureau has also explored the possibility of using pulpmill and paper-mill sludges as a binder.[23] The sludges have little if any dollar value, but in bench tests about 10 times as much sludge had to be used to produce the results obtained with pure organic gelled polymers. Various mixes of secondary paper sludge and municipal sewage sludge wastes were tried and also showed promise.

Smelting.—Companies were evaluating a number of ironmaking and steelmaking processes as an alternative to the traditional coke oven-blast furnace route. (See figure 7.) Two factors served as a driving force for the research: the increasing competitiveness of the world steel market, and new Federal and State environmental regulations tightening air emission and water discharge requirements at steelworks and iron mines. (See Legislation and Government Programs.) In 1990, after years of debate, Congress passed one of the more significant and comprehensive pieces of environmental legislation ever enacted. The Clean Air Act Amendments (Public Law 101-549) broke new ground by establishing specific programs to reduce pollutants that cause acid rain and ozone depletion. The U.S. Environmental Protection Agency (EPA) is developing a host of new regulatory standards for heavy industry. The new standards will significantly impact a variety of facilities in the iron and steel sector, including coke oven batteries, ironmaking and steelmaking furnaces, sintering plants, and taconite pelletizing plants. Some of these facilities have been in operation for more than 40 years and are fast approaching obsolescence. Because of the enormous financial expenditures required to modernize existing coke oven batteries and sintering plants, steelmakers were actively looking for an economical process that would completely bypass cokemaking. Two of the more promising ironmaking processes being investigated were the Corex process and the HIsmelt process. Both processes can use noncoking grades of bituminous coal instead of coke. The AISI, in cooperation with DOE, has also launched a research program to develop an innovative direct steelmaking process. The goal of the long-range AISI program is to produce liquid steel from prereduced iron ore pellets in a closed system on a continuous basis.

Integrated steel mills operating blast furnaces were able to compete with electric arc furnace (EAF) operations because of (1) the introduction of fluxed pellets and other improvements in hot-metal practices, (2) economies of scale, and (3) growing demand for higher quality steels free of tramp elements. Integrated steelmakers continued to move toward their goal of 100% continuous casting, improving steel mill processing yields. At the same time, the adoption of continuous casting reduced the amount of "home" (internally generated) scrap available to both integrated and minimill operations. In 1990, home scrap constituted only 27% of the total scrap consumed by U.S. steel mills, down from 60% in 1970.

FIGURE 7

DIFFERENT METHODS OF PRODUCING LIQUID IRON



Over the past 5 years, domestic companies that make steel solely in electric arc furnaces have expanded their product line and have begun to move into the higher quality carbon steel market. Until recently, the high-quality end of the U.S. carbon steel market had been the exclusive domain of the integrated steel producers. The move into higher quality products has put the electric arc furnace operators in a quandary regarding feed material. These "minimills" are facing a shrinking supply of high-quality "home" scrap because of the adoption of continuous casting by integrated steel producers. At the same time, scrap purchases contain increasing amounts of impurities as a result of the adoption of more sophisticated alloying techniques. The integrated steel producers are now generating significantly less high-quality home scrap than a decade ago.[24] The minimill operators are now having to purchase increasing amounts of virgin iron units to dilute the impurities in their scrap feed.

In the past, the required virgin iron units have come from two sources: direct-reduced iron (DRI), the bulk of which was imported from Venezuela or Canada, and ingots of pig iron purchased from blast furnace operators. In 1990, a third option—the Corex process—became available to the "minimills," but only a few companies are willing to build a Corex plant in North America at the present time because of concern that the recession will deepen. Finely divided iron carbide could also be used, but work on a commercially viable version of the process is still at an early research stage. The iron carbide would be injected into the molten bath of the EAF through tuyeres or with a lance.

U.S. minimill operators are being forced to purchase increasing amounts of "new" (prompt industrial) scrap and "old" (obsolete) scrap, both of which frequently contain undesirable tramp elements. Copper, for example, commonly occurs in old scrap and can be a problem in the making of deep-drawing steels. To dilute these contaminants, minimill operators have begun buying increased tonnages of hot-briquetted iron (HBI) and other direct-reduced-iron products from offshore suppliers. HBI, an enhanced form of DRI recently developed for the merchant iron market and suitable for ocean shipping, is made by continuously discharging hot DRI from a shaft furnace directly into a special briquetting machine. Nucor Corp. and Oregon Steel Mills Inc. were considering building a 500,000- to 750,000-mt/year HBI plant in Venezuela. Corporacion Venezolana de Guayana, the State-owned development company, would have an equity interest of up to 20% in the joint venture.

Iron Carbide.—Iron carbide (Fe_3C) may be a suitable alternative to DRI. CCI and North Star Steel Co. formed a joint venture in late 1990 to evaluate the feasibility of producing iron carbide on a commercial scale. North Star is the ninth largest steelmaker in the United States and potentially a major consumer of iron carbide. The Minneapolis-based company has miniplants in 7 States and can produce 2.4 Mmt/yr of raw steel in its 11 electric arc furnaces. Melting and casting operations are at Wilton, IA; Monroe, MI; St. Paul, MN; Youngstown, OH; Milton, PA; and Beaumont, TX. CCI is a major iron ore merchant and manages six iron mines in North America and Australia.

The joint venture will use technology licensed by Iron Carbide Holdings Inc. of Golden, CO. The iron carbide is produced from iron ore concentrates in a fluidized bed reactor.[25] The concentrates are reduced in the pressurized fluid bed at a temperature of about 600° C (1,100° F) using a mixture of hydrogen, methane, and carbon monoxide. The mixture of gases (i.e., the process gas) is produced on-site by reforming natural gas. Before being fed into the bed, the iron ore concentrates are preheated in a series of cyclones to a temperature of 700° C (1,300° F). Any magnetite in the concentrates is oxidized to hematite during the preheating. The preheated concentrates can now be fed into the pressurized bed through a lock hopper mechanism, while the process gas is introduced through tuyeres in the base of the fluid bed vessel. The reduction reaction is quite rapid and slightly endothermic. The carbide product is discharged from the fluid bed through a second lock hopper mechanism and is cooled in a process gas or inert atmosphere to prevent reoxidation of the hot carbide.

The bulk of the iron carbide would be sold to steelmakers with electric arc furnace operations. The new product would supplement premium-quality scrap and compete against imports of HBI from direct reduction plants in Venezuela and Asia. In

1990, electric furnace operations accounted for 37% of total U.S. raw steel production, but to date the facilities have not used large amounts of conventional iron ore pellets because of the resulting drop in productivity and higher electrical power consumption.

Direct-Reduction Processes.—Direct-reduction processes reduce iron oxides to metal, using gaseous or solid reductants at temperatures below the melting point of iron. The processes are attractive because they can be used to produce iron in relatively small quantities and thus avoid the expense of building and operating a full-size blast furnace. Direct-reduction plants have been built with production capacities as small as 20,000 metric tons per year (mt/yr), although most of those in operation today have capacities of 350,000 to 850,000 mt/yr.[26]

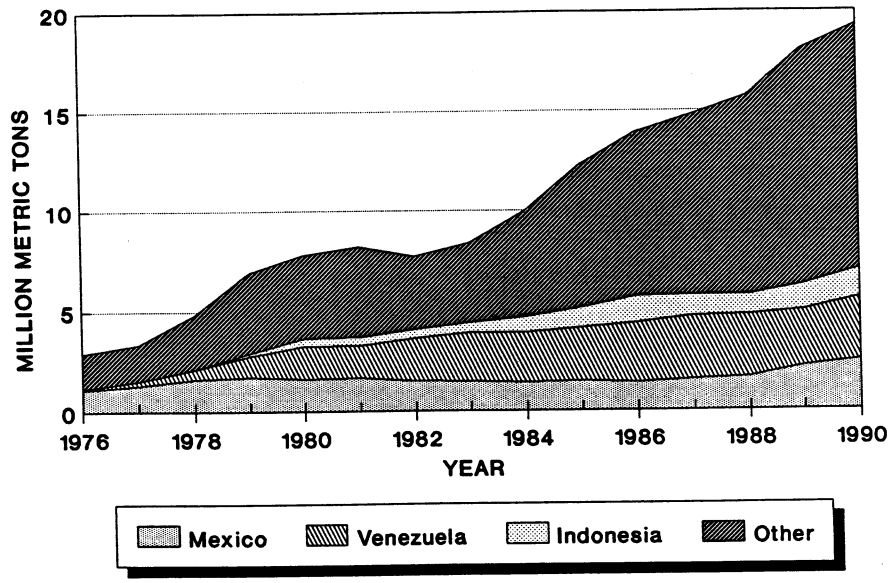
World production of DRI has more than doubled since 1980 and is expected to exceed 18 Mmt in 1991. The growth potential is enormous because current production represents only about 2% of the total iron units consumed by the world steel industry.

The iron content of DRI is usually 2% to 6% less than that of pig iron because most direct-reduction processes do not remove silica, alumina, or other impurities from the ore. As a result, the chemical specifications for the lump ore and pellets used in a DRI plant are significantly tighter than the specifications for material going into the blast furnace. Silica, for example, is normally kept below 2%. U.S. blast furnace pellets, in contrast, have silica values ranging from 3.0% to 5.5%. When high-grade lump ore or pellets are used, a high quality DRI product can be made that contains 93% to 95% total iron. The percent of total iron present as metallic iron (i.e., the metallization) is somewhat adjustable, but is normally set at some constant value between 92% and 95% to ensure product uniformity. The carbon content can also be adjusted and typically ranges from 1.0% to 2.5%.

DRI is a suitable feed for steelmaking furnaces and can be used in combination with scrap or as a scrap substitute. Most DRI plants have been built in conjunction with electric steelworks of the "minimill" type; some are built for the merchant trade while others have been built at integrated steelworks. A few small plants, such as those using the Hoganaes process, use exceptionally high-grade ore mixed with coke to produce high-purity iron for special products such as iron powder. Most of the large conventional plants use ore containing 66% to 69% iron and are fueled by natural gas.

FIGURE 8

WORLD DRI PRODUCTION



Direct-reduction plants are energy-intensive, requiring 14 to 16 gigajoules per mt (12 to 14 million Btu per short ton) of product. The cost of fuel is therefore extremely important. Almost all of the newer DRI plants have been built in countries that have surplus, low-cost natural gas. These countries include Venezuela, other major members of the Organization of Petroleum Exporting Countries, Mexico, and the U.S.S.R. High prices for gas and strong competition from ferrous scrap forced one DRI plant in the United States and two in Western Europe to close toward the end of the 1979-82 oil crisis. Only one commercial plant is still operating in the United States—Georgetown Steel Corp. at Georgetown, SC. With higher prices for gas, interest in coal-based processes have increased; nine coal-based plants were built between 1980 and 1991, mostly in India and the Republic of South Africa.

More than 90% of world production capacity for DRI is based on the Midrex and HyL processes, originally developed by the Midland-Ross Corp. of the United States and Hojalata y Lamina S.A. of Mexico, respectively. Both processes use carbon monoxide and hydrogen as reductants, obtained by reforming natural gas, and can use either lump ore or pellets as feed. The fluidized iron ore reduction (FIOR) process, developed by Esso Research and Engineering Co., is also gas-based but reduces iron ore fines in a fluidized bed. The final product is briquetted. The only commercial FIOR plant is at Matanzas, Venezuela. It started up in 1976, but did not attain full production until several years later. The FIOR plant is currently operating near its rated capacity of 400,000 mt/yr.

The SL/RN[27] process uses coal or coke as a reductant. Since 1969, a total of eight plants based on SL/RN technology have been built in Brazil, India, New Zealand, Peru, and the Republic of South Africa. All of the plants except for the one in New Zealand are currently operating. A 300,000-mt/yr unit is also under construction at Geelong, Australia. The newer SL/RN plants were built by Lurgi Chemie und Huttentechnik GmbH of Germany, but the company's designs were based on processes originally developed by Stelco, Lurgi, and two U.S. companies that were restructured during the 1980's—Republic Steel Corp. and National Lead Corp. The name of the process comes from the first letter of each of the four company names.

The ACCAR[28] process, which was developed by Allis-Chalmers Corp. and is now marketed by Boliden-Allis, is also coal-based. The only plant using this process came on-line at Keonjhar, India, in 1983. The DRC process, developed by Direct Reduction Corp., is similar to the SL/RN process. The only DRC plant in existence is at Germiston in the Republic of South Africa. The single 80,000-mt/yr kiln unit, owned by Scaw Metals Ltd., was completed in 1983. A second unit of identical size was added in 1989. Krupp Stahl AG is also actively promoting its CODIR process. One CODIR plant has been operating at Benoni in the Republic of South Africa since 1973, and a second is under construction at Bhandara, India. The South African plant was originally owned by Dunswart Iron & Steel Works (Pty.) Ltd., but was acquired by the Iscor Group in 1983. The entire annual production of 75,000 to 115,000 mt has been going to Iscor Ltd.'s Vanderbijlpark steelworks. Although only a limited number of coal-based DRI plants have been built to date, recent advances have been made in the development of rotary hearth furnaces that use pulverized coal and iron ore fines. The possibility of an advanced coal-based DRI plant being constructed in North America sometime in the next 20 years cannot be ruled out.

The FASTMET Process, being developed by MIdrex, could conceivably fill this niche.[29] In this process, iron ore concentrate, pulverized coal, and a binder are mixed together and pelletized. After drying, the pellets are spread on a rotating hearth in an even layer, one to two pellets deep. As the hearth rotates, the pellets are heated to about 1,300° C (2,370° F) and the iron oxide is reduced by the coal to metallic iron. The hearth burners would most likely run on natural gas. The conversion takes about 8 to 20 minutes, compared with 4 to 8 hours for other processes. The shorter residence time is possible because of the relatively high furnace temperature and the fact that the carbon is contained within the pellet and in intimate contact with the iron oxide. The hot DRI pellets can be discharged into refractory-lined transfer cans and taken directly to an adjoining EAF. The FASTMET process has two additional advantages. First, iron ore fines or concentrates are used instead of higher priced pellets or lump ore. Second, the capital costs appear to be significantly lower than those of competing ironmaking processes.

Gas-based direct-reduction technology has been used to produce iron on a commercial basis since 1969, but there has been a tremendous scale-up in the size of the reactor vessels since then. Gas-based HBI modules are now being built with capacities on the order of 1.2 Mmt/yr.[30] The first of these megaton modules went into a renovated plant owned by Minerales Ordaz CA (MINORCA) in Venezuela. The newly refurbished and modified facility was scheduled to produce 810,000 mt of HBI in 1991.[31] It has a single shaft furnace designed to use 100% lump ore, 100% oxide pellets, or any combination of the two. The facility is near the ore docks at Puerto Ordaz and was reactivated in early 1990.

Design improvements have been made to DRI plants so that iron ores with high sulfur contents can be utilized. The adoption of steam reforming technology has eliminated the need for water quenching and the reheating of the reformed gas prior to reduction. Improvements in reformer design have eliminated the need for a CO_2 removal system, reformed gas quenching and reheating, a steam generation system, and auxiliary boilers. In 1984, the first HBI plant was put into operation on Labuan Island in Malaysia. By the end of 1990, there were four additional HBI modules operating: two in India and two in Venezuela. These five plants are expected to have a combined HBI output of 2.3 Mmt in 1991.

Plasma-Arc Technologies.—Plasma-arc reduction processes differ from those previously mentioned in that they operate at higher temperatures, require relatively large quantities of electrical energy, and produce molten iron rather than sponge iron. Energy requirements are on the order of 21 gigajoules/mt (18 million Btu/short ton) of product. Electrical energy requirements are about 1,000 kilowatt hours per ton of product, in addition to the energy derived from fossil fuels used as a source of reductant. On the other hand, plasma-arc processes permit wide flexibility in choice of fuel and type of iron ore feed, and their product is similar to iron produced in a blast furnace. If these advantages can offset the relatively high cost of energy, plasma-arc smelting may be more economically feasible in some regions of the world than conventional blast furnace practice.

Several plasma processes have made it to the pilot plant stage, but none are commercially viable at this time. One of the more promising has been the Plasmasmelt process, which was developed by SKF Stal at its laboratory in Hofors, Sweden. In the Plasmasmelt process, prereduced iron ore fines or micropellets are injected together with coal and slag formers into the bottom of a coke-filled shaft. The prereduced material is then smelted using energy from plasma torches mounted above the hearth. In the late 1970's, SKF set up a 10-mt/d pilot plant at Hofors that showed that the process would indeed work. However, several technical problems have not been solved, and the economics of the process are currently unattractive. SKF has also developed a second, somewhat similar, direct-reduction process called Plasmared. This second process combines features of existing commercial DRI processes with those of the Plasmasmelt process. A Plasmared demonstration plant was built at Hofors in 1981 and was able to produce DRI at the rate of about 5,000 mt/yr.

While this work was going on in Sweden, Pickands Mather, Westinghouse Electric Corp., and Minnesota Power formed a joint venture to evaluate various plasma smelting technologies. The group was looking for a way to produce molten iron from taconite concentrates using coal as a reductant. This research program later became known as the Mesabi Plasma Metal Project. A pilot plant was built at Hibbing, MN, that consisted of a reactor vessel, a gas recycling system, a recuperation system, and a plasma generator. The plasma system included a 1.5-megawatt (MW) plasma torch fabricated by Westinghouse. The next step was to have been the construction of a demonstration plant capable of producing 100,000 mt of iron per year. The project was shelved in 1987 after Westinghouse Electric Co. shifted its corporate interests and CCI acquired Pickands-Mather. In 1985, Fluor Corp. built a unique 300,000-mt/yr gas-based reduction plant for Union Steel Corp. (now Usko Ltd.) at Vereeniging in the Republic of South Africa. The design incorporated novel plasma technology developed by Chemische Werk Huls of Germany for the chemical industry. The plant was supposed to use coal gas from the neighboring Sasol synthetic fuels plant, but encountered technical problems and closed within 3 years.

For further descriptions of direct-reduction processes and their economic aspects, the reader should refer to selected publications of the Metals Society[32] and AIME.[33]

The Corex Process.—In 1985, Iscor Ltd. began building the first commercial-scale plant employing the Corex process at its Pretoria steelworks in the Republic of South Africa. The Corex plant was commissioned on a trial basis in August 1988, but required several modifications before it became fully operational in 1990.

The Pretoria plant is the first facility in the world to produce molten iron on an industrial basis by charging coal directly into the smelting furnace. The plant produced 270,000 mt of liquid steel during its first full year of operation. The original process was developed jointly by Korf Engineering of Germany and Voest-Alpine AG of Austria. Voest-Alpine Industrieanlagenbau was the principal contractor for Iscor. A key feature of the Corex process is that it uses untreated raw coal in place of coke. Coking coal has become increasingly scarce in the Republic of South Africa, but the country has large reserves of coal of lower rank.

From an environmental standpoint, a Corex plant has several advantages over the conventional blast furnace. First, coke ovens are not needed, eliminating all the problems associated with the generation of coal tar byproducts such as benzene, phenol, and amines. Second, the dust problems associated with blast furnaces are eliminated because the off-gas is used as fuel. When the off-gas emerges from the smelting vessel, it is passed first through a scrubbing system and then an electrostatic precipitator to remove furnace dust. The off-gas could be flared in theory, but the economic viability of the operation would seriously deteriorate because of the loss of gas credits.

The Corex plant is the only practical alternative to the blast furnace at the present time. However, it has one key disadvantage for integrated steel producers. The size of the plant is currently restricted to less than 450,000 mt/yr, compared with 2.8 to 3.5 Mmt/yr for a new blast furnace. A series of modules meeting the needs of a large, integrated steelworks would probably be too expensive to operate. Despite this key disadvantage, Geneva Steel and some other integrated producers are still interested in this technology.

The Corex plant also has some appeal for minimill operators because they have difficulty producing high-quality drawing steel owing to excessive absorption of monatomic nitrogen. The arc of the electric furnace dissociates diatomic nitrogen molecules in the furnace atmosphere. Because of its relatively large radius, the diatomic nitrogen molecule is not readily absorbed into the hot metal. The monatomic nitrogen daughter, on the other hand, is one-half the size of its diatomic parent and is readily dissolved by the hot metal. The nitrogen problem would be avoided in the Corex process.

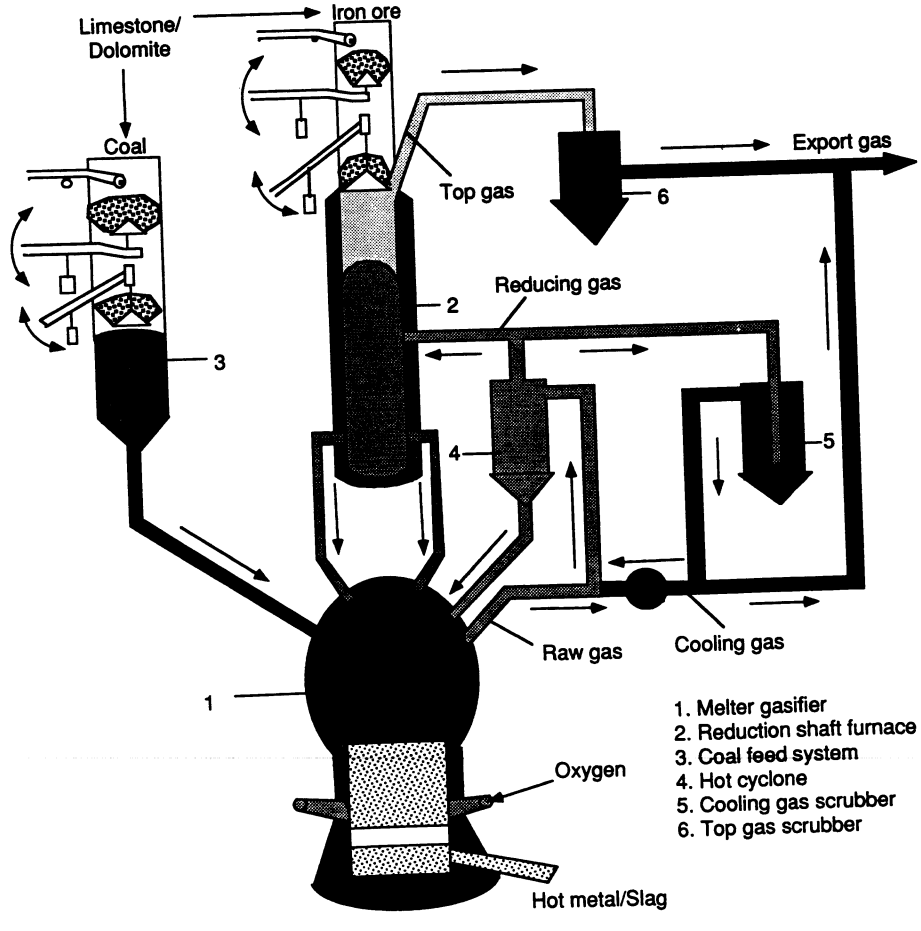
The details of the Corex process are given in the most recent edition of "The Making, Shaping and Treating of Steel," a reference used worldwide by steelmakers.[34] The reactions in the process are similar to those in the conventional blast furnace, but take place in two separate chambers. (See figure 9.) One chamber contains a fluidized bed where coal is gasified and prereduced iron is melted. The other is a vertical shaft furnace where ore is reduced by gas from the fluidized bed. Lump ore, sinter, or pellets can be used to provide the iron units. The direct charging of raw coal lowers hot-metal costs and bypasses the environmental pollution problems associated with coke ovens. The Corex process produces hot metal with carbon and silicon levels approaching blast furnace standards. The sulfur content of the metal, though, is significantly higher because of the substitution of raw coal for coke.

Because of the success of the South African operation, several companies are considering building similar units in North America. Some of the sites suggested include Cleveland, OH; Duluth, MN; Norfolk, VA; and Provo, UT.

Direct Ironmaking Processes.—HIsmelt Corp. Pty. Ltd., a joint venture of CRA Ltd. and Midrex Corp., recently announced plans to build a $77.5 million research and development facility at Kwinana in Western Australia. The heart

FIGURE 9

THE COREX PROCESS



of the new complex will be a 100,000-mt/yr prototype smelter, which is scheduled to start up in early 1993. If the full-scale pilot plant tests at Kwinana are successful, several U.S. companies may follow suite. The HIsmelt process is a single-stage process that involves the direct smelting of iron ore in a closed molten bath reactor. Iron ore fines and coal are injected directly into the molten bath.

Direct Steelmaking.—In the spring of 1990, the AISI, in cooperation with DOE, began a research program to develop a new smelting and refining process for making steel. The goal of the program is to produce a liquid steel product from prereduced iron ore pellets on a continuous basis in a closed system of coupled process vessels. This direct steelmaking process contrasts sharply with current practice, where steel is made in batches using vessels, some of which are largely open to the atmosphere. If successful, the new process could simplify steelmaking, increase productivity, reduce energy consumption, and improve operational flexibility. The 4-year research program is expected to cost almost $50 million, with DOE providing 77% of the funds and AISI the balance.

As the process is currently envisioned, coal and pellets partially prereduced to wustite (FeO) are charged directly into a vessel that contains a bath of molten iron. The mixture in the vessel is injected with oxygen for combustion, and the resulting heat facilitates the conversion of the ore to high-carbon liquid steel via smelting. The burning accomplished by injection of oxygen, also called postcombustion, assists in maintaining a self-sustaining heat balance. To prepare for production of finished product, further treatment with oxygen reduces the carbon content of the melt to levels currently acceptable to conventional ladle-metallurgy facilities. The heat from postcombustion of the carbon monoxide is needed to offset the heat consumed by smelting and system heat losses. The direct addition of coal eliminates the need for metallurgical coke produced from coke ovens in the current ore-based production flowsheet utilizing the blast furnace.

A large part of the research is now being carried out at a pilot plant near Pittsburgh, PA. The heart of the plant is an in-bath smelter, which became operational in June 1990. The smelting vessel can produce up to 120 short tons of iron per day from a variety of feed materials, including different types of prereduced iron ore, iron ore pellets, direct-reduced iron, and limited amounts of scrap. The 15-short ton vessel is also designed for coal injection and oxygen blowing. Special equipment has been incorporated so that postcombustion of the carbon monoxide and other gases generated during smelting can be regulated to varying degrees. Initial tests have involved anthracite and wustite pellets.

Operating Factors

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 mt of iron ore, was placed in service. Since then, 12 similar vessels have been built, each about 300 m (1,000 feet) long and capable of carrying about 60,000 mt of iron ore pellets. Each of these carriers replaced about four older vessels and can deliver about 2.5 Mmt of ore to lower lake ports during an 8-month shipping season. The last of this group of ships was completed in 1981.[35] While these vessels were being built, a similar number of older ships were lengthened to increase their carrying capacity and were also fitted with self-unloading equipment. By the spring of 1991, all but 2 of the 58 bulk carriers in the U.S.-flag fleet were self-unloaders. The average cargo capacity of the lake vessels has thus increased since 1971, while the total number of vessels has been reduced by more than 60%.

To accommodate the "1,000 footers," new loading facilities and materials handling systems were built at four of the seven upper lake ports, the last of which was completed in 1983, and three new receiving terminals were completed on Lake Erie. The self-unloading vessels have all but eliminated the use of Hulett clamshell unloaders at lower lake ports. The "1,000 footers" have unloading capacities of up to 10,000 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.[36]

Cargo capacities of vessels traveling the St. Lawrence Seaway between Montreal and Lake Erie are still limited to about 26,000 mt. On the north shore of Lake Erie, Stelco Inc., which has equity in several U.S. taconite mines, completed an unloading facility in 1979 that can accommodate 1,000-foot carriers. The Nanticoke facility can handle up to 6,000 mt of pellets per hour and has a stockpiling capacity of 860,000 mt of pellets and 1.06 Mmt of coal.[37]

U.S. coastal ports are still limited to incoming cargoes of 65,000 mt or less. Hunterston, Rotterdam, Taranto, and several other ports in Western Europe can now accommodate iron ore cargoes of 150,000 to 300,000 mt. The Ertsoverslagbedrijf Europoort terminal west of Rotterdam currently holds the world record for the largest single cargo of iron ore ever unloaded. On August 22, 1989, 356,541 mt of Carajas sinter feed and natural pellet ore was delivered to the terminal by the world's largest ore carrier, the 365,000-deadweight-ton (dwt) *Berge Stahl*. The *Berge Stahl* and the *Docefjord*, another vessel capable of carrying more than 300,000 mt of ore, were built in 1986, primarily for trade between Brazil and Japan. In Japan, cargoes of 200,000 to 260,000 mt can be accommodated at Fukuyama, Kakogawa, Keihin, and Oita. Similar size cargoes are also routinely delivered to the island of Mindanao in the Philippines for sintering. The 351-m/long main berth of the Philippine Sinter Corp. has a depth of 23 m and can handle all but the very largest vessels that load at Ponta da Madeira. The three major loading ports in Western Australia—Dampier, Port Hedland, and Port Walcott—have all been modernized and had their berths deepened to permit loading of ore carriers of the 250,000-dwt class.

Two major pipelines for transport of iron ore slurries were completed in northern Mexico in 1983, connecting the La Perla and Hercules Mines with a pelletizing plant in Monclova. An 8-inch, 87-km line from La Perla is connected to a 14-inch, 295-km line that runs from the Hercules Mine to Monclova. The pipeline system can transport up to 4.5 Mmt of iron ore concentrates per year. A second system is operating in the Pacific Cordillera of Mexico. Two parallel lines transport concentrates 45 km from the Pena Colorada Mine in the mountains of northwestern Colima down to a pelletizing plant on the coast near Manzanillo. The 900-m drop in elevation permits the lines to be gravity operated. Major pipelines have also been built in Brazil and India since 1977, and others are operating in Argentina, Australia, New Zealand, and Peru.

ANNUAL REVIEW

Legislation and Government Programs

The Clean Air Act Amendments of 1990 were signed into law by the President on

November 15. The new law (Public Law 101-549) updates Federal air pollution standards for the first time since 1977 and is one of the more significant pieces of environmental legislation enacted to date by the Congress. The 1990 amendments establish specific programs to control pollutants that cause acid rain and ozone depletion. The hazardous air pollutants program is also being completely overhauled. The new legislation will have a major economic impact on the iron and steel industry and will require steelworks to obtain operating permits from appropriate regulatory agencies. Operations specifically mentioned in the new regulations include iron and steel mills, coke oven batteries, sintering plants, taconite ore processing plants, and fossil fuel-fired steam electric plants. EPA is required to publish a list of major sources of hazardous air pollutants by November 15, 1991.

The legislation also requires DOE and EPA to undertake a 6-year study of coke oven emission control technologies. Five million dollars per year has been appropriated to carry out the program from 1992 through 1997. Regulatory standards for coke oven batteries are to be issued by December 31, 1992.

The new acid rain program focuses on two pollutants: sulfur dioxide (SO_2) and nitrogen oxides (NO_x). That part of the program will impact both pelletizing plants and the coal-fired electric generating stations that provide power to the giant agglomerating operations.

Production

The North American iron ore industry has strengthened its position considerably over the past 4 years. In 1986, a number of U.S. and Canadian mine owners had serious financial problems, and at least five were tied up in complex bankruptcy litigation. However, by reducing costs, recapitalizing, adopting new technologies, and improving pellet quality, the majority of producers were able to successfully extricate themselves from a difficult situation. By 1988, demand for finished steel products had improved dramatically on both sides of the border, and most iron ore operations in the United States had returned to profitability. Two relatively small pelletizing plants in Ontario, though, could no longer compete with the three giants of the Quebec-Labrador Trough and were forced to close. In 1989, U.S. mine shipments totaled 58.30 Mmt, the highest since 1981. The Canadian industry also had a good year in 1989, with shipments reaching 40.69 Mmt.

Secondary factors contributing to the 1988-89 turnaround were the weak U.S. dollar, which made the importation of some steels less attractive and increased exports of goods fabricated from steel; higher prices for quality steel scrap; and increased demand for steel worldwide. In the United States, the Federal Voluntary Restraint Agreements program gave additional momentum to the recovery by reducing steel imports to a little more than 20% of the U.S. market.

In the fourth quarter of 1990 and first quarter of 1991, recessionary forces brought the recovery to a halt. These forces were fueled by serious problems in the banking and real estate sectors. Domestic ore sales, which had been stable after leveling off in early 1990, took a downturn in December. The downturn was too late in the year to drastically affect the 1990 totals. As a result, overall shipments for the year reached a respectable 57.01 Mmt. Shipments would have been higher if the Empire and Minorca Mines had not been shut down for 4 months by the wage dispute between CCI and the USWA.

Iron ore was produced by 22 open pit mines and 1 underground mine. Fifteen mines produced ore for the iron and steel industry, while the remainder shipped ore mainly to cement plants. Installed production capacity for usable ore on December 31, 1990, was estimated at 83 Mmt/yr, including 81 Mmt of capacity for pellets. Effective production capacity for pellets was at least 15 Mmt less than installed capacity. Only 2 of the 10 active pelletizing plants utilized more than 85% of their installed capacities, despite the upswing in demand since 1987. Total output of usable ore was equivalent to about 68% of installed production capacity, down from 71% in 1989. This drop in utilization was due partly to weakening steel demand and partly to the startup of Cyprus.

An average of 3.2 mt of crude ore was mined in 1990 for each mt of usable ore produced. This ratio does not take into account the tonnage of waste rock or overburden removed. The ratio of total materials mined to usable ore produced was probably greater than 5:1. Low-grade ores of the taconite type mined in Michigan and Minnesota accounted for 99% of total crude ore production. U.S. production of pellets totaled 54.82 Mmt, 97% of usable ore output. The average iron content of usable ore produced was 63.3%.

Shipments from U.S. loading docks on the upper Great Lakes totaled 51.10 Mmt in 1990. The dock shipment figure was only slightly less than that of 1989, despite the labor dispute in Michigan. Because of the strike, shipments from Marquette for the year amounted to only 5.04 Mmt compared with 9.62 Mmt in 1989. The decrease at Marquette was offset, though, by the reopening of Silver Bay and increased loadings at three other Minnesota ports. The reopened port handled 2.11 Mmt of pellets and chips between April 19 (when the first vessel docked) and December 31. An additional 71,000 mt was loaded at Silver Bay in the first half of January 1991 before the U.S. Army Corps of Engineers closed the locks at Sault Ste. Marie for the winter.

Employment.—Statistics on employment and productivity in the U.S. iron ore industry in 1990, shown in table 2, were derived from quarterly employment data supplied by the Mine Safety and Health Administration (MSHA) and from production data derived from U.S. Bureau of Mines surveys. Both sets of data were obtained from producers' reports.

The statistics include production workers employed at mines, concentrators, pelletizing plants, and in repair and maintenance shops, but do not include 830 persons engaged in management, research, or officework at mines and plants. Employees engaged in ore preparation, such as sintering, at blast furnace sites are not included. An additional 98 individuals were engaged in the secondary beneficiation of iron ore for heavy-media and other nonsteel uses. The number of employees in this last category shrank 30% between 1989 and 1990 when NL Chemicals Inc. shut down its byproduct magnetite recovery operations at Tahawus, NY.

Because employment data reported to MSHA are primarily for safety analysis, hours spent by salaried employees in mines or plants may be included by operators in the total number of hours worked at individual mines or plants. This has resulted in understatement of calculated productivity by 10% to 25% for some operations, but its effect on others is not known. If company reporting practice is consistent, however, comparison of productivity from one year to the next should be reasonably valid.

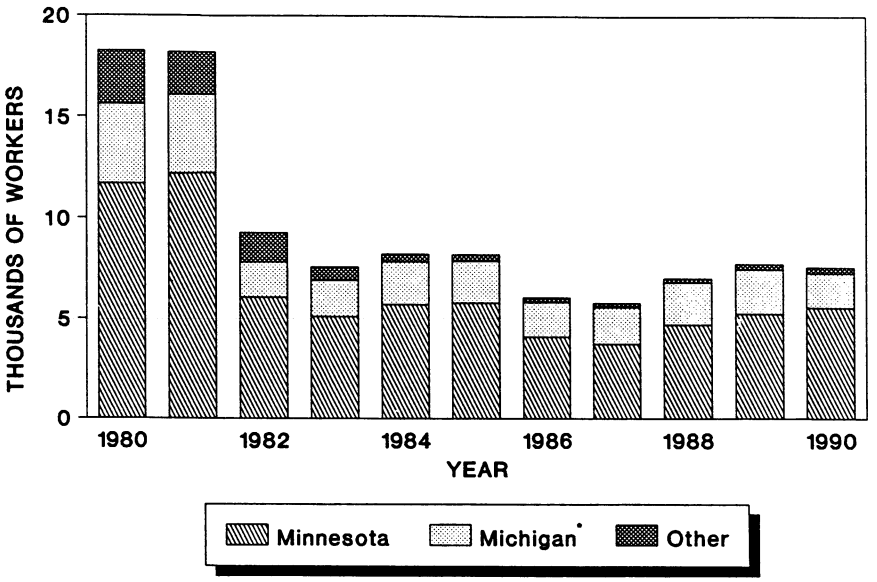
Average quarterly employment was slightly less than that of 1989, with at least two mine operators temporarily laying off

workers because of declining pellet demand from domestic steel producers. Because of the layoffs, the iron ore industry reduced its output of usable ore by 4%. The relatively small loss in output is somewhat misleading because 214 production workers were recalled during the last quarter of 1989 to help renovate the idled operations at Silver Bay and Babbitt, MN.

Total hours worked were almost identical to the 1989 figure despite the 4-month strike in Michigan and decreased level of production. The decrease in demand came at a time when at least three operations in the Lake Superior District had begun switching over to fluxed pellet production or making other major technological improvements. The conversion to fluxed pellets adversely affected productivity because pelletizing lines and grinding lines had to be shut down so that existing equipment could be modified and new equipment installed. As a result, operating parameters and procedures had to be readjusted. The switchover at the Tilden Mine from hematite to magnetite also helped to temporarily lower productivity. Consequently, average productivity for usable ore in the Lake Superior District was 3.5% lower than that of 1989. Because the district accounts for the bulk of U.S. output, the average productivity for the entire industry dropped 4.5%.

FIGURE 10

EMPLOYMENT AT IRON MINES AND BENEFICIATING PLANTS



Includes workers in Wisconsin for years prior to 1984.

Bankruptcy Settlements and Labor Agreements.—The iron ore industry of Canada and the United States continued to untangle itself from the web of financial and legal problems created by the collapse of steel demand in 1985 and 1986. LTV Corp., Sharon Steel Corp., and Wheeling-Pittsburgh Steel Corp. were all forced to file for bankruptcy at the time of the collapse, but continued to operate under the protection of chapter 11 of the Federal Bankruptcy Code. The bankruptcy problems of the three integrated steel producers spilled over into the iron ore industry, which had been under direct control of United States and Canadian steel companies for decades. The Reserve Mining Co., a 50-50 joint venture between Armco Inc. and LTV, was forced to suspend production in July 1986 and was eventually sold by the bankruptcy court to Cyprus Minerals Co. in August 1989. From 1987 to 1989, the mining partners of the bankrupt steel companies continued to ship pellets to the three companies' blast furnaces and relied on the courts and lengthy legal negotiations to resolve their financial claims. Sharon Steel and Wheeling-Pittsburgh have since been reorganized, and the majority of the claims against these two steelmakers have been settled.

On December 18, 1990, the U.S. Bankruptcy Court approved Wheeling-Pittsburgh's reorganization plan. The plan included a settlement agreement between Wheeling-Pittsburgh and CCI that satisfied several of CCI's claims against the reorganized West Virginia steelmaker. Under the settlement, CCI received from the steel company $56.0 million in cash plus common stock valued at $10.9 million. Wabush Mines, a Canadian joint venture managed by CCI, received $33.3 million in cash together with Wheeling stock valued at $6.4 million. CCI's indirect share of the Wabush settlement was $4.4 million. The Wheeling bankruptcy settlement thus resulted in a total gain of $71.3 million for CCI, netting the iron ore merchant $47.1 million after taxes. The CCI claims date back to 1985 when Wheeling-Pittsburgh defaulted on its Tilden, Wabush, and Empire partnership obligations. Wheeling-Pittsburgh regained its 9.95% interest in the Empire partnership on January 1, 1989, as part of a preliminary settlement, but was forced to surrender its 4.0% interest in the Tilden Mining Co. to CCI. The Cleveland-based iron ore merchant has been managing the Tilden Mine since its startup in 1974.

Sharon Steel Corp., another former partner in the Tilden Mining Co., also emerged from bankruptcy proceedings at the end of 1990. Under the reorganization plan approved by the U.S. Bankruptcy Court on December 28, two independent companies were created from the old integrated steel producer: Mueller Industries Inc. and a new Sharon Steel Corp. The new steel company was formed when Castle Harlan Inc., an investor group, purchased Sharon's steel assets as part of the overall reorganization. Sharon has two blast furnaces, one basic oxygen furnace, and two electric furnaces at Farrell, PA. The company also operates a coke plant at nearby Monessen.

Sharon's reorganization plan included settlement of a $27 million claim brought against the steelmaker by CCI. The claim was filed after Sharon filed for protection under chapter 11 in April 1987. As part of the 1990 settlement, CCI took over Sharon's 5.0% interest in the Tilden Mining Co. In addition, CCI received 312,120 shares of Mueller common stock plus a promissory note from Mueller for $780,000.

The Mueller stock brought $3.5 million when it was sold in early 1991. From 1987 to December 1990, Sharon continued to take pellets from Tilden as part of an interim agreement with CCI. CCI has agreed to supply all of the iron ore requirements of the successor steel company for the near future.

On June 18, 1990, the U.S. Supreme Court ruled that the Pension Benefit Guarantee Corp. could force LTV Corp. to resume responsibility for its underfunded pension plans. This ruling was expected to further delay LTV's bankruptcy reorganization. On June 28, 1989, CCI executed an agreement with LTV that tentatively settled the iron ore merchant's bankruptcy claims against LTV Steel Co. Inc., the steelmaking group of LTV Corp. CCI brought suit after LTV Steel rejected its Tilden Mine obligations, related purchase contracts, and a royalty agreement at its LTV Steel Mining Co. subsidiary. Under terms of the settlement, CCI received an unsecured claim of $205 million for damages. CCI also assumed an additional 10% interest in the adjoining Empire Mine from LTV on January 1, 1990. The equity transfer left each company with a 25% interest in Empire, which had the capacity to produce 8.1 Mmt/yr of fluxed pellets. Other partners in the mine were Inland Steel Co. (40%) and Wheeling-Pittsburgh (10%). CCI also had the right to supply 75% of any future iron ore requirements of LTV above its existing equity interests as long as CCI's prices were competitive. The terms of the settlement were approved by the U.S. Bankruptcy Court for the Southern District of New York on August 17, 1989. As part of the settlement, LTV agreed to reject its 12% interest in the Tilden Mining Co. However, the claims of several major creditor groups were still to be resolved.

Wabush Mines of Labrador and Quebec was allowed a similar claim of $59 million, but two lesser claims by Wabush were being disputed. Prior to its filing, LTV had a 15.6% interest in the Canadian joint venture. At yearend 1990, Stelco, Dofasco, and the four other partners were still negotiating with LTV. An exchange of equities was proposed in 1989, but the details were never worked out. The 10.2% interest formerly held by Wheeling-Pittsburgh was being held in trust for the other owners.

The 4-month mine strike in Michigan was costly to both labor and management and accomplished little. The strike ran from August 1 to December 1 and idled 1,800 members of the United Steelworkers of America (USWA) at the Empire and Tilden Mines. The Cleveland-Cliffs Iron Co., which represented the mine owners, and the union could not agree on a new contract when the old one expired on July 30. The dispute involved not only wages, but also pension rights and cost-of-living escalators. Cleveland-Cliffs Iron made several offers based on settlements made in 1989 and 1990 at other U.S. iron ore and steel operations. Union leaders, though, were concerned about the erosion of real wages and refused to back down from their demands. The walkout triggered layoffs at several related operations, including the Lake Superior and Ishpeming Railroad, which hauls pellets from the mines to the Presque Isle ore dock on Lake Superior, and the Chicago and Northwestern Railway, which hauls pellets to the Escanaba ore dock on Lake Michigan.

An agreement was finally reached in late November with the aid of a Federal mediator. The new contract, which expires on July 31, 1993, immediately raised wages an average of $1.25 per hour. Workers will receive an additional $0.25 per hour raise on January 1, 1992. The 122-day strike was the longest in the history of the two mines. The last strike was in 1977 and lasted 114 days. Tilden has traditionally supplied pellets to steelworks operated in Canada by The Algoma Steel Corp. Ltd. and Stelco Inc. Algoma and Stelco were struck at the same time as the Michigan mines, causing a sharp drop in U.S. exports of pellets. The Tilden Magnetite Partnership is a joint venture of Algoma (50% equity), CCI (33.3%), and Stelco (16.7%). The Canadian steel strike was settled on November 21, 10 days before the Michigan strike ended. The Interlake Steamship Co. and other Great Lakes carriers worked long hours throughout December and early January to move backlogged tonnage before pack ice formed and halted operations until spring. The strike reportedly reduced the 1990 operating earnings of CCI by as much as 50%. It also came at a time when Algoma was experiencing financial difficulties.

In March 1991, USX Corp. and the USWA signed a new 3-year labor contract, narrowly avoiding a second costly and damaging strike. The new contract restored about $1.00 per hour in wage sacrifices made by the steelworkers during the 1982-83 recession and raised wages an additional $1.50 per hour. The base salary for USX steelworkers at the end of 1990 was $11.23 per hour. USX rejected the union's demand for cost-of-living increases, but agreed to pay a cost-of-living bonus of $2,500 over the next 3 years.

The agreement also contained clauses that would protect the steelworkers should USX sell all or part of its steel operations. The company agreed to guarantee all accrued pension benefits in the event of a sale or spinoff. This concession was extremely important to the 20,000 rank-and-file members. Many of the steelworkers were concerned that management's upcoming plans to divide the company's common stock into separate steel and energy issues would eventually lead to either a breakup or a significant downsizing of the steel group.

Minnesota.—Minnesota produced 80% of the national output of usable ore in 1990. All of the State's production came from open pit mines on the Mesabi Range. Production of pellets totaled 44.63 Mmt, equivalent to about 71% of installed production capacity of the State's seven taconite plants. Utilization of active pelletizing capacity by the seven, though, was 91%. The remainder of the output consisted of hematite concentrates produced by LTV Steel from natural ores.

Cyprus Northshore Mining Corp. spent more than $30 million refurbishing the mining and pelletizing complex of the defunct Reserve Mining Co. at the northeastern end of the Range.[38] Cyprus Minerals Co., Northshore's parent, acquired the complex in August 1989 after successfully bidding $52 million for Reserve's assets in Federal bankruptcy court. The taconite operation had been idle since August 1986 when Reserve filed for protection under chapter 11 of the Federal Bankruptcy Code. After settlement, Cyprus moved quickly to reopen both the Peter Mitchell Mine at Babbitt and the E. W. Davis pelletizing plant at Silver Bay. The two facilities required immediate attention because some of the equipment had begun to deteriorate from lack of maintenance. Key pieces of equipment had also been cannibalized earlier by the bankruptcy trustee to pay expenses.

Cyprus wisely hired most of the former Reserve employees. The employees, whose average age was more than 50, were quickly able to solve numerous refurbishing problems because of their familiarity with the deteriorated equipment and other aspects of the mothballed operation. On January 5, 1990, 120-car unit trains began hauling

crushed ore on the 76-km-long railroad extending from Babbitt to the concentrator at Silver Bay. However, on January 12, a fire broke out in the pelletizing plant 3 days before the plant was to begin production. The fire destroyed two electrostatic dust collectors and caused an estimated $1 million damage to the fluid ionics section of the plant. The damage was quickly repaired, and pellet production began on January 27 with the startup of the No. 12 furnace. The No. 11 furnace was reactivated on March 10.

On April 19, Cyprus began shipping pellets from its Silver Bay dock. The first cargo of 21,900 mt went to one of the steelworks operated by Armco Inc. L.P. in the Ohio River Valley. Armco, a former partner in Reserve, had previously signed a 7-year contract with Cyprus as part of the Reserve settlement. Additional details on the startup of Cyprus Northshore are given in reference 38. The standard acid pellet being made by Cyprus contained 63.74% iron (Fe), 4.74% silica (SiO_2), and 0.020% phosphorus (P) on a wet basis.

The Northshore operation produced a total of 2.43 Mmt in 1990,[39] of which about 1.5 Mmt went to Armco. Cyprus' other customers reportedly included Algoma, Bethlehem Steel, Shenango Inc., and Wheeling-Pittsburgh. If all goes well, the complex could be producing 4.0 Mmt/yr by 1994. Reserve removed so much overburden at the mine between 1979 and 1983 that mining can be carried out for 10 to 14 years with little or no additional stripping. At the end of 1990, Cyprus had 112 employees at Babbitt and 323 at Silver Bay.

In mid-September, Inland Steel Mining Co. began construction of its new Laurentian Taconite Mine. The site is southeast of the City of Virginia, between Gilbert and McKinley. The Minnesota Department of Natural Resources (DNR) released the Final Environmental Impact Statement (EIS) for the mine on August 27 and issued the necessary mining permit on September 18. The project is the first new mine to be constructed on the Range in more than a decade. Inland immediately began clearing the site and was ready to blast at yearend. Inland Steel Mining is a wholly owned subsidiary of the Inland Steel Co. The new open pit operation will provide iron units for the parent company's integrated steelworks at Indiana Harbor, IN.

By May 1991, crude taconite from the first benches was being trucked 10 km to Inland's existing Minorca mining and pelletizing complex on the northeastern edge of Virginia. The Laurentian taconite is replacing ore from the Minorca pit, where reserves are almost exhausted. The new mine will enable the 2.5-Mmt/yr pelletizing plant to continue operating until the year 2031. The 4.9-km^2 (1,200-acre) project includes a service building and a 2.4-km^2 (600-acre) stockpile area in addition to the haul road and 1.8-km^2 (440-acre) pit. When completed, the service building will have an equipment maintenance shop, a change room for employees, and offices. The initial stage of the project cost more than $10 million. Inland expects to spend at least another $10 million to fully develop the Laurentian Mine site.

Like Minorca, the ore occurs in the Biwabik Iron Formation of Early Proterozoic age (1.9 to 2.2 billion years old). Approximately 0.92 million cubic meters of glacial overburden is being removed from the north end of the ore body. The overburden was being hauled to the western third of the stockpile area and kept separately from both the waste rock and lean taconite. The first $10 million covered the costs of removing part of the overburden, constructing the haul road, and installing electrical transmission lines. The electrical power substation at the mine site is now operational.

Minorca produced 2.50 Mmt of fluxed pellets in 1990, almost breaking the record set in 1989, and continued to operate at full capacity. At the current rate of production, the existing pit at Minorca would have been exhausted by the end of 1992 without supplemental ore from the Laurentian. The Laurentian ore body provides the plant with more than 15 years of reserves. Inland also hoped to negotiate leases on adjoining properties that could supply another 25 years of reserves. Inland has additional ore at two other sites—the Ordean Reserve west of Minorca and the East Rouchleau pit on the outskirts of Virginia.

In June 1991, Inland began blending the Laurentian ore with ore from Minorca. The blending may be able to extend the life of the Minorca pit until 1995, when mining would be shifted entirely to the new ore body. A dedicated haul road was constructed from the pelletizing plant through the Pike River Basin to the mine site. The use of a conveyor system in place of the haul road was not considered economically feasible. During the public review and comment period, homeowners in Gilbert expressed concerns about the dust and noise that would be created by the mine trucks, blasting, and various stockpile activities. Inland has agreed to water the haul road and has built a series of berms to reduce nuisance noise from the operation. Overburden and waste rock were used to construct a 12-m-high sound barrier along the section of haul road that borders Gilbert. Inland was experimenting with several new methods of blasting designed to minimize ground shock to homeowners. The company has also instituted a blast monitoring program to minimize air shock noise and further reduce the risk of vibration damage.

Environmental permits had to be obtained from the U.S. Army Corps of Engineers, the Minnesota DNR, the Minnesota Pollution Control Agency (MPCA), and three local governments before construction could start. Although the EIS addressed a variety of environmental and socioeconomic issues, special emphasis was given to the operation's impact on surface water and ground water. The MPCA, the city of McKinley, and several other parties were concerned about the effect that mine dewatering would have on local water levels. The Laurentian site is bordered on the south and southeast by seven abandoned open pits that are now filled with water. One of these pits, the Corsica Mine, serves as the water supply for McKinley. Another four form Lake Orebegone, a local recreational area. There are also several natural lakes in the immediate area. On the north side, the new haul road cuts through the protected Pike River headwaters and its environmentally sensitive wetlands. The project will eventually remove or alter approximately 3.5 km^2 (860 acres) of forest and 0.29 km^2 (71 acres) of wetlands. Dewatering discharge will be rerouted to restore water levels in wetlands and lakes affected by ground water changes. Aeration systems will be installed in key lakes to lessen the impact on fish, and revegetation programs would be undertaken to restore wildlife habitat. If the Laurentian Mine had not been developed, the Minorca complex would have been forced to close sometime between 1992 and 1995. The community would have lost more than 300 jobs and a $12 million per year payroll.

National Steel Pellet Co. (NSPC) produced a record high 4.89 Mmt of standard acid pellets at its Keewatin complex in 1990.[40] The pellets averaged 65.10% Fe, 4.93% SiO_2, and 0.010% P on a wet basis. The complex, situated at the southwestern end of the Mesabi Range, operated above

its rated capacity for most of the year. About 66% of the production was railed on the Burlington Northern to the Allouez Terminal at Superior, WI, and later loaded onto vessels for delivery to the Great Lakes steelworks of National Steel Corp. (NSC) in Detroit. The remaining 34% was hauled in 135-car unit trains to NSC's smaller steelworks at Granite City, IL. The unit trains going to Superior were somewhat longer than those bound for Granite City and were made up of approximately 160 cars. In both cases, each car held about 90 mt of pellets.

NSPC was a wholly owned subsidiary of NSC. NSC was controlled in turn by NKK Corp., the second largest steel producer in Japan. In 1990, NKK increased its equity in NSC from 50% to 86.7%. The remaining 13.3% was held by National Intergroup Inc.

In recent years, NSPC has been exploring ways of lowering its grinding costs. The 5.9-Mmt/yr concentrator at Keewatin has 10 grinding lines, each of which has a 27- by 18-foot semiautogenous mill charged with relatively expensive, 5-inch grinding balls. Plant personnel believe that these balls can be eliminated by linking each of the semiautogenous mills to a pebble crushing circuit. The No. 10 grinding line was being used as a test unit. Taconite pebbles greater than 3 inches in diameter were being removed from the mill on a continuous basis, shattered in a cone crusher, and then fed back into the mill in minus ¾-inch fragments.

All of LTV Steel's natural ore production came from its McKinley Extension Mine, 4 km north of Aurora. The mine, operated by LTV Steel's Northwest Ore Div. under a lease from USX, shipped 416,000 mt of beneficiated sinter fines and 13,000 mt of 1- by 4-inch coarse ore in 1990.[41] The lump ore was being added by LTV Steel and outside customers to their electric arc furnaces to assist in the oxidation of impurities and to serve as a coolant.

Reserves at the McKinley Extension are almost exhausted, and the operation is slated to close in the fall of 1993. Crews are to begin dismantling the beneficiation plant in late 1992. Mining has been restricted to the Donora pit since 1990 when the last 15,000 mt was removed from the adjoining Stephens pit. The Donora crude ore has been averaging 57% to 58% Fe. The Connie Mine was reactivated in May 1991 to supplement the McKinley Extension's output during the 2-year phaseout. Pittsburgh Pacific Co. shut down the Connie in 1979, but continued to process ore stockpiled at the site intermittently until 1988. The new contractor is Premier Aggregates Inc.

Excessive pelletizing capacity continued to be a problem for LTV Steel Mining. LTV Steel Mining owns the third largest operation on the Range. The complex is at Hoyt Lakes, 32 km east of the city of Virginia. The Hoyt Lakes operation has a rated annual capacity of 8.1 Mmt of standard acid pellets and shipped 7.95 Mmt in 1990. The design capacity of the mining complex is significantly higher than the rated figure published and is about 11 Mmt/yr. CCI manages the Hoyt Lakes operation for LTV Steel. The complex made 8.14 Mmt of products during the year. The total included 7.70 Mmt of pellets, 378,000 mt of chips, and 69,000 mt of filter cake. Almost all of the production was railed to ore docks at Taconite Harbor for loading into self-unloaders. From there, the bulk of the material went to LTV's steelworks at Indiana Harbor, IN. A fifth flotation line has been installed at the Hoyt Lakes plant to help lower the silica content of the concentrate. Carbinder was also being added during the balling stage as a partial substitute for bentonite, further reducing the silica content of the fired pellet. Because of these improvements, LTV's average silica content (on a wet basis) has dropped from 5.20% in 1987 to 4.94%.

In January 1990, representatives of LTV Steel Mining met with MPCA officials to discuss ways of improving the quality of surface waters in the vicinity of the Dunka pit. The Dunka pit, 6 km east of Babbitt at the northeastern tip of the Mesabi Range, was one of six pits supplying crude taconite to the Hoyt Lakes plant. In early 1989, environmental monitoring teams discovered that rain and melted snow percolating through 4.9 km^2 (1,200 acres) of stockpiled waste rock were picking up excessive amounts of cobalt, nickel, and zinc. The three metals apparently were being leached from minor sulfides that had begun to oxidize in some of the stockpiles. A number of remedial actions were taken during the year to minimize leaching. Reconfiguring some of the waste piles helped correct part of the problem.

The Hibbing Taconite Co. (Hibtac) operated at almost full capacity throughout 1990, producing 8.41 Mmt of standard pellets.[42] The mining staff moved a record 47.9 Mmt of crude ore and overburden, but pellet production fell somewhat short of the record 8.79 Mmt made in 1988. The company began producing ore from its new Mahoning IV pit in August 1990. The pit is 5 km southwest of the main Section 36 pit that started up in 1976. The new mining area encompasses parts of the former Mahoning natural ore pit, worked by Pickands Mather & Co. from 1923 to 1973. At the present rate of production, Hibtac has enough reserves of magnetic taconite to permit mining to continue until the year 2022. Since 1989, five 240-short-ton haulage trucks have been added to the fleet. The fleet also includes seventeen 170-ton and three 120-ton trucks. Eighteen of the 25 trucks normally operate on a shift. The pelletizing plant, which was expanded in 1979 to 8.2 Mmt, had an effective capacity of 9.0 Mmt at the end of 1990. Hibtac's biggest customer was Bethlehem Steel, which owned 70.3% of the joint venture. The remaining equity was divided between CCI (15.0%), which managed the complex, and Stelco (14.7%).

Minntac, the largest iron mine in the United States, produced 12.15 Mmt of fluxed pellets and 1.53 Mmt of standard acid pellets.[43] The complex at Mountain Iron is now the largest producer of fluxed pellets in the world and is owned and operated by the USS steel segment of USX. The 1990 output came close to breaking the 14.37 Mmt record set in 1980, when only acid pellets were made, but was still far short of the pelletizing plant's installed capacity of almost 19 Mmt.

USX has been producing fluxed pellets since 1988. The limestone-dolomite fluxed pellet made during the 1990 campaign contained 62.26% Fe and 3.93% SiO_2 on a wet basis. The acid pellet had slightly higher values—64.58% for Fe and 5.32% SiO_2. The pelletizing plant received 1.01 Mmt of fluxstone during the year. The 50-50 blend of limestone and dolomite was being shipped from Michigan to Duluth in self-unloaders and then transferred to DM&IR ore cars that would normally return empty to the plant.

An additional 2-Mmt/yr pelletizing line, idle since 1982, was started up in August 1989 to meet increased demand for fluxed pellets from the company's blast furnaces at Gary, IN, and Braddock, PA. Most of the acid pellets went to the USS and Kobe Steel Co. joint venture at Lorain, OH. About 1.31 Mmt of fluxed pellets was railed to Geneva Steel's works at Orem, UT, as part of a 5-year contract signed in 1987.

The output of Eveleth Mines dropped slightly from the 4-year high of 1989. The

joint venture produced 4.57 Mmt of partially fluxed pellets, 9% less than in 1989. The magnetite concentrate from the taconite was mixed with Peridur and a 1% limestone additive to make a pellet averaging 64.54% Fe, 5.03% SiO_2, 0.015% P, and 0.75% lime (CaO) on a wet basis. The limestone comes from the quarries of the Iowa Limestone Co. near Des Moines. Eveleth was managed and partly owned by the Oglebay Norton Co., which had an 18.5% equity in the venture. The remaining equity was divided between Armco Inc. (35.1%), the Rouge Steel Co. (31.7%), and Stelco (14.7%). The Fairlane pelletizing plant has a total effective capacity of 6.2 Mmt/yr, but only the newer of its two lines has been in continuous operation in recent years. This newer line, commissioned in 1976, operated at 90% of capacity during the year, producing 3.39 Mmt. The older line, which dates back to 1965 and is used only during periods of strong demand, made an additional 1.18 Mmt.

Eveleth's Thunderbird Mine consists of two pits. About three-fourths of the crude ore mined in 1990 came from the south pit. However, almost all of the stripping took place in the north pit. Eveleth was preparing to upgrade the crushing plant that serves the north pit. The upgrading will allow the company to put the south pit on standby and replace its output with increased production from the newly expanded north pit. At yearend, Eveleth employed about 600 hourly and 140 salaried personnel.

In October, explosives were used to demolish the last remnants of the Butler Taconite pelletizing plant in the south-central part of the Range. The demolition was part of the final stage of a 5-year closing process. The site is between the towns of Nashwauk and Pengilly. An extensive reclamation project will be initiated in cooperation with the State of Minnesota when the site is completely cleared. Butler Taconite, a joint venture of Inland Steel Co. (38.0%), M.A. Hanna Co. (37.5%), and Wheeling-Pittsburgh (24.5%), was closed in 1985 after Wheeling-Pittsburgh filed for bankruptcy protection. The 2.7-Mmt/yr mining and pelletizing complex was built on top of three exhausted natural ore mines and came on-line in March 1967. Butler Taconite shipped a total of 41.2 Mmt of pellets during its 18 years of operation.

Michigan.—Michigan accounted for only 17% of the national output of usable ore in 1990. Almost 99% 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 CCI's Cleveland-Cliffs Iron subsidiary. Empire shipped 5.90 Mmt of pellets produced from magnetite concentrate. Tilden shipped 2.19 Mmt of magnetite pellets and 2.04 Mmt of hematite pellets, for a total of 4.23 Mmt.[44] The company's wholly owned Republic Mine remained idle throughout the year.

Production of usable material was down 39% from the 1989 figure of 15.61 Mmt because of the labor dispute discussed earlier. Production of pellets totaled 9.37 Mmt, of which 5.35 Mmt was made at the Empire plant and 4.02 Mmt was made at Tilden.[45]

Algoma has been seeking a buyer for its holdings in Tilden since the spring of 1990. The Canadian steel company has been a partner in the upper Michigan venture since the complex's inception in 1972. The proposed sale is part of Algoma's efforts to restructure, retire debt, and focus on its core steel business. The restructuring comes 2½ years after Algoma was acquired by Dofasco Inc., another Canadian steel company. That acquisition made Dofasco the fourth largest steelmaker in North America.

Algoma owns and operates an integrated steelworks at Sault Ste. Marie, Ontario. In recent years, iron units for the four blast furnaces at Sault Ste. Marie have come from three principal sources:

- Tilden pellets have been brought in vessels across Lake Superior from Marquette.
- Superfluxed sinter has been railed 300 km along the northeastern shore of Lake Superior from Algoma's sintering plant at Wawa on the Michipicoten Range. The bulk of the iron units in the Wawa sinter has come from siderite mined at the neighboring George W. MacLeod Mine, an underground operation opened in 1960.
- Conventional sinter has been produced by Algoma at Sault Ste. Marie from ore fines and recycled waste materials. The one-strand plant, built in 1952, can produce 440,000 mt/yr of sinter.

Algoma is the principal partner in Tilden. The current equity ownerships for the venture are shown in figure 2. Two partnerships are involved: the new Tilden Magnetite Partnership and the older Tilden Mining Co. CCI manages the mining complex for the two partnerships and receives royalties and management fees based on production. CCI, one of the larger iron ore merchants in North America, has owned the property near Ishpeming since 1865. Algoma's fee payments to CCI had been averaging about $600,000 per month. The mine partnership arrangements were restructured between 1987 and 1988. Since then, the three partners have spent $30 million to develop the Cliffs Drive III magnetite ore body and upgrade the pelletizing plant so that it can process both magnetite and hematite.

As a result of its restructuring problems, Algoma may have to take fewer pellets from Tilden. Tilden had been scheduled to produce 6.7 Mmt in 1991, with 3.8 Mmt going to CCI, 2.6 Mmt to Algoma, and 300,000 mt to Stelco. In February 1991, CCI decided to accelerate its own take of pellets and increase its payments to the joint venture so that the scheduled production rate could be maintained at least until midyear. Since then, the 1991 production goal has been reduced to 5.0 Mmt, compared with 7.17 Mmt of pellets made during the transition year of 1989.

Because of the economic downturn, CCI's management took another look at its Republic Mine and was debating whether to decommission the complex. The mine has been on standby since October 1981.

Missouri.—The Pea Ridge Iron Ore Co. produced olivine-enriched pellets, magnetite concentrate, and iron oxide powder at its mining and pelletizing complex near Sullivan, MO. The company has the only active underground iron mine in the country and operates the smallest of the Nation's 10 active pelletizing plants. The mine is on the northeast flank of the Ozark uplift and has proven reserves of 160 Mmt tons of ore grading 55% magnetic iron. The mining and pelletizing complex was developed jointly by St. Joe Minerals Corp. and Bethlehem Steel Corp. between 1957 and 1964 at a cost of about $52 million. At that time, Pea Ridge was known as the Meramec Mining Co.

More than 90% of the 1990 production consisted of olivine-enriched pellets made from magnetite concentrate containing 70% Fe and less than 1% SiO_2. The addition of 5% olivine increases the reducibility of the pellet while improving its high-temperature properties in the blast furnace and increasing its resistance to low-temperature breakdown. The final product, the "Pro 18" flux pellet, averaged 64.28% Fe, 2.99% SiO_2, and 0.020% P on a wet basis. The silica content is significantly lower than that found in any of the Lake

Superior pellets. The magnesia (MgO) runs 1.92% and is similar to the magnesia levels of different fluxed pellets from Michigan. The complex also produced heavy-medium magnetite for coal cleaning, as well as a variety of iron oxides for ceramic magnets, brake linings, magnetic printing inks, and color pigments.

In the spring of 1990, Fluor Corp. sold Pea Ridge to Big River Minerals Corp. for $11.78 million. The sale resulted in a one-time gain of $8 million for Fluor, an engineering and construction company headquartered in Irvine, CA. Fluor acquired Pea Ridge in the 1981 takeover of St. Joe, but had been carrying the Missouri company as a discontinued operation since 1987. Big River is a diversified natural resource company formed by former executives of St. Joe and Fluor in late 1987 and is based in St. Louis. The parent company also has interests in a zinc refinery at Sauget, IL, and seven coal mines in Ohio and West Virginia.

According to Big River officials, Pea Ridge was planning to increase production of its heavy-media-grade of concentrate and was hoping to expand its niche in the coal preparation portion of the market. Shares in the heavy-media market had to be readjusted after NL Chemicals Inc. shut down its magnetite concentrating operation at Tahawus, NY, in November 1989.[46] Pea Ridge also sells an iron oxide powder known as M-25 that is used in the manufacturing of ceramic magnets. The high-purity, magnetic powder contains 71.9% Fe and has a mean particle size of 8 to 12 micrometers (μm). The company recently began producing a new type of pellet for the magnet industry. Hematite concentrate is used in place of magnetite as pellet feed. The new H-25 ferrite pellet is made with Peridur (the cellulose-based organic binder discussed earlier) and averages 69.7% Fe. The SiO_2 is only 0.21%, while the phosphorus content is the same as that in the "Pro 18"—0.020%.

Pea Ridge has initiated a long-term project to reduce iron oxide particulate emissions from its five shaft furnaces. Company officials have been working with the Missouri Department of Natural Resources (DNR) to improve air quality in the Sullivan area. In March 1990, DNR and company officials reached a settlement that should eventually bring the pelletizing plant in compliance with the Missouri Air Conservation Law. As part of the agreement, Pea Ridge had to install pollution control equipment on one of its five furnaces by September 30, 1990. The company and DNR are currently analyzing the test data for the modified furnace stack. If the tests show that particulate emissions have been reduced sufficiently to meet air quality standards, the company has agreed to install similar pollution control equipment on one furnace each year through 1994. DNR, on its part, will forgo any further enforcement against Pea Ridge for the duration of the agreement, which expires November 30, 1994.

In December 1990, Pea Ridge temporarily suspended production of blast-furnace-grade pellets after fulfilling its contract with National Steel. National Steel, the mine's principal customer, was forced to cut back hot-metal production at its Granite City steelworks when steel sales started to drop nationwide. The Illinois steelworks is only 160 km (100 miles) north of the mine, but is obligated to use acid pellets from NSPC's Keewatin complex on the Mesabi Range.

Pea Ridge continued to explore the feasibility of producing rare-earth oxides (REO) as a byproduct. At least seven different rare-earth minerals have been identified in breccia pipes, veins, or carbonate pods along the edges of the massive magnetite ore bodies.[47] Monazite (a cerium-lanthanum-yttrium-thorium phosphate), xenotime (a yttrium phosphate), and allanite (a cerium-yttrium epidote) are three of the more abundant ore minerals. The company has produced test quantities of a concentrate of mixed REO-bearing minerals and begun erecting a small pilot plant. The Rolla Research Center of the U.S. Bureau of Mines was working with Pea Ridge to improve recovery of different REO-bearing minerals. The Bureau was evaluating several beneficiation processes involving fine-particle gravity separation and froth flotation.[48] It may be possible to rework existing tailings from the iron ore concentrator. The REO concentrate from the tailings could then be blended together with the primary REO concentrate from the high-grade breccia ores. Marketing of the Pea Ridge REO concentrate should be relatively easy because yttrium and the highly valued members of the "heavy" rare-earth subgroup (terbium through lutetium) have been enriched relative to the "light" subgroup (cerium through gadolinium).

Utah.—Geneva Steel of Utah operated three open pit mines in the Iron Springs District of Iron County. The district, 24 km west of Cedar City, has provided magnetite and hematite ores for blast furnaces in the Rocky Mountain region on an intermittent basis since 1923. Coarse ore and fines were shipped 370 km on the Union Pacific Railroad to Geneva's integrated steelworks at Provo. The ore was hauled twice a week in 106-car unit trains. The actual mining was contracted out to the Gilbert Development Corp.

Run-of-mine ore averaging 54.0% Fe, 8.7% SiO_2, and 0.30% P was crushed and screened at the Comstock-Mountain Lion Mine, two adjoining properties on the northeast side of the Iron Mountain intrusion, east of Newcastle. Geneva had been working the Comstock under a lease from CF&I Steel Corp. of Pueblo, CO, but eventually decided to buy the mine outright. The sale was completed on August 1, 1990. The Utah steelmaker also acquired the Desert Mound Mine from USX. The Desert Mound Mine is in a low hilly area north of County Highway 253, about 1 km southwest of the Granite Mountain intrusion. The mine, an open pit operation, has been shut down since 1982. The ore body consists primarily of hematite and is part of a skarn created when Jurassic limestone was intruded by Granite Mountain quartz monzonite porphyry during Tertiary time.[49]

Ore was being shipped from the new Excellsior pit on Iron Mountain, about 1 km southwest of the older Comstock pit. The magnetite ore occurs in a 300-m-long fissure vein in quartz monzonite porphyry. The Excellsior material was averaging 56% Fe, 7.0% SiO_2, and 0.26% P on a wet basis. The neighboring Chespeak Mine was idle in 1990. Gilbert Development continued to produce wet screened and magnetically cobbed material from stockpiles of lean ore at the former Iron Mountain Mine, 3 km to the southwest, on the opposite side of Iron Mountain. The mine site was being used only as a processing point and had no production of its own. A total of 741,000 mt was shipped from the Iron Springs District in 1990.[50] About 45% of the material consisted of -10 mm (-⅜ inch) fines, which could not be charged directly into Geneva's three blast furnaces and had to be sintered.

Other States.—Three California mines produced iron ore during the year—the Baxter, the Beck, and the Soledad Canyon. The bulk of the shipments went to cement plants in the Los Angeles basin. The

Baxter and Beck Mines are both in San Bernardino County in the eastern half of the Mohave Desert. The Baxter Mine is operated by the California Portland Cement Co.; the Beck Mine, by Standard Industrial Minerals Inc. The P.W. Gillibrand Co. produced a magnetite concentrate as a byproduct of its Soledad Canyon sand and gravel operations in Los Angeles County. The Soledad Canyon District is at the northwestern end of the San Gabriel Mountains and encompasses parts of the environmentally sensitive Angeles National Forest. The district has several promising alluvial and lode deposits of titaniferous magnetite and ilmenite.

In South Dakota, Pete Lien & Sons Inc. mined low-grade hematite at the CF&I pit near Nemo in Lawrence County. The mine was reopened in 1988 after a hiatus of 9 years, but operated only during part of 1990. The company produced direct-shipping ore averaging 29.1% Fe. Production was limited by the relative remoteness of the Black Hills mine site from consumers. The bulk of the ore was shipped to the Dakota cement plant operated at Rapid City by the State Cement Commission. The ore comes from a 30- to 90-m-thick Precambrian iron formation that forms a ridge along the east side of Boxelder Valley. The BIF is severely folded and in some areas is partially buried under an escarpment of Paleozoic limestone and quartzite.[51]

Limited amounts of siderite and limonite were produced from the Eocene Weches Formation of east Texas. Mathis & Mathis Mining & Exploration Co. mined siderite at its Linden Mine in Cass County, while Hudson Brothers Mining Co. Inc. recovered a mixture of limonite and siderite from its Rusk Mine in Cherokee County. Algoma is the only other producer of siderite in North America.

Consumption and Uses

Consumption of ore and agglomerates held firm until December, when the country began experiencing the full effects of a general economic downturn. Consumer confidence dropped off significantly during the last few weeks of 1990 because of the deteriorating political situation in the Persian Gulf region and growing tension throughout the entire Middle East. The drop in consumer spending and concurrent cutback in business spending on new plants and equipment caused sales of products incorporating steel to weaken even further in the first quarter of 1991. The slackening of demand for steel was just one of several economic indicators signaling that the United States was entering its first significant downturn since 1982. The steel industry responded by reducing hot-metal production and mothballing unneeded blast furnaces.

In spite of the fourth quarter downturn in demand from the iron and steel industry, consumption of iron ore was slightly higher than the figure for 1989. Consumption for ironmaking and steelmaking totaled 74.27 Mmt, including 67.55 Mmt in blast furnaces, 5.81 Mmt in sintering plants, and 0.58 Mmt for production of DRI. Only 89,000 mt went into steelmaking furnaces. The use of iron ore in electric arc furnaces has fallen off dramatically over the past 20 years. An additional 235,000 mt was used by the industry for miscellaneous and unspecified purposes. Monthly consumption of pellets, direct-shipping ore, and merchant sinter by the industry averaged 6.14 Mmt compared with 6.09 Mmt in 1989. Reported consumption of iron ore for manufacture of cement, heavy-medium materials, animal feed, ballast, ferrites, pigments, and other nonsteel products was 940,000 mt.

The near-term outlook for the iron and steel industry is proving to be more austere than had been forecasted. At the end of 1990, the entire U.S. economy was struggling to overcome recessionary problems. U.S. production of hot metal and pig iron totaled 49.67 Mmt, only a 2% drop from that of 1989, but was expected to decline substantially more in 1991. Hot-metal and pig iron production was extremely stable throughout 1990, averaging 4.14 Mmt/month. The deviation from the mean was never more than 8% for any 1 month until December when pig iron production fell to 3.87 Mmt.

Monthly iron ore consumption statistics reflected this stability. Consumption of pellets, direct-shipping ore, and merchant sinter for the first 6 months was 36.18 Mmt, a 6% decrease from the same period in 1989. The situation improved somewhat in the second half of the year, with blast furnace output slightly exceeding corresponding 1989 levels. During 1990, the number of blast furnaces in operation ranged from 46 to 48. At yearend, 46 of the 79 blast furnaces available were on-line. Furnace operators had, on the average, enough ore in their yards to operate for 91 days. The monthly blast furnace data show how pig iron production had stabilized since 1986, when the number of furnaces operating dropped from 50 to 31 over a 7-month period. The industry continued to dismantle obsolete furnaces and improve active furnace utilization. Thirty-three blast furnaces had been scrapped since December 1983.

Consumption of iron ore and all types of agglomerates reported to the AISI by integrated producers of iron and steel totaled 75.33 Mmt. This included 60.56 Mmt of pellets; 12.24 Mmt of sinter, briquettes, etc; and 2.53 Mmt of natural coarse ore. Of the primary ore consumed, 76% was of domestic origin, 11% came from Canada, and 13% 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. In some operations, conventional ferrous scrap constituted as much as 7% of the blast furnace burden. According to AISI, 2.54 Mmt of ferrous scrap was consumed in blast furnaces in 1990.

The blast furnace of Shenango Group Inc. at Neville Island, PA, was permanently closed in December 1990 after 38 years of operation. The 408,000-mt/yr furnace was the last producer of merchant pig iron in the United States. One-half of the furnace's production went to Shenango's own foundry, with the rest sold on the open market.

Because of the weakening economy, LTV Corp. also banked one of two operational blast furnaces at its Cleveland, OH, works in December. Both were commissioned in 1972. The idled furnace was capable of producing 2,000 mt/d of hot metal. Three older, smaller blast furnaces at the works have been shut down for some time. The idling was necessitated by a dropoff in orders for steel from domestic automakers and appliance manufacturers. The LTV cutback in production was followed by similar cutbacks later in the month and in the first quarter of 1991 at the Armco Steel Co., Inland, and USX. By June 1991, four additional furnaces had been idled, leaving only 41 in operation.

Stocks

Stocks of iron ore and agglomerates reported at U.S. mines, docks, and consuming plants have been gradually dropping for more than 30 years. This trend temporarily reversed itself in 1988, but has since continued downward. At yearend,

total industry stocks were 21.57 Mmt, only 3% more than the record low set in 1987. Furnace yard stocks stood at 15.91 Mmt, a 56% drop from the 36.28 Mmt reported at yearend 1980. Combined stocks at furnace yards and receiving docks included 12.60 Mmt of domestic ores, 2.66 Mmt of Canadian ores, and 2.92 Mmt of other foreign ores, for a subtotal of 18.18 Mmt. Mine stocks at yearend were 11% less than those of 1989 primarily because of the mine strike in Michigan.

End-of-month stocks reported at mines peaked at 12.81 Mmt in March and continuously declined to 4.80 Mmt in December. Stocks of ore at consuming plants were 180 degrees out of phase with those at the mines, ranging from a low of 7.25 Mmt in April to a high of 15.91 Mmt in December. As in previous years, these variations were principally caused by the seasonal nature of ore shipping on the Great Lakes.

Stocks of unagglomerated concentrates reported at pelletizing plants totaled 0.98 Mmt at yearend and ranged in Fe content from 55% to 70%. 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 locks at Sault Ste. Marie, MI, remained the major weak point in the system. All of the ore going to domestic steelworks from the six ports on Lake Superior must pass through the Soo Locks. Relatively mild weather allowed the Corps of Engineers to keep the locks open until January 15, 1991. Ore shipments from Escanaba on Lake Michigan continued until January 31. The 1990-91 navigation season lasted 335 days (March 3 to February 1) and was the longest in more than a decade. In 1989, intense cold and the early formation of mature ice on the St. Marys River forced the Corps to close the locks on December 28, 2 weeks earlier than scheduled.

The U.S. Great Lakes fleet hauled 54.1 Mmt of ore, agglomerates, and related products during the 1990-91 season, 4% more than that in 1989. This increase was limited by below average water levels and the Michigan labor dispute. The fleet operated 64 of its 69 serviceable vessels, with the 64 vessels accounting for 97% of carrying capacity. Since 1980, the number of U.S.-flag vessels on the Great Lakes has dropped from about 140 to 69. At the same time, the average carrying capacity has risen from 20,900 mt to 27,900 mt. Of the 69 vessels, 64 were self-unloaders. However, 7 of the 69 were cement carriers, and 3 were self-propelled tankers.

Vessel shipments of iron ore from U.S. ports on the Upper Great Lakes totaled 51.65 Mmt, slightly more than those of 1989. Almost 94% was destined for U.S. consumers, with the rest going to Canada. Shipments of iron ore through the St. Lawrence Seaway to U.S. ports on the Great Lakes totaled 4.56 Mmt and accounted for 25% of U.S. imports. The balance of imports, 13.49 Mmt, was shipped primarily through ports on the east and gulf coasts.

Ore shipments from all five U.S. ports on the western shore of Lake Superior were up from 1989 levels, with the largest cumulative tonnage loaded at Two Harbors, MN. The cumulative tonnage shipped from each port in 1990 is shown in table 11. The number of vessel shipments was also slightly ahead of that of 1989. The combined number of shipments from the seven ports totaled 1,543, indicating an average cargo of 33,472 mt. In 1989, abnormally high water levels allowed individual cargoes of 60,000 mt or more to be loaded at five of the seven ports. In 1990, though, the water level in Lake Superior stayed below average the entire year. As a result, only one port, Escanaba on Lake Michigan, had any shipments exceeding 60,000 mt. The average shipment from individual ports ranged from 23,497 mt at Marquette to 40,513 mt at Two Harbors.

On July 23, 1990, The Interlake Steamship Co. and other lake carriers raised freight rates between 7% and 8% to offset reduced productivity created by lower water levels, increased shipyard expenses, and higher premiums for maritime insurance. The shipping industry continued to give discounts on class X vessels (i.e., vessels with hulls greater than 1,000 feet in length), but the discounts were less generous than in the past. The different rates are compared in table 12.

Published bulk vessel freight rates from the Gulf of St. Lawrence to Lake Erie and Lake Michigan were $5.00 and $7.00 per ton, respectively. Freight rates for self-unloading vessels were $1.50 per ton higher.

The two principal issues concerning U.S. lake shipping in 1990 continued to be the proposed construction of a second Poe-class lock at Sault Ste. Marie and the question of sharing domestic lake and coastal trade with Canadian and Mexican vessels.[52] The second issue resurfaced in 1987 during negotiation of the United States-Canada Free-Trade Agreement (FTA), causing both the Reagan and Bush Administrations to review the justifications for existing cabotage laws. Title I of the Merchant Marine Act of 1936 mandates that all domestic waterborne commerce be conducted in vessels that are built in, owned by, and crewed by the United States. The Government of Canada wanted these cabotage restrictions waived as part of the FTA. In exchange, U.S. vessels would have been allowed to carry cargo between Canadian ports. Because of the complexity of the cabotage issue, United States and Canadian negotiators agreed to exclude the controversial section dealing with maritime services from the final trade agreement. However, the cabotage issue could be resurrected at any time during the annual review process. United States and Canadian iron ore shipments on the Great Lakes for 1986-90 are compared in table 13. The need for a strong U.S. merchant marine was reinforced by the recent Persian Gulf War. The cabotage issue has been further complicated by the ongoing free trade negotiations with the Government of Mexico.

Construction of a second Poe-sized lock at Sault Ste. Marie continued to be stymied by funding problems.[53] The new lock was desperately needed as a backup to prevent total paralysis of bulk shipping on Lake Superior should the Poe be shut down for more than 30 days. The new lock would also be needed to accommodate the growing number of class X vessels projected for the 21st century.[54] The Water Resources Development Act of 1986 (section 1149 of Public Law 99-662) authorized construction of the new lock, but required 35% of the funding to come from non-Federal sources. In 1990, the Congress extended this authorization for an additional 5 years (section 107 of Public Law 101-640: Water Resources Development Act of 1990). Estimates made by the Corps of Engineers in October 1989 indicated that the lock would cost $256 million, but more recent figures suggest that the cost will approach $500 million.

The Soo Lock Funding Alternatives Task Force formed by the Great Lakes Commission has recommended that the lock be

built at full Federal expense. The task force concluded that the cost-sharing provision should be waived because of the uniqueness and international nature of the project.

All-rail shipments of iron ore and agglomerates in the United States and Canada totaled 7.57 Mmt, a drop of 20% from the 9.48 Mmt of 1989. Separate statistics for the United States are not published to protect proprietary company information. All-rail shipments of pellets from Minnesota by the DM&IR and connecting lines amounted to 2.65 Mmt, 15% more than the 2.31 Mmt hauled in 1989.[55] Shipments from USX's Minntac Mine at Mountain Iron to the Geneva works in Utah accounted for 1.35 Mmt or 51% of the all-rail total. An additional 1.02 Mmt of Minntac pellets was railed to USX's Edgar Thomson steelworks at Braddock, PA. About 155,000 mt of Minntac pellets went to the Chicago & Northwestern terminal at Escanaba for transhipment to Indiana Harbor. The 2.65 Mmt total also included 115,000 mt of Eveleth pellets that went to USX's Fairfield works near Birmingham, AL. Shipments of filter cake and miscellaneous ores accounted for another 110,000 mt. Shipments of pellets, small quantities of natural ore, and miscellaneous products to the Ports of Duluth and Two Harbors totaled 18.41 Mmt for a total ore movement on the railway of 21.17 Mmt during the 1990-91 shipping season. Approximately 1.71 Mmt of pellets was also hauled all rail via the Burlington Northern to NSC's two blast furnaces at Granite City, IL.

Published railway freight rates for pellets from mines to upper lake shipping ports were unchanged in Minnesota in 1990. The volume rate for pellets from the western Mesabi Range to the Allouez docks at Superior remained at $5.01 per long ton. On April 1, 1990, the rate for pellets from the Marquette Range of Michigan to Presque Isle was raised from $2.35 per long ton to $2.45. Three days later, the rate to Escanaba (delivered direct into vessel) was raised from $3.11 to $3.18. Escanaba also had various dock and handling charges ranging from 3.5 cents to about 29 cents per long ton.

Selected ore transfer charges at lower lake ports were raised slightly in the third quarter of 1990. At Lake Erie ports, dockage charges for self-unloaders ranged from 15 cents per long ton at Conneaut to 27 cents at Cleveland. Ore transfer charges for self-unloaders from rail-of-vessel via dock-receiving areas into railway cars varied from $1.09 to $1.21 per long ton.

Published nominal ocean freight rates for iron ore from eastern Canada to U.S. mid-Atlantic ports were $3.50 to $3.75 per dwt of cargo, but some spot rates quoted for cargoes of 60,000 to 110,000 dwt were as low as $2.75 per dwt.

Prices

Very few published prices for domestically produced pellets changed in 1990. CCI and Oglebay Norton were both still quoting a price of 72.45 cents per *long ton unit* of iron, natural, for their standard grades of Lake Superior pellets. A long ton unit (ltu) is equivalent to 0.01 long ton or 22.4 pounds. The quotation included delivery to rail-of-vessel at *lower* lake ports. The Eveleth special grade of Oglebay Norton was listed slightly higher at 74.00 cents per ltu. Mineral Services Inc. continued to quote its lower price of 58.00 cents per ltu set in August 1985. At that time, Pickands Mather and Inland abandoned the traditional lower lake pricing base and began quoting 59.40 cents per ltu for pellets delivered to hold of vessel at *upper* lake ports. At yearend 1987, Inland dropped the price of its Minorca pellets to 46.84 cents per ltu, but Pickands Mather refused to follow. The 59.40 and 46.84 quotations were still in effect at the end of 1990. USX also retained its 1987-89 quotation. The price for Minntac acid pellets was left at 37.344 cents per *dry* ltu of iron, delivered into railcars at the Minnesota mine. This price equated to about $24.12 per long ton of undried pellets containing 64.58% Fe and 1.39% moisture. The range of all of the above prices was approximately equivalent to $34.91 to $46.37 per long ton of pellets containing 64% Fe, delivered rail of vessel at lower lake ports. Some producers were charging a premium for fluxed pellets.

Prices for most foreign ores marketed in the United States are normally not published. There are two exceptions. The first exception is CCI's traditional quotation for Wabush pellets, which remained at 63.5 cents per ltu f.o.b. Pointe Noire, Quebec. In May 1989, the M.A. Hanna Co., the manager and marketing agent for the Iron Ore Co. of Canada (IOC), began quoting a price of 74.65 cents per ltu of iron, natural, for Carol Lake pellets. The quotation included delivery to rail-of-vessel at *lower* lake ports. The average f.o.b. value of all Canadian ores and agglomerates imported by the United States, as determined from data compiled by the Bureau of the Census, was $36.35 per mt. This value was slightly lower than the average Canadian pellet value of $36.90 because Canada also sold limited quantities of specially processed concentrates to the U.S. chemical industry. Other average f.o.b. values compiled under the new harmonized tariff system are compared in table 20.

Published f.o.b. prices for DRI were also unchanged from those quoted in 1989, and were as follows, per mt: at Georgetown, SC, $125 to $135; at Contrecoeur, Quebec, $115; and at Point Lisas, Trinidad and Tobago, $120. In 1990, the customs value of DRI imported from Venezuela ranged from $100 to $113 per mt.

Foreign Trade

U.S. exports of iron ore were 40% lower than those of 1989 because of the Michigan mine strike and related strikes at Canadian steelworks. 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. Consumption of iron ore at Canadian blast furnaces plummeted from 13.98 Mmt in 1989 to 9.93 Mmt. U.S. material accounted for 3.13 Mmt or 31% of the blast furnace total. An additional 56,000 mt of U.S. material was consumed at Canadian sintering plants.

U.S. imports of iron ore dropped 8% to 18.05 Mmt primarily because of cutbacks in blast furnace activity at selected steelworks in the mid-Atlantic region. Another factor was higher prices for Brazilian and Canadian ore on the world market, which made U.S. pellets more competitive in the Ohio River Valley and western Pennsylvania. In early 1991, several older, less efficient blast furnaces were shut down on the Eastern seaboard, further discouraging imports.

Total tonnage for 1990 was slightly greater than the mean of the previous 5 years, 17.93 Mmt, and was equivalent to 24% of ore consumption. Sharp drops of imports into the Baltimore and Chicago customs districts (both 41%) offset increases at Mobile, Cleveland, and Detroit (52%, 24%, and 85%, respectively). Canadian ores accounted for 52% of total U.S. imports; however, since 1982, Canada has had to struggle to maintain its share of the increasingly competitive U.S. market. Canada increased its share slightly to 12% from its 10-year low of 1989. Brazil, the second largest supplier, lost market share, slipping from 6.9% to 5.7%. Venezuela was

close behind with a 4.7% share, down from 5.7% in 1989.

World Review

At least 47 countries mined iron ore during the year, producing a total of 919 Mmt. The U.S.S.R. was the largest producer, with an output of 168 Mmt of concentrate or direct-shipping ore plus 68 Mmt of pellets. Soviet production accounted for about 24% of the world's marketable output in terms of metal content. World production of pig iron, which directly reflects ore consumption, decreased slightly to 527 Mmt.

The world ore trade was estimated at 395 Mmt, of which about 86% was oceanborne.[56] Brazil, the leading exporter, shipped 114.3 Mmt to world markets, slightly more than that in 1989. The top three customers of the Latin American giant were the European Community (EC) (43% of total exports), Japan (26%), and the Republic of Korea (7%). Australian shipments, in second place, dropped from 108.1 to 100.0 Mmt, primarily because of decreased imports by Japanese and German steelmakers. Japanese steelmakers produced 80.2 Mmt of hot metal in their blast furnaces, the same output as that in 1989. Japanese imports of Venezuelan ore have been gradually increasing since 1986, resulting in a readjustment of market shares. Australian exports to Europe stood at 18.98 Mmt (on a dry weight basis) and were down 10% from the 21.09 Mmt of 1989. The 12-member EC received a total of 133.0 Mmt of ore and agglomerates, down from 140.3 Mmt in 1989 but still edging out Japan as the world's principal importer. Japanese imports decreased slightly from 127.7 Mmt to 125.3 Mmt.

World production of pellets was estimated at 223 Mmt, about 84% of rated capacity. Preliminary data suggest that pelletizing plant output was down 4% from the 232.6 Mmt reported for 1989. Most plants in Brazil, Canada, Mexico, and Sweden were operating close to capacity. Producers in Bahrain, India, Peru, and the United States, though, still had significant underutilized capacity. More and more customers asked plant managers to switch to self-fluxed or olivine-base pellets. Dolomite-limestone fluxed pellets continued to be made in record amounts in Canada, Japan, and the United States.

According to the Midrex Corp., world production capacity for DRI in 1990 was 29.37 Mmt/yr.[57] Actual production was 17.88 Mmt, for an overall utilization of 61%. A breakdown by country is given in the "Iron and Steel" chapter. Gas-based plants accounted for 16.52 Mmt or 92% of the world total. Coal-based plants produced the remaining 1.36 Mmt. Gas-based plants in Argentina, Egypt, Qatar, Saudi Arabia, the United States, and the U.S.S.R. were running close to or exceeded rated capacity. The 800,000-mt/yr British Steel Corp. plant at Hunterston, Scotland, remained idle because of weak demand for steel in Europe and price competition from ferrous scrap. An additional 12 Mmt of capacity was expected to be completed by 1994.

HBI was in considerable demand throughout 1990, with shipments tripling to 1.36 Mmt. Merchant DRI remained in direct competition with high-quality home scrap (i.e., scrap internally generated within the steelworks). The long-term outlook for DRI was favorable because of the rapid dropoff in the generation of home scrap since the advent of continuous casting. Efficiency improvements at rolling mills had made the home scrap dropoff even more pronounced.

The second of two Midrex modules was started up at the new Misurata plant in Libya.[58] At the beginning of 1991, each of the modules was operating at its design rate of 75 mt/hr. New units were also brought on-line in India, Iran, and Venezuela.[59] The improved utilization of existing gas-based facilities in Indonesia, Mexico, and Venezuela was largely responsible for the 12% increase in world DRI production between 1989 and 1990. About 43% of the total output for 1990 was produced in Latin America. The four-module, 1.67-Mmt/yr Soviet complex at Stary Oskol was still operating at 102% of rated capacity and accounted for an additional 10% of the 17.88 Mmt.

For the first time in 4 years, iron ore exporters completed their annual price negotiations in Europe before fixing prices in Japan. This represented a return to the traditional negotiating pattern of the early 1980's. The traditional sequence of negotiations grew out of the fact that European contracts are based on the calendar year, while Japanese contracts are on an April-to-March fiscal year.

CVRD recaptured its old role as price setter. Formal negotiations between CVRD and the purchasing agents for the West German steel industry, Rohstoffhandel GmbH and Erzkontor Ruhr GmbH, began on November 8, 1989, but reached an impasse when CVRD insisted on a 29.9% price increase for its fines and a 24.7% increase for pellets. The Brazilian producer felt that world iron ore prices should be restored to 1982 levels, with an adjustment for inflation. Between 1982 and 1986 world prices slumped, discouraging mining companies from investing in improvements needed to ensure long-term stability of supply. On January 17, 1990, after 10 weeks of choppy negotiations, West German steelmakers finally agreed to a price increase of 15.96% for Itabira fines, setting the Itabira price at 30.80 cents per Fe 1% per dry metric ton (dmt) f.o.b. Tubarão. This equated to a Rotterdam arrival price of about 41.40 cents. The price increase for Carajás fines was 16.78%, resulting in a new f.o.b. price of 32.50 cents.

Japanese steelmakers were carefully following the European negotiations and quickly settled with Hamersley Iron Pty. Ltd., the largest Australian producer, on January 24. The Japanese agreed to an across-the-board hike of 15.96% for all direct-shipping ores, regardless of country, with two minor exceptions. However, the Japanese felt that demand for pellets for blast furnaces was weakening and would only acquiesce to a pellet price increase of 9.02%. As in past years, premiums were paid on both pellets and lump. Prices negotiated under Japanese contracts for fiscal year 1990 are shown in table 25.

On an f.o.b. (shipping port) basis, most 1990 prices apparently ranged from about $11.10 to $25.60 per dmt for fines, $19.70 to $25.15 per dmt for lump, and $28.75 to $39.25 per dmt for pellets. Delivered prices (at receiving port) were about $2 to $15 higher, depending on ocean freight costs.

Seaborne trade in iron ore dipped slightly from the 1989 high of 362 Mmt.[60] The high shipping level reflected the continuing upswing in pig iron production in Asia.

World production of pig iron was only 3% less than the alltime high of 546 Mmt set in 1989. Pig iron production was off slightly in the EC, the main market for Brazilian ore, but blast furnaces in several other market economy countries continued to operate at rates not seen since the peak year of 1979. Ocean freight rates for iron ore declined steeply during the first 6 months of 1990. This decline came on the heels of 2 years of strong growth. By the end of June, rates had reached their lowest levels since the summer of 1987 and were still dropping. The invasion of Kuwait in August and the resulting crisis in the Persian Gulf region created an atmosphere of uncertainty within the shipping community.

In September, freight rates began to recover, making short-haul suppliers like Mauritania and Sweden more competitive. Published rates for spot charterings to the EC from Western Australia ranged from $7.50 to $11.85 per dwt for cargoes of 100,000 to 150,000 dwt compared with $7.90 to $12.50 in 1989. The 1990 rate ranges for other shipments to the EC are shown in table 26.

Rates for cargoes of 100,000 to 150,000 dwt to Japan from Western Australia ranged from $5.10 to $6.40. Higher rates applied to Port Latta in Tasmania because it cannot accommodate vessels greater than 100,000 dwt and is farther from Japan. Rates to Japan from the Brazilian Port of Tubarão for cargoes of similar size were $10.55 to $15.70. Rates to Japan from Ponta da Madeira, the loading point for Carajás ores, were about $0.40 more than those for Tubarão.

Integrated iron ore operations have become extremely complex and resemble medium-sized towns in some cases. The production capacity of an operation of this magnitude is determined by equipment limitations at several stages of recovery. To simplify analysis and make comparisons of individual mines easier, data were collected that represent the rated or design capacity at three key points in the recovery process: crusher-screen output, concentrator output, and furnace output. These three points were chosen because they serve to readily separate the mining, beneficiating, and agglomerating stages of the operation. At the first two points, the iron ore is already in a marketable form and can be diverted for sale or tolling if bottlenecks occur either downstream at the operation or upstream at competitors' facilities.

Changes in the economics of the process could also make diversion feasible. Table 27 shows world pelletizing capability at the close of 1990. The data represent the rated capacities of 78 plants in 26 countries. Five of the plants were near or part of integrated steelworks and had no captive iron mines. A sixth, the natural-gas-based merchant operation in Bahrain, was also dependent on imported feed. A significant part of the data was collected by the International Iron and Steel Institute in 1987. The table excludes plants that have not produced since 1982. Four of these idled plants are identified in the table footnotes because they could be reactivated in some realistic scenarios. Table 27 also excludes all of the world sintering plants. Similar tables were being developed by the U.S. Bureau of Mines that list world crude ore production capability and world concentrating capability.

OUTLOOK

The U.S. iron ore industry is totally dependent on the domestic steel industry for sales. This dependence is not expected to change in the near future. Because of this relationship, the reader is referred to the outlook sections in the "Iron and Steel" and "Iron and Steel Scrap" chapters. Only 6% of the iron ore shipped in 1990 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.

The United States has exhausted the vast 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. 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.

For the near term, growth of the U.S. iron ore industry is tied to the growth of the integrated steelworks along the Great Lakes. This growth is expected to average less than 2% per year over the next decade and could very easily be negative if the current recession is prolonged. The U.S. steel industry is concentrating on making high-value, quality steels, *not* increasing tonnage. Domestic blast furnace production in the year 2000 is expected to be no more than 60 Mmt compared with 49.83 Mmt in 1990. The U.S. iron ore industry has no choice but to focus on making higher quality agglomerates, such as fluxed pellets, that meet much tighter chemical and physical specifications than have been required in the past.

Electric arc furnaces currently account for more than one-third of total crude steel production. With advances in steelmaking, the impurity levels in the better grades of scrap are rising. This indicates a role for imported DRI in the coastal regions of the United States. As discussed in the "Technology" section, growth of gas-based DRI production capacity outside North America has been spectacular in recent years. Although a large part of this growth has occurred in Venezuela, the bulk of the construction has been spread evenly through a myriad of countries that have surplus natural gas. It is too early to tell whether coal-based DRI production will be economically feasible in the United States. No matter how spectacular DRI growth is over the next decade, it will not be able to replace more than a fraction of the world's blast furnace production because of technological restrictions. The blast furnace is expected to remain the mainstay of the iron and steel industries in most developed countries over the next 25 years.

In contrast to the United States, demand for iron ore in other parts of the world is expected to escalate. Some of the greatest growth is being experienced in the Far East. China is currently producing more hot metal than the United States and is modernizing and expanding blast furnace operations throughout the country. For example, a second blast furnace was commissioned at the key Baoshan iron and steel complex outside Shanghai in mid-1991. In 1990, China imported 14.34 Mmt of iron ore products and accounted for almost one-fifth of world consumption. Smaller but no less spectacular growth is occurring in the Republic of Korea and Taiwan. Pohang

Iron & Steel Co. Ltd. of Korea now has seven blast furnaces—four at Pohang and three at Kwangyang, with a fourth planned for Kwangyang. Steelworks in the EC have become more competitive in recent years and should benefit from the growth in steel consumption that is forecasted to occur in Western Europe after the single market takes effect in 1992 and internal trade barriers are removed. Consumption of iron ore in Latin America is driven by pig iron production in Brazil and to a lesser extent, Argentina and Mexico. Brazilian pig iron production more than doubled between 1981 and 1989, but dropped off 34% in 1990. Price controls were reportedly responsible for the dropoff. Mexican pig iron production has been relatively constant since 1981, ranging from 3.2 Mmt to 3.9 Mmt. Japanese imports of iron ore are not expected to increase dramatically, in spite of the country's dynamic construction and automotive industries, because Japanese companies are moving upstream to higher value products.

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[6]The gamma is a unit used in geophysical prospecting to measure variations in the intensity of the Earth's magnetic field. The average magnetic field intensity at the Earth's surface is about 0.5 oersted. In magnetic surveying, a much smaller unit than the oersted is needed. One gamma equals 10^{-5} oersteds.

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FIGURE 11

COMPARISON OF U.S. IRON ORE PRODUCTION WITH TOTAL PRODUCTION FOR THE WORLD

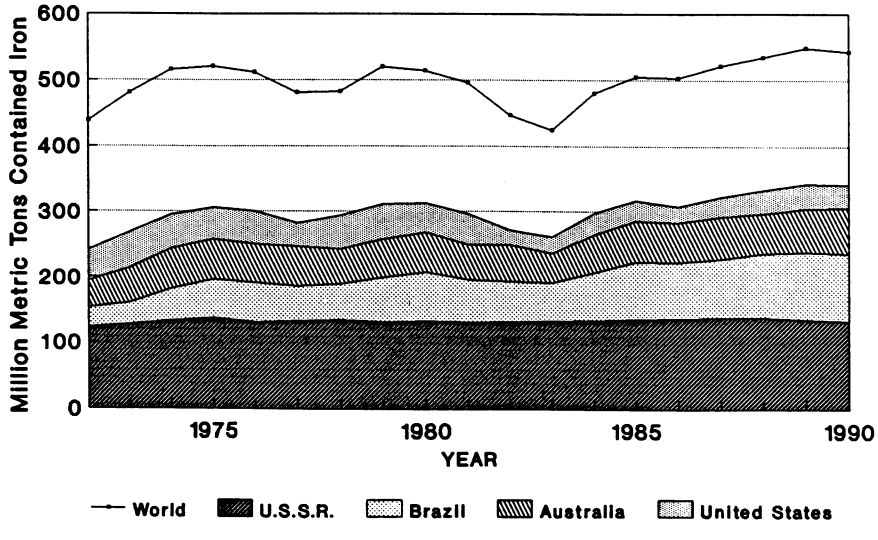

TABLE 1

SALIENT IRON ORE STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Iron ore (usable,[1] less than 5% manganese):					
Production	39,486	47,648	57,515	59,032	56,408
Shipments	41,991	47,983	57,113	58,299	57,010
Value	$1,472,511	$1,503,087	$1,716,661	r$1,839,873	$1,740,925
Average value at mines, dollars per ton	$35.07	$31.33	$30.06	r$31.56	$30.54
Exports	4,553	5,093	5,285	5,365	3,199
Value	$204,738	$198,254	$193,796	$192,796	$124,076
Imports for consumption	17,011	16,849	20,183	19,596	18,054
Value	$460,643	$408,783	$484,543	$522,262	$559,525
Consumption (iron ore and agglomerates)[2]	62,097	67,768	83,694	80,447	76,855
Stocks, December 31:					
At mines[3]	3,307	2,402	2,957	3,800	3,386
At consuming plants	17,439	16,565	18,005	15,730	15,911
At U.S. docks[4]	2,019	2,056	2,537	2,171	2,273
Total industry	22,765	21,023	23,499	21,701	21,570
Manganiferous iron ore (5% to 35% manganese):					
Shipments	13	W	W	W	W
World: Production	r863,650	r889,627	907,522	p926,070	e919,255

eEstimated. pPreliminary. rRevised. W-Withheld to avoid disclosing company proprietary data.

[1]Direct-shipping ore, concentrates, agglomerates, and byproduct ore.

[2]Consumption data after 1987 are not entirely comparable with those of prior years owing to changes in data collection.

[3]Includes some material stockpiled at Upper Lake ports, but excludes byproduct ore nationwide.

[4]Transfer and receiving docks at Lower Lake ports.

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 1990, BY DISTRICT AND STATE

District and State	Average number of employees	Worker-hours (thousands)	Production (thousand metric tons)			Iron content, natural (percent)	Average per worker-hour (metric tons)		
			Crude ore	Usable ore	Iron contained (in usable ore)		Crude ore	Usable ore	Iron contained
Lake Superior:									
Michigan	1,701	3,137	29,128	9,467	5,881	62.1	9.29	3.02	1.87
Minnesota	5,577	11,952	149,828	45,160	28,761	63.7	12.54	3.78	2.41
Total[1] or average	7,278	15,088	178,956	54,628	34,642	63.4	11.86	3.62	2.30
Other States[2]	314	623	2,486	1,780	1,053	59.2	3.99	2.86	1.69
Grand total[1] or average	7,592	15,712	181,442	56,408	35,695	63.3	11.55	3.59	2.27

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

[2]Includes California, Missouri, Montana, New Mexico, South Dakota, Texas, and Utah.

TABLE 3

CRUDE IRON ORE[1] MINED IN THE UNITED STATES IN 1990, 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[2]
Lake Superior:				
Michigan	2	29,128	—	29,128
Minnesota	8	149,828	—	149,828
Total	10	178,956	—	178,956
Other States:				
Missouri	—	1,549	1,549	
Other[3]	11	936	—	936
Total	12	936	1,549	2,486
Grand total	22	179,892	1,549	181,442

[1]Excludes byproduct ore.
[2]Data may not add to totals show because of independent rounding.
[3]Includes California, Montana, New Mexico, South Dakota, Texas, and Utah.

TABLE 4

USABLE IRON ORE PRODUCED IN THE UNITED STATES IN 1990, BY DISTRICT, STATE, AND TYPE OF PRODUCT

(Thousand metric tons and exclusive of ore containing 5% or more manganese)

District and State	Direct-shipping ore	Concentrates	Agglomerates[1]	Total quantity
Lake Superior:				
Michigan	98	—	9,369	9,467
Minnesota	11	524	44,625	45,160
Total[2]	110	524	53,994	54,628
Other States:				
Missouri	—	194	822	1,016
Other[3]	677	87	—	764
Total	677	281	822	1,780
Grand total[2]	787	805	54,816	56,408

[1]Data may include pellet chips and screenings.
[2]Data may not add to totals 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 1990

(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	Concentrates	Agglomerates	Total[2]		
Lake Superior:						
Michigan	97	—	9,937	10,034	62.3	W
Minnesota	11	486	44,642	45,139	63.7	1,308,920
Total reportable or average	108	486	54,579	55,174	63.4	1,308,920
Other States:						
Missouri	—	195	807	1,002	62.8	W
Other[3]	760	74	—	834	54.4	W
Total reportable or average[2]	760	268	807	1,836	59.0	—
Total withheld	—	—	—	—	—	432,005
Grand total or average[2]	868	755	55,386	57,010	63.3	1,740,925

W Withheld to avoid disclosing company proprietary data; included in "Total withheld."
[1]Includes byproduct ore.
[2]Data may not add to total shown because of independent rounding.
[3]Includes California, Montana, New Mexico, South Dakota, Texas, and Utah.

TABLE 6

USABLE IRON ORE PRODUCED IN THE U.S. LAKE SUPERIOR DISTRICT, BY RANGE

(Thousand metric tons and exclusive after 1905 of ore containing 5% or more manganese)

Year	Marquette	Menominee	Gogebic	Vermilion	Mesabi	Cuyuna	Spring Valley	Black River Falls	Total[1]
1854-1983	547,983	334,629	325,474	105,189	3,442,540	71,465	8,280	9,869	4,845,432
1984	13,190	—	—	—	37,286	—	—	—	50,476
1985	12,679	—	—	—	35,470	—	—	—	48,148
1986	10,727	—	—	—	27,476	—	—	—	38,203
1987	12,491	—	—	—	34,265	—	—	—	46,756
1988	14,590	—	—	—	41,449	—	—	—	56,038
1989	15,611	—	—	—	41,370	—	—	—	56,981
1990	9,467	—	—	—	45,160	—	—	—	54,628
Total[1]	636,738	334,629	325,474	105,189	3,705,016	71,465	8,280	9,869	5,196,662

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

TABLE 7

AVERAGE ANALYSES OF TOTAL TONNAGE[1] OF ALL GRADES OF AGGLOMERATES SHIPPED FROM MINES IN THE UNITED STATES

Year	Quantity (thousand metric tons)	Content (percent)[2]					
		Iron	Phosphorus	Silica	Manganese	Alumina	Moisture
		SINTER[3]					
1980	533	44.04	0.136	13.66	0.18	6.04	2.00
1981	423	44.57	.166	13.84	.19	6.34	NA
1982	254	45.94	NA	12.99	NA	6.40	NA
		PELLETS OF ALL TYPES					
1980	63,819	63.42	.022	5.65	.14	.32	2.35
1981	66,994	63.59	.019	5.48	.12	.32	2.38
1982	33,950	63.76	.018	5.38	.10	.30	2.40
1983	43,865	63.64	.018	5.26	.10	.27	2.41
1984	49,549	63.83	.018	5.15	.11	.31	2.47
1985	47,182	63.91	.016	5.12	.10	.28	2.45
1986	40,645	63.90	.015	5.14	.09	.28	2.44
1987	46,337	63.86	.014	5.02	.09	.22	2.04
		STANDARD PELLETS					
1988	41,349	64.17	.015	5.08	.11	.21	2.18
1989	36,239	64.46	.013	4.93	.05	.24	1.83
1990	33,626	64.43	.013	4.91	.05	.23	1.91
		FLUXED PELLETS[4]					
1988	13,618	60.71	.017	4.52	.21	.24	2.10
1989	19,755	61.36	[5].015	4.37	[5].08	.16	2.12
1990	20,796	61.65	.006	4.25	.03	.12	2.14

NA Not available.
[1]Railroad weight—gross metric tons.
[2]Natural basis.
[3]Sinter has not been produced at U.S. mines since 1982.
[4]Ratio of $(CaO + MgO)/(SiO_2 \div Al_2O_3)$ is 0.6 or greater.
[5]Revised by American Iron Ore Association.

Source: American Iron Ore Association.

TABLE 8

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		
1980	54,851	8,430	1,390	16,167	9,993	90,832
1981	61,279	7,207	656	18,377	8,963	96,482
1982	35,789	3,446	76	10,967	5,840	56,119
1983	40,344	2,246	123	11,612	7,876	62,202
1984	44,384	1,680	109	12,130	8,747	67,049
1985	45,089	1,438	1	9,138	9,012	64,678
1986	39,881	1,164	401	7,818	6,905	56,170
1987	44,004	710	—	8,686	7,651	61,051
1988	51,048	1,242	—	9,453	10,122	71,866
1989	51,845	1,710	—	7,473	12,034	73,062
1990	54,341	1,516	—	8,257	9,571	73,685

[1]Excludes dust, mill scale, and other revert ironbearing materials added to sinter.
[2]Data may not add to totals shown because of independent rounding.

Source: American Iron Ore Association.

TABLE 9

CONSUMPTION OF IRON ORE AND AGGLOMERATES AT U.S. IRON AND STEEL PLANTS, BY TYPE OF PRODUCT

(Thousand metric tons)

Type of product	1986	1987	1988	1989	1990
Blast furnaces:					
Direct-shipping ore	1,893	2,696	5,155	3,211	2,479
Pellets	43,610	49,500	61,025	61,659	60,512
Sinter[1]	13,221	14,420	15,497	13,664	12,226
Total[2]	58,725	66,616	81,676	78,533	75,217
Steelmaking furnaces:					
Direct-shipping ore	65	123	194	142	53
Pellets	31	44	88	76	50
Sinter[1]	25	42	—	—	13
Total[2]	122	209	282	219	115
Grand total[2]	58,846	66,824	81,958	78,752	75,333

[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 10

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]	Direct-reduced iron for steelmaking[4]	Nonsteel end uses[5]	Total
1980	74,593	492	15,617	130	90,832	NA	1,151	91,983
1981	80,022	343	16,028	87	96,482	NA	1,421	97,903
1982	45,898	248	9,062	911	56,119	NA	1,084	57,203
1983	51,610	225	10,134	234	62,202	—	848	63,050
1984	56,072	380	10,353	245	67,049	179	1,222	68,450
1985	55,589	184	8,440	465	64,678	224	1,147	66,049
1986	48,539	97	7,424	110	56,170	244	1,099	57,513
1987	54,614	144	6,270	23	61,051	325	1,049	62,425
1988	63,172	282	8,381	30	71,866	443	1,293	73,602
1989	65,597	336	7,118	10	73,062	487	1,208	74,757
1990	67,551	89	5,809	235	73,685	583	940	75,208

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]U.S. Bureau of Mines estimates based on production reports compiled by Midrex Corp.
[5]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 11

IRON ORE SHIPMENTS FROM U.S. GREAT LAKES PORTS DURING THE 1990 NAVIGATION SEASON

(March 20, 1990, through January 31, 1991)

Port	Date of first shipment	Date of last shipment	Total shipments (thousand metric tons)
Duluth, MN	Apr. 4	Jan. 1	7,728
Two Harbors, MN	Mar. 20	Jan. 13	11,668
Silver Bay, MN[1]	Apr. 19	Jan. 7	2,234
Taconite Harbor, MN	Mar. 26	Jan. 2	8,795
Superior, WI	Mar. 24	Jan. 2	11,230
Marquette, MI	Mar. 22	Jan. 1	5,005
Escanaba, MI	Mar. 22	Jan. 31	4,987
Total[2]			51,648

[1]Cyprus Minerals Co. acquired all of the facilities of the defunct Reserve Mining Co. in Aug. 1989 and began shipping from Silver Bay on Apr. 19, 1990. This was the first shipment from Silver Bay since Nov. 1987.
[2]Data do not add to total shown because of independent rounding.

Source: Lake Carriers' Association, 1990 Annual Report.

TABLE 12

GREAT LAKES FREIGHT RATES FOR IRON ORE

From	To	Dollars per long ton[1]					
		Oct. 13, 1988		Sept. 25, 1989		July 23, 1990	
		Class X	Other	Class X	Other	Class X	Other
Head of the Lakes	Lower lake ports	4.95	5.60	5.60	6.00	6.00	6.50
Marquette	do.	—	4.69	—	4.98	—	5.40
Escanaba	Lake Erie ports	3.74	4.20	4.20	4.50	4.50	4.88
Do.	Lower Lake Michigan ports	2.97	3.19	3.36	3.60	3.60	3.90

[1]Self-unloader rates. Excludes winter surcharges for shipments after Dec. 15 and before Apr. 15.

Sources: Cleveland-Cliffs Inc., Interlake Steamship Co., and Skillings' Mining Review.

TABLE 13

UNITED STATES AND CANADIAN IRON ORE SHIPMENTS ON THE GREAT LAKES

(Thousand metric tons)

Loading district	1986	1987	1988	1989	1990
Lake Superior	31,677	41,835	46,098	45,296	46,661
Lake Michigan	7,497	6,032	6,660	5,742	4,987
Eastern Canada	7,108	8,109	9,209	9,480	10,836
Total[1]	46,282	55,976	61,966	60,518	62,484
U.S.-flag fleet shipments[2]	39,457	48,952	55,028	51,799	54,055
Percent carried by U.S. fleet	85	87	89	86	87

[1]Includes transshipments. Data may not add to totals shown because of independent rounding.
[2]Includes mill scale, scarfer ore, and slag, in addition to iron ore.

Source: Lake Carriers' Association Annual Reports.

TABLE 14

CLASSIFICATION OF IRON ORE AND PRIMARY IRON CHEMICALS UNDER THE HARMONIZED TARIFF SCHEDULE OF 1990

HTSUS No.	Description
	OXIDE ORES
2601.11.0030	Concentrates.
2601.11.0060	Coarse ores.
2601.11.0090	Fine ores.
2601.12.0030	Pellets.
2601.12.0060	Briquettes.
2601.12.0090	Sinter and other agglomerates.
	SULFIDE ORES
2502.00.0000	Unroasted pyrites.
2601.20.0000	Roasted pyrites.
	PRIMARY CHEMICALS
2827.33.0000	Iron chlorides.
2833.29.2000	Iron sulfates.

TABLE 15

U.S. EXPORTS OF IRON ORE AND AGGLOMERATES, BY COUNTRY OF DESTINATION

(Thousand metric tons and thousand dollars)

Country	1986		1987		1988		1989		1990	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Canada	4,551	204,600	5,091	198,108	5,277	193,249	5,359	192,334	3,193	123,601
India	(1)	17	—	—	(1)	25	1	59	1	57
Mexico	1	45	1	42	1	62	(1)	15	1	103
Netherlands	(1)	17	—	—	(1)	3	—	—	(1)	6
Venezuela	(1)	39	1	95	4	348	(1)	44	—	—
Other	(1)	20	(1)	9	3	109	4	345	4	308
Total[2]	4,553	204,738	5,093	198,254	5,285	193,796	5,365	192,796	3,199	124,076

[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

U.S. EXPORTS OF IRON ORE AND AGGLOMERATES, BY TYPE OF PRODUCT

Type of product	1989			1990		
	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value[1] (dollars per ton)	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value[1] (dollars per ton)
Concentrates	353	13,887	39.39	11	333	31.45
Coarse ores	—	—	—	6	213	36.53
Fine ores	[2]145	[2]559	[2]3.86	10	346	35.25
Pellets	4,852	177,980	36.68	3,018	116,845	38.71
Briquettes	(3)	22	97.95	—	—	—
Other agglomerates	14	230	16.60	136	5,498	40.38
Roasted pyrites	1	117	80.17	19	840	45.12
Total[4]	5,365	192,796	35.94	3,199	124,076	38.78

[1]Unit values shown are calculated from unrounded data.
[2]Data was reviewed and confirmed by the Bureau of Census.
[3]Less than 1/2 unit.
[4]Data may not add to totals shown because of independent rounding.
Source: Bureau of the Census.

TABLE 17

U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1987		1988		1989		1990	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Australia	194	5,141	1,076	16,780	394	5,211	14	584
Brazil	3,698	64,820	4,935	78,092	5,169	90,885	4,276	90,443
Canada	7,981	246,181	9,157	285,961	8,538	292,866	9,344	339,622
Chile	636	12,601	139	2,772	61	1,200	138	2,905
India	—	—	126	2,820	59	1,037	—	—
Liberia	994	13,707	128	1,460	200	2,950	—	—
Mauritania	412	6,403	522	7,864	594	10,130	666	14,142
Norway	—	—	—	—	40	693	—	—
Peru	84	1,691	181	2,939	186	4,280	59	1,623
Philippines[1]	59	1,575	239	5,432	66	1,622	—	—
Spain	1	27	—	—	—	—	1	61
Sweden	139	3,334	88	4,678	57	1,000	54	2,273
Venezuela	[2]2,622	[2]52,889	3,568	75,443	4,232	110,367	3,503	107,848
Other	29	413	[3]24	[3]301	([4])	21	[5]([4])	[5]24
Total[6]	16,849	408,783	20,183	484,543	19,596	522,262	18,054	559,525

[1]Sinter made from raw materials supplied by Australia, Brazil, and other countries.
[2]Excludes 18,370 metric tons of sponge iron valued at $1,849,584, originally reported as iron ore.
[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]Less than 1/2 unit.
[5]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.
[6]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 18

U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY TYPE OF PRODUCT

Type of product	1989			1990		
	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	371	7,760	20.93	294	7,733	26.27
Coarse ores	662	15,566	23.52	545	14,445	26.51
Fine ores	11,629	297,913	25.62	7,338	181,696	24.76
Pellets	5,628	175,728	31.22	9,875	355,470	36.00
Briquettes	—	—	—	2	165	92.41
Other agglomerates	1,186	23,251	19.61	([2])	14	730.58
Roasted pyrites	121	2,045	16.97	([2])	2	343.60
Total[3]	19,596	522,262	26.65	18,054	559,525	30.99

[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 19

U.S. IMPORTS OF IRON ORE AND AGGLOMERATES IN 1990, BY COUNTRY AND TYPE OF PRODUCT

(Thousand metric tons)

Country or origin	Concentrates	Coarse ores	Fine ores	Pellets	Other agglomerates	Roasted pyrites	Total[1]
Australia	—	—	14	—	—	—	14
Brazil	11	—	3,755	509	—	—	4,276
Canada	230	[2]	1,526	7,588	[2]	—	9,344
Chile	—	—	138	—	—	—	138
Mauritania	—	—	666	—	—	—	666
Peru	—	—	—	59	—	[2]	59
Spain	—	—	1	—	—	—	1
Sweden	54	—	—	—	—	—	54
Venezuela	—	545	1,237	1,719	2	—	3,503
Other	[2]	[2]	—	—	[2]	—	[2]
Total [1]	294	545	7,338	9,875	2	[2]	18,054

[1]Data may not add to toals because of independent rounding.
[2]Less than ½ unit.

Source: Bureau of the Census.

TABLE 20

AVERAGE UNIT VALUES FOR SELECTED IMPORTS OF IRON ORE AND AGGLOMERATES IN 1990

Type of product	Country of origin	Average unit value[1] (dollars per metric ton gross weight)
Coarse ores	Venezuela	26.49
Fine ores	Brazil	20.04
Do.	Canada	35.68
Do.	Mauritania	21.24
Do.	Venezuela	27.73
Pellets	Brazil	29.34
Do.	Canada	36.90
Do.	Peru	27.39
Do.	Venezuela	34.29

[1]Weighted average of individual Customs values.

Source: Bureau of the Census.

TABLE 21

U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY CUSTOMS DISTRICT

(Thousand metric tons and thousand dollars)

Customs district	1987		1988		1989		1990	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Baltimore	5,975	125,887	7,759	183,932	6,062	158,193	3,559	99,849
Buffalo	(1)	30	(1)	14	—	—	(1)	2
Charleston	322	7,580	439	10,088	524	14,858	563	16,629
Chicago	2,007	40,224	1,837	28,820	2,795	52,162	1,654	32,561
Cleveland	1,490	54,551	1,401	41,315	1,557	48,401	1,931	66,811
Detroit	637	27,196	520	19,607	528	24,773	978	42,185
Houston-Galveston	9	177	62	1,115	28	519	(1)	18
Mobile	1,063	22,645	1,595	40,708	2,284	68,830	3,480	121,704
New Orleans	1,530	27,230	1,496	22,673	1,845	30,830	1,910	37,308
Philadelphia	3,809	103,101	5,031	135,335	3,968	123,112	3,967	141,970
Other	7	163	43	937	4	584	12	486
Total[2]	16,849	408,783	20,183	484,543	19,596	522,262	18,054	559,525

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 22

U.S. IMPORTS OF PELLETS, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1989		1990	
	Quantity	Value	Quantity	Value
Brazil	400	11,287	509	14,948
Canada	3,146	104,984	7,588	279,961
India	59	1,037	—	—
Peru	159	3,930	59	1,621
Venezuela	1,863	54,490	1,719	58,940
Total[1]	5,628	175,728	9,875	355,470

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

Source: Bureau of the Census.

TABLE 23

PRINCIPAL IRON MINES OF THE WORLD IN 1991[1]

Country	Company	Mine	Principal ore minerals
Australia	Goldsworthy Mining Ltd.	Shay Gap and Sunrise Hill, Pilbara, WA	Soft hematite and goethite.[2]
Do.	Hamersley Iron Pty. Ltd.	Mount Tom Price, Pilbara, WA	Do.
Do.	do.	Paraburdoo, Pilbara, WA	Do.
Do.	Mount Newman Mining Co. Pty. Ltd.	Mount Whaleback, Pilbara, WA	Do.
Do.	do.	Ore Body 29 (Marra Mamba), Pilbara, WA	Do.
Do.	Robe River Iron Associates	Eastern Deepdale, Pannawonica, Pilbara, WA	Pisolitic limonite.
Brazil	Cia. Vale do Rio Doce	Carajas, Para	Hematite and goethite.
Do.	do.	Caue, Minas Gerais	Secondary hematite and goethite derived from itabirite.
Do.	do.	Conceicao-Dois Corregos, Minas Gerais	Do.
Do.	do.	Timbopeba, Ouro Preto, Minas Gerais	Do.
Do.	Ferteco Mineracao SA	Fabrica, Belo Horizonte, Minas Gerais	Do.
Do.	Minas da Serra Geral SA	Capanema, Ouro Preto, Minas Gerais	Do.
Do.	Mineracoes Brasileiras Reunidas SA.	Aguas Claras and Mutuca, Belo Horizonte, MG	Do.
Do.	Samarco Mineracao SA	Germano and Alegria Sul, Minas Gerais	Do.
Do.	SA Mineracao da Trindade	Alegria, Minas Gerais	Do.
Canada	Iron Ore Co. of Canada	Humphrey, Carol Lake, Labrador	Specular hematite and magnetite.
Do.	Quebec Cartier Mining Co.	Mount Wright, Fermont, Quebec	Specular hematite.
Do.	Wabush Mines	Scully, Wabush, Labrador	Do.
Chile	Cia. Minera del Pacifico SA	El Algarrobo, Vallenar, Region III	Titaniferous magnetite.
Do.	do.	El Romeral, La Serena, Region IV	Do.
China	Anshan Metallurgical Co.	Dagushan, Liaoning	Magnetite and hematite occurring in taconite.
Do.	do.	Dongganshan, Liaoning	Do.
Do.	do.	Gongchangling, Liaoning	Do.
Do.	do.	Qidashan, Liaoning	Do.
Do.	do.	Yangian, Liaoning	Do.
Do.	Baotou Iron and Steel Co.	Baiyin, Nei Monggol	Magnetite and hematite-martite.
Do.	Benxi Iron and Steel Co.	Nanfen and Waitoushan, Liaoning	Magnetite and hematite occurring in taconite.
Do.	Hainan Mining Co.	Shilu, Hainan	Hematite and magnetite.
Do.	Maanshan Iron and Steel Co.	Gushan and Nanshan, Anhui	Titaniferous magnetite.
Do.	do.	Taochong, Anhui	Do.
Do.	Panzhihua Mining Co.	Lanjian and Zhujiabaobao, Sichuan	Do.
Do.	Shoudu Iron and Steel Co.	Dashine, Beijing Municipality	Magnetite occurring in quartzite.
Do.	do.	Shuichang, Beijing Municipality	Do.
Do.	Wuhan Iron and Steel Co.	Chengchao, Hubei	NA.
Do.	do.	Daye Complex, Huangshi City, Hubei	Magnetite, hematite, chalcopyrite, and pyrite.
Do.	do.	Jinshandian, Hubei	NA.
Do.	do.	Lingxiang, Hubei	NA.
France	Arbed SA	Ferdinand and Montrouge, Lorraine Basin	Oolitic limonite.
India	Chowgule & Co. Pvt. Ltd. (et al.)[3]	Goa	Hematite and magnetite.
Do.	Indian Iron and Steel Co. Ltd.	Gua and Manoharpur, Singhbhum district, Bihar	Hematite.
Do.	Kudremukh Iron Ore Co. Ltd	Kudremukh, Chikmagalur district, Karnataka	Magnetite in taconite.
Do.	National Mineral Development Corp. Ltd.	Bailadila, Bastar district, Madhya Pradesh	Hematite.
Do.	do.	Donimalai, Bellary district, Karnataka	Do.
Do.	Steel Authority of India Ltd.	Kiriburu and Bolani, Singhbhum district, Bihar	Do.
Do.	do.	Rajhara and Dalli, Durg district, Madhya Pradesh	Do.
Do.	do.	Kendujhar and Sundargarh districts, Orissa	Do.
Do.	Tata Iron and Steel Co. Ltd.	Noamundi, Singhbhum district, Bihar	Do.

See footnotes at end of table.

TABLE 23—Continued

PRINCIPAL IRON MINES OF THE WORLD IN 1991[1]

Country	Company	Mine	Principal ore minerals
India—Continued	Tata Iron and Steel Co. Ltd.	Kendujhar district, Orissa	Hematite.
Korea, North.	Government owned	Musan, Chongjin	Magnetite.
Liberia.	Bong Mining Co.[4]	Zaweah Pits and Bong Peak, Bong County	Hematite and magnetite associated with itabirite.
Do.	LAMCO Joint Venture[5]	Nimba, Gbahm and Tokadeh Pits, Yekepa	Hematite and goethite.
Mauritania	Societe Nationale Industrielle et Miniere	Tazadit (et alia), Kedia D'Idjil	Hematite.
Do.	do.	El Rhein Guelb, Zouerate	Magnetite in taconite.
South Africa, Republic of	ISCOR Ltd.	Sishen, Griqualand West, Cape Province	Hematite.
Do.	do.	Thabazimbi, Transvaal	Hematite and goethite.
Sweden	Luossavaara-Kiirunavaara AB	Kiruna, Lapland	Magnetite.
Do.	do.	Malmberget, Lapland	Do.
U.S.S.R.	Government owned	Bakal, Ural Mountains, RSFSR	Sideroplesite and pistomesite (magnesian siderite).
Do.	do.	Blagodat, Ural Mountains, RSFSR	Magnetite and martite.
Do.	do.	Gora Vysokaya, Ural Mountains, RSFSR	Do.
Do.	do.	Kachar, Turgay Depression, Kazakh SSR	Magnetite.
Do.	do.	Kaz, Gornaya Shoriya, RSFSR	Do.
Do.	do.	Kachkanar/Gusevogorsk, Ural Mountains, RSFSR	Titaniferous magnetite.
Do.	do.	Korshunika, Angara-Ilim, Irkutsk Oblast, RSFSR	Magnesian magnetite.
Do.	do.	Kostomuksha, Lake Kujto, Karelia ASSR	Magnetite.
Do.	do.	Kovdor, Kola Peninsula, RSFSR	Do.
Do.	do.	Kremenchug (four complexes), Ukrainian SSR	Magnetite, martite-hematite, and siderite.
Do.	do.	Krivoy Rog (six complexes), Ukrainian SSR	Martite-hematite, limonite, and magnetite.
Do.	do.	Lebedinsk, Kursk Magnetic Anomaly, RSFSR	Magnetite and hematite.
Do.	do.	Lisakovsk, Turgay Depression, Kazakh SSR	Oolitic limonite and siderite.
Do.	do.	Magnitnaya Gora, Ural Mountains, RSFSR	Magnetite and martite.
Do.	do.	Mikhaylovsk, Kursk Magnetic Anomaly, RSFSR	Martite-hematite.
Do.	do.	Olenegorsk, Kola Peninsula, RSFSR	Magnetite and hematite.
Do.	do.	Sheregesh and Tashtagol, Gornaya Shoriya, RSFSR	Magnetite.
Do.	do.	Sokolov-Sarbaysk, Rudnyy, Kazakh SSR	Do.
Do.	do.	Stoylensk, Kursk Magnetic Anomaly, RSFSR	Martite-hematite.
Do.	do.	Yakovlevo, Kursk Magnetic Anomaly, RSFSR	Do.
United States	Empire Iron Mining Partnership	Empire, Marquette Range, Palmer, MI	Magnetite occurring in taconite.
Do.	Eveleth Mines	Thunderbird, Mesabi Range, Eveleth, MN	Do.
Do.	Hibbing Taconite Co.	Hibbing, Mesabi Range, Hibbing, MN	Do.
Do.	LTV Steel Mining Co.	Erie, Mesabi Range, Hoyt Lakes, MN	Do.
Do.	National Steel Pellet Co.	NSPC Project, Mesabi Range, Keewatin, MN	Do.
Do.	Tilden Magnetite Partnership	Tilden, Marquette Range, Ishpeming, MI	Magnetite and hematite occurring in taconite.
Do.	USX Corp.	Minntac, Mesabi Range, Mountain Iron, MN	Magnetite occurring in taconite.
Venezuela	C.V.G. Ferrominera del Orinoco CA	Cerro Bolivar, Piar district, Bolivar State	Hematite and goethite.
Do.	do.	San Isidro, Piar district, Bolivar State	Do.
Do.	do.	Los Barrancos, Piar district, Bolivar State	Do.

NA Not available.

[1]Includes only those mines, complexes, or mining groups that had shipments of at least 4.0 million metric tons in 1989, 1990, or 1991.

[2]The mixed ore is considered to be the result of "hematite enrichment."

[3]Other Goan shippers include Damodar Mangalji & Co. (Pvt.) Ltd., V.S. Dempo & Co. (Pvt.) Ltd., Socieda de Fomento Industrial (Pvt.) Ltd., Minerals & Metals Trading Corp. of India Ltd., Orient Goa (Pvt.) Ltd., V.M. Salgaocar & Brother Ltd., A.V. Sarmalkar, and Sesa Goa Ltd.

[4]On July 6, 1990, Bong Mining Co. halted all mining and processing activities because of the civil war. Four days later, the company declared force majeure.

[5]Liberian Mining Corp. (LIMINCO) assumed full control of the LAMCO Joint Venture in late 1989. The mining complex was being operated for LIMINCO by a subsidiary of the African Mining Consortium Ltd. Mining operations and shipments were interrupted by the civil war, but resumed at a reduced rate in Apr. 1991.

TABLE 24

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]				
	1986	1987	1988	1989[p]	1990[e]	1986	1987	1988	1989[p]	1990[e]
Albania[e 5]	r1,200	1,200	1,200	61,179	61,093	r400	r400	r400	r370	360
Algeria	3,359	3,382	3,118	2,748	2,800	1,679	1,691	1,559	1,374	1,375
Argentina	810	567	674	635	620	514	360	379	414	400
Australia[7]	94,015	101,748	96,084	105,810	112,000	60,082	64,798	61,494	67,718	70,560
Austria	3,120	3,061	2,301	2,410	62,300	976	954	727	740	720
Bolivia	11	7	34	14	140	7	5	21	9	88
Brazil	r129,405	r134,497	146,008	153,740	6154,370	85,290	r89,134	97,139	102,300	102,600
Bulgaria	2,179	1,857	1,826	1,613	1,500	661	559	528	482	480
Canada[8]	36,167	37,702	39,934	39,445	636,443	23,002	23,882	24,268	23,971	622,147
Chile	6,981	6,637	7,710	8,761	68,248	4,197	4,380	5,089	5,783	5,400
China[e 9]	90,000	100,000	99,000	100,000	108,000	45,000	50,000	49,500	50,000	54,000
Colombia	508	614	609	573	6628	e234	e282	e280	r e260	283
Czechoslovakia	1,784	1,798	1,773	1,780	6790	458	462	e440	e400	200
Egypt	2,135	2,048	2,112	2,562	2,500	e1,065	e1,100	e1,000	e1,500	1,500
Finland[10]	973	648	556	—	—	e390	588	360	—	—
France	12,437	11,267	9,872	9,319	68,720	3,855	3,511	3,119	2,945	62,654
Germany, Federal Republic of:										
Western states	717	247	70	102	684	212	68	10	14	612
Greece[5]	e1,600	r1,032	1,573	2,013	2,000	e650	r423	640	820	800
India	47,800	51,018	49,961	51,434	653,700	29,923	31,937	31,226	32,198	33,600
Indonesia	153	194	203	143	6145	89	113	118	83	684
Iran[11]	2,130	1,692	2,005	2,296	2,300	r e1,200	r e900	r e1,100	r e1,300	1,300
Japan	291	266	96	42	633	182	166	61	25	621
Korea, North[e]	8,500	8,500	9,000	9,500	9,500	4,000	4,000	4,200	4,400	4,400
Korea, Republic of	582	470	390	334	6298	326	263	218	187	6180
Liberia	15,295	13,742	12,767	12,300	64,050	9,480	e8,520	e7,910	e7,450	2,490
Malaysia	208	161	132	193	6344	127	98	81	118	6210
Mauritania	r9,170	9,002	9,780	12,114	611,420	r5,960	5,851	6,357	7, 874	67,250
Mexico[12]	7,298	7,523	8,431	8,141	68,073	4,817	4,965	5,564	5,373	6 5,328
Morocco	196	210	114	176	6148	123	128	70	107	90
New Zealand[13]	e2,580	2,290	2,240	2,000	2,000	e1,425	e1, 300	1,266	1,150	1,150
Norway	3,659	3,141	2,644	2,358	62,031	2,378	2,042	1,719	1,528	61,320
Peru	5,036	5,019	4,171	4,460	63,246	3,356	3,305	2,839	3,032	62,147
Poland	9	6	6	7	6	2	2	2	e2	2
Portugal[14]	51	27	33	13	612	19	9	8	6	64
Romania	2,431	2,281	e2,300	2,482	2,400	632	595	e596	e647	640
South Africa, Republic of[15]	24,483	22,008	25,248	29,958	630,347	15,424	13,865	e15,906	e18,873	19,119
Spain[16]	6,089	4,492	4,212	4,566	63,030	2,778	2,124	1,925	2,120	6 1,375
Sweden	r20,475	r19,636	20,440	21,763	619,877	13,246	r12,809	13,393	14,124	612,901
Thailand	37	97	99	177	6129	21	r53	55	98	671
Tunisia	311	295	325	280	6291	e167	159	e175	e140	145
Turkey	5,249	5,366	5,481	3,602	5,242	r2,833	r2,881	2,983	e1,950	2,850
U.S.S.R.	249,959	250,874	249,754	241,348	6236,200	r137,252	r138,216	138,217	134,789	132,000
United Kingdom	289	263	224	34	633	61	58	49	8	612
United States[16]	39,486	47,648	57,515	59,032	656,408	25,295	30,526	36,468	37,413	635,695

See footnotes at end of table.

TABLE 24—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]				
	1986	1987	1988	1989[p]	1990[e]	1986	1987	1988	1989[p]	1990[e]
Venezuela	[r]16,753	[r]17,782	18,932	18,390	[6]20,365	[r]10,817	[r]11,670	12,340	12,016	[6]12,655
Yugoslavia	6,618	5,983	5,545	5,080	[6]4,132	1,983	1,764	1,844	[e]1,690	1,400
Zambia	1	1	([17])	([17])	([17])	([17])	1	([17])	([17])	([17])
Zimbabwe	1,110	1,328	1,020	1,143	[6]1,259	[r]690	824	632	[e]686	730
Total	[r]863,650	[r]889,627	907,522	926,070	919,255	[r]503,278	[r]521,741	534,275	548,487	542,748

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through July 28, 1991.

[2]In addition to the countries listed, Cuba and Vietnam may 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, China, Hungary, and North Korea.

[5]Nickeliferous iron ore.

[6]Reported figure.

[7]Dry weight.

[8]Series represent gross weight and metal content of usable iron ore (including byproduct ore) actually produced, natural weight.

[9]U.S. Bureau of Mines estimate of China's usable iron ore production. The ore grade of the series is equivalent to 50% Fe content to provide data approximately comparable with world market production. In actuality, run-of-mine ore in China averages only about 35% Fe. Production of crude ore, as reported by the Trust Fund Project on Iron Ore Information of UNCTAD was as follows, in thousand metric tons: 1986—142,480; 1987—152,540 (revised); 1988—154,380; 1989—162,160 (revised); and 1990—169,360.

[10]Includes magnetite concentrate, pelletized iron oxide (from roasted pyrite), and roasted pyrite (purple ore).

[11]Data are for year beginning Mar. 21 of that stated.

[12]Gross weight calculated from reported iron content based on grade of 66% Fe.

[13]Concentrates from titaniferous magnetite beach sands.

[14]Includes manganiferous iron ore.

[15]Includes magnetite ore as follows, in thousand metric tons: 1986—4,000 (estimated); 1987—4,979; 1988—5,492; 1989—6,594; and 1990—5,613.

[16]Includes byproduct ore.

[17]Less than ½ unit.

TABLE 25

SELECTED PRICES FOR IRON ORE IN THE JAPANESE MARKET

(F.o.b. shipping port basis. U.S. cents per dry long ton unit of iron unless otherwise specified)

Country and producer	Ore type	Prices (April 1-March 31)		
		Fiscal year 1988	Fiscal year 1989	Fiscal year 1990
Australia:				
Hamersley Iron Pty. Ltd. and Mount Newman Mining Co. Pty. Ltd.	Lump ore	28.78	33.76	39.15
Do.	Fines	23.68	26.76	31.03
Robe River Iron Associates	do.	20.51	23.18	26.88
Savage River Mines Ltd.	Pellets	36.46	42.77	46.63
Brazil:				
Cia. Nipo-Brasileira de Pelotizaçâo (Nibrasco)	do.	38.54	45.20	49.28
Cia. Vale do Rio Doce (Carajás)	Fines	21.23	23.99	27.82
Do.	Lump ore	24.92	30.99	35.94
Cia. Vale do Rio Doce (Itabira)	do.	22.24	25.60	29.69
Mineraçôes Brasileiras Reunidas S.A.	do	21.77	25.05	29.05
Do.	Fines	21.73	24.46	28.36
Samarco Mineracâo S.A.	Pellet feed	17.46	19.73	22.88
Canada: Iron Ore Co. of Canada (Carol Lake)	Concentrates	20.25	22.88	26.53
Chile:				
Minera del Pacífico S.A. (El Algarrobo)	Pellets	32.98	40.73	44.40
Minera del Pacífico S.A. (El Romeral)	Fines	16.44	18.58	21.55
India:				
Minerals and Metals Trading Corp. (Bailadila)	Lump ore	27.75	32.55	37.74
Do.	Fines	22.75	25.71	29.81
Liberia: LAMCO Joint Venture Operating Co	do.	18.58	21.00	(1)
Peru: Empresa Minera del Hierro del Perú S.A.	Pellets	27.59	(1)	(1)
South Africa, Republic of:				
South African Iron and Steel Industrial Corp. Ltd.	Lump ore	2 22.21	2 26.05	2 30.21
Do.	Fines	2 18.03	2 20.37	2 23.62

[1]No quotation published.
[2]Price per dry metric ton unit.

Source: The TEX Report (Tokyo), v. 23, No. 5375, Apr. 8, 1991, p. 12.

TABLE 26

OCEAN FREIGHT RATES FOR IRON ORE IN 1990: RATE RANGES FOR SHIPMENTS TO THE EUROPEAN COMMUNITY

Country	Loading port	Cargo size (thousand dead-weight tons)	Rate dollars per deadweight ton)
Australia	Pilbara ports	65- 95	9.50-11.70
Do.	do.	100-150	7.50-11.85
Do.	do.	160-210	7.40- 9.45
Brazil	South Atlantic ports	60- 95	6.80-10.25
Do.	do.	100-150	5.25- 9.40
Do.	do.	160-240	5.30- 7.00
Canada	Sept-Iles or Port Cartier	60- 90	4.50-11.45
Do.	do.	100-150	4.38- 8.40
Liberia	Buchanan or Monrovia	60- 95	5.90- 7.90
Mauritania	Nouadhibou	60- 95	3.50- 6.00
Do.	do.	100-150	3.20- 5.95
South Africa, Republic of	Saldanha Bay	100-150	8.00- 9.75
Sweden	Narvik (Norway)	65- 70	2.90- 5.10
Do.	do.	100-150	3.10- 4.00
Venezuela	Puerto Ordáz or Orinoco Delta	40- 60	9.90-10.50

Sources: Drewry Shipping Consultants Ltd. (London), Maritime Data Network Ltd. (London), Simpson Spence & Young Shipbrokers Ltd. (London), and The TEX Report (Tokyo).

TABLE 27

IRON ORE: WORLD PELLETIZING CAPACITY, BY CONTINENT AND COUNTRY

Country	Number			Rated capacity (million metric tons, gross weight)
	Sites	Plants[1]	Units	
North America:				
Canada	3	4	11	24.10
Mexico	5	6	6	9.50
United States[2]	10	18	50	65.23
Total	18	28	67	98.83
South America:				
Argentina	1	1	4	1.00
Brazil	3	8	8	24.30
Chile	1	1	1	4.00
Peru	1	2	2	3.20
Venezuela	1	1	2	6.60
Total	7	13	17	39.10
Europe:				
Belgium-Luxembourg[3]	1	1	1	.80
Czechoslovakia	1	1	1	.25
Netherlands[3]	1	1	1	3.80
Norway[4]	1	1	1	1.50
Sweden[5]	3	3	4	10.40
Turkey	1	1	1	1.30
U.S.S.R.[6]	7	13	NA	80.00
Yugoslavia[7]	1	1	1	.60
Total	16	22	NA	98.65
Africa:				
Liberia[8]	1	1	1	3.20
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	6.10
Asia:				
Bahrain[3]	1	1	1	4.00
China[6]	4	4	NA	4.50
India[10]	1	1	1	2.00
Iran	1	1	1	2.50
Japan[3]	1	2	2	4.40
Total	8	9	NA	17.40
Oceania: Australia1[11]	2	2	6	4.00
World total	55	78	NA	264.08

NA Not available.

[1]Staged additions are treated at some mining complexes as if they were separate plants. Site data exclude 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]Two older plants in Norway are no longer considered economically viable. The first, the older of two plants operated by A/S Sydvaranger at Kirkenes, has been idle since 1986. The second, 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, Switizerland), 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.

IRON OXIDE PIGMENTS

By David A. Templeton

Mr. Templeton is a physical scientist with the Branch of Industrial Minerals and has been with the Bureau for 3 years. He has covered iron oxide pigments for less than 1 year. Domestic survey data were prepared by Ms. Sarah P. Guerrino, and world production data were prepared by Ms. Audrey Wilkes.

According to the U.S. Bureau of Mines, U.S. Department of the Interior, mine production of iron oxides returned to pre-1989 levels, a decrease of almost 12% from the 1989 peak. Domestic sales of synthetic pigments, not total production, declined nominally (about 4%) in 1990 from the peak also seen in 1989. Sales of regenerator and steel-plant waste iron oxides totaled 28,161 tons as compared with 30,745 in 1989.

DOMESTIC DATA COVERAGE

Data for mine production, sales of finished pigments, and quantified steel-plant wastes were compiled from responses to a voluntary survey conducted by the U.S. Bureau of Mines. Mine production of and sales data for crude iron oxide pigments as shown in table 1 were tabulated using information supplied by the five known producers. Hematite shipped from the Cleveland-Cliffs Iron Co. Mather Mine stockpile is not included in "Mine production," but rather in "Crude pigments sold or used." These shipments are not depicted by the difference in data because mine sales can be either greater or less than production (i.e., stocks decreased or increased, respectively). Survey response by the finished pigment producers was 100%. Table 2 presents the data for domestic sales of finished pigment, not total production, obtained through the Bureau survey. Seven companies operating a total of eight plants provided the Bureau with a full accounting of regenerator and steel-plant waste iron oxides sold.

CONSUMPTION AND USES

The continued use of iron oxides in diverse markets ranged from construction products and pigments to magnetic materials (ferrites) and catalysts. As in the past, this use was due to the low cost, ready availability, and adequate, if not superior, performance of iron oxides. The majority of iron oxides, both natural and synthetic, was consumed as pigments in formulating paints and in construction materials such as concrete bricks, paving stones, and roofing tiles and granules. Minor uses included catalysts for the manufacture of industrial chemicals; fertilizer; trace mineral supplements in animal feed; binding medium for foundry sands; colorants for glass, plastic, and rubber; and several uses incorporating the magnetic properties of specialty iron oxides (e.g., hard and soft ferrites and magnetic inks and toners).

FOREIGN TRADE

Except for a significant increase in exports of nonpigment-grade iron oxide (most notably to Australia, Austria, Belgium, Canada, Japan, and the United Kingdom), the trade picture remained relatively unchanged. Total exports of nonpigment-grade material increased nearly sixfold. (It is likely that the data in table 5 received from the Bureau of the Census is in error and is being reviewed for accuracy.) Exports of pigment-grade iron oxide declined only slightly from 1989 levels. Imports of iron oxide pigment exceeded exports by just more than 3½

TABLE 1

SALIENT U.S. IRON OXIDE PIGMENTS STATISTICS

		1986	1987	1988	1989	1990
Mine production	metric tons	30,744	31,816	30,747	r36,661	32,421
Crude pigments sold or used	do.	37,183	38,803	39,711	r40,202	37,071
Value	thousands	$2,908	$3,598	$3,815	r$4,561	$4,615
Finished pigments sold	metric tons	116,444	124,293	126,640	127,665	122,921
Value	thousands	$126,388	$136,427	$134,325	$134,567	$138,343
Exports	metric tons	26,164	20,184	21,966	19,966	9,510
Value	thousands	$30,830	$31,689	$33,014	$15,700	$18,533
Imports for consumption	metric tons	33,360	38,394	38,929	136,669	34,000
Value	thousands	$21,517	$20,680	$27,128	$30,540	$36,909

rRevised.

1Data reflects conversion to the Harmonized Tariff Schedule, effective Jan. 1, 1989, Public Law 100-418, subtitle B.

TABLE 2

FINISHED IRON OXIDE PIGMENTS SOLD BY PROCESSORS IN THE UNITED STATES, BY KIND

Kind	1989		1990	
	Quantity (metric tons)	Value (thousand dollars)	Quantity (metric tons)	Value (thousand dollars)
Natural:				
Black: Magnetite	10,253	$2,129	W	W
Brown:				
Iron oxide	W	W	W	W
Umbers:				
Burnt	W	W	W	W
Raw	W	W	W	W
Red:				
Iron oxide[1]	26,395	4,710	25,219	$4,540
Sienna, burnt	W	W	W	W
Yellow:				
Ocher	W	W	W	W
Sienna, raw	W	W	W	W
Undistributed	12,725	7,218	21,315	9,411
Total	49,373	14,057	46,534	13,951
Synthetic:				
Brown: Iron oxide[2]	23,621	36,048	22,766	35,579
Red: Iron oxide	32,748	50,833	32,489	54,238
Yellow: Iron oxide[3]	21,923	33,629	21,132	34,575
Other: Speciality oxides	(4)	(4)	(4)	(4)
Mixtures of natural and synthetic iron oxides	(4)	(4)	(4)	(4)
Total	78,292	120,510	76,387	124,392
Grand total	127,665	134,567	122,921	138,343

W Withheld to avoid disclosing company proprietary data; included with "Undistributed."
[1]Includes pyrite cinder.
[2]Includes synthetic black iron oxide.
[3]Includes other specialty oxides and mixtures of natural andsynthetic iron oxides.
[4]Included with synthetic yellow iron oxide to avoid disclosing company proprietary data.

TABLE 3

PRODUCERS OF IRON OXIDE PIGMENTS, REGENERATOR IRON OXIDES, AND STEEL-PLANT WASTE IRON OXIDES IN THE UNITED STATES IN 1990

Producers	Plant location
Finished pigments:	
AST Co.	Granite City, IL.
American Minerals Inc.	Camden, NJ.
Blue Ridge Talc Co. Inc.	Henry, VA.
Columbian Chemicals Co.	St. Louis, MO.
DCS Color & Supply Co. Inc.	Milwaukee, WI.
Harcros Pigments Inc.	Emeryville, CA.; East St. Louis, IL.; Easton, PA.
Hilton-Davis Co.	Cincinnati, OH.
Hoover Color Corp.	Hiwassee, VA.
Mobay Corp., Inorganic Chemicals Div.	New Martinville, WV.
New Riverside Ochre Co.	Cartersville, GA.
Pea Ridge Iron Ore Co.	Sullivan, MO.
Prince Manufacturing Co.	Quincy, IL, and Bowmanstown, PA.
Solomon Grind-Chem Services Inc.	Springfield, IL.

times, and synthetic material accounted for 95% of the 34,000 tons imported. The largest sources of imports, in descending order, were Canada, the Federal Republic of Germany, Japan, Mexico, China, Cyprus (crude ore only), Brazil, and the United Kingdom. A complete listing of foreign sources of natural and synthetic pigments is given in table 7, and the breakdown in terms of color can be found in table 6.

WORLD REVIEW

Pfizer Inc.'s longstanding desire to divest itself of its pigment interests was realized in March with the $65 million sale to Harrisons & Crosfield PLC's U.S. subsidiary, Harcros Pigments Inc. Harcros had heretofore been the sole U.S.

TABLE 3—Continued

PRODUCERS OF IRON OXIDE PIGMENTS, REGENERATOR IRON OXIDES, AND STEEL-PLANT WASTE IRON OXIDES IN THE UNITED STATES IN 1990

Producers	Plant location
Crude pigments:	
Cleveland-Cliffs Iron Co., Mather Mine and Pioneer plant (closed July 31, 1979; shipping from stockpile)	Negaunee, MI.
Hoover Color Corp.	Hiwassee, VA.
New Riverside Ochre Co.	Cartersville, GA.
Pea Ridge Iron Ore Co.	Sullivan, MO.
Swansea Minerals Inc.	Tempe, AZ.
Virginia Earth Pigments Co.	Hillsville, VA.
Regenerator and steel plant waste iron oxides:	
Armco Steel Co.	Ashland, KY.
Cheseapeake Specialty Products	Baltimore, MD.
Gulf States Steel Inc.	Gadsden, AL.
Perox	Birmingham, AL, and Sharon, PA.
Petco Inc.	Lehi, UT.
Shance Chemical Corp.	Philadelphia, PA.
Weirton Steel Corp.	Weirton, WV.

distributor for the United Kingdom-based parent. The sale included pigment operations located in Emeryville, CA, East St. Louis, IL, and Easton, PA.

Another significant industry transaction included the $12 million sale of the Pea Ridge Iron Ore Co., Sullivan, MO, by the Fluor Corp. of Irvine, CA, to the Big River Minerals Corp., St. Louis, MO. Pea Ridge produces a natural black oxide (magnetite) used primarily in ceramic magnets and brake linings.

The AST Co., Granite City, IL, began production of synthetic yellow iron oxide with a proprietary process in which the material is precipitated from a ferric chloride-rich pickle liquor. The process is said to be much less energy intensive than other methods of producing regenerator oxides (e.g., spray roasting or acid evaporation) and uses a warm (170° F) hydrochloric acid bath to pickle nonscrap, low-carbon steels. The process can be perceived as double value added: not only does it accomplish the servicing of finished

TABLE 4

ESTIMATED IRON OXIDE PIGMENT CONSUMPTION,[1] BY END USE, AS A PERCENTAGE OF REPORTED SHIPMENTS

End use	All iron oxides		Natural iron oxides		Synthetic iron oxides	
	1989	1990	1989	1990	1989	1990
Coatings (industrial finishes, trade sales, lacquers, paints, varnishes)	24	24	17	17	29	29
Construction materials (cement, mortar, preformed concrete, roofing granules)	35	32	23	24	42	39
Colorants for ceramics, glass, paper, plastics, rubber, textiles	17	17	21	20	14	14
Foundry sands	5	4	12	12	(2)	(2)
Industrial chemicals (such as catalysts)	5	6	1	1	7	9
Ferrites	W	W	W	W	W	W
Animal feed and fertilizers	5	5	11	11	W	W
Other (including cosmetics, magnetic tape and magnetic ink, and polishing agents)	[3]9	[3]12	[3]15	[3]15	[4]8	[4]9
Total	100	100	100	100	100	100

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Data do not include magnetic iron oxide usage.
[2]Less than 1/2 unit.
[3]Includes ferrite iron oxide usage.
[4]Includes ferrites and animal feed and fertilizers iron oxide usage.

TABLE 5

U.S. EXPORTS OF IRON OXIDES AND HYDROXIDES, BY COUNTRY

Country	1989				1990			
	Pigment grade		Other grade		Pigment grade		Other grade	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quanitiy (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Algeria	—	—	—	—	—	—	12	$37
Argentina	10	$50	59	$208	47	$172	17	96
Australia	292	357	732	1,404	33	45	1,147	2,262
Austria	14	18	—	—	356	214	1,194	2,627
Barbados	—	—	—	—	—	—	17	27
Belgium-Luxembourg	43	43	433	877	701	731	6,711	2,516
Bolivia	—	—	—	—	—	—	12	32
Brazil	192	823	110	331	126	764	196	626
Canada	1,316	2,195	1,087	3,538	873	1,398	[1]134,549	23,389
Chile	1	2	—	—	—	—	138	111
China	16	73	31	113	32	120	248	618
Colombia	5	7	132	185	—	—	287	597
Costa Rica	—	—	—	—	—	—	79	84
Cyprus	—	—	—	—	—	—	20	31
Denmark	—	—	—	—	—	—	498	468
Dominican Republic	66	78	—	—	35	43	43	37
Ecuador	—	—	—	—	17	3	57	24
El Salvador	20	36	—	—	—	—	12	14
Finland	18	33	18	33	33	50	10	13
France	235	1,397	156	852	160	424	549	1,009
Germany, Federal Republic of	1,292	2,010	12,236	12,644	231	281	10,926	12,249
Greece	—	—	42	29	—	—	—	—
Guatemala	71	63	—	—	—	—	88	92
Honduras	—	—	10	20	—	—	—	—
Hong Kong	538	1,567	504	1,566	[1]1,696	5,418	184	597
India	56	169	185	771	158	455	394	1,547
Indonesia	38	42	200	137	136	161	221	173
Ireland	30	62	29	57	62	122	—	—
Israel	16	8	—	—	2	10	—	—
Italy	23	49	1,090	2,094	60	91	2,790	2,208
Jamaica	104	50	1	3	58	29	29	31
Japan	2,141	1,758	4,117	4,584	[1]587	774	[1]12,774	22,185
Jordan	—	—	—	—	—	—	148	176
Korea, Republic of	427	995	3,538	13,777	406	913	4,836	11,659
Kuwait	—	—	—	—	—	—	73	154
Macao	—	—	73	104	—	—	78	296
Malaysia	43	43	54	95	19	8	16	29
Mexico	207	383	4,949	4,815	229	418	7,139	7,836
Netherlands	572	735	644	1,317	531	1,078	1,274	2,656
Netherlands Antilles	7	8	—	—	—	3	32	344
New Zealand	42	51	11	36	2	6	38	47
Nigeria	—	—	—	—	—	—	131	164
Pakistan	—	—	(2)	14	—	—	—	—
Peru	10	4	—	—	—	—	(2)	4
Philippines	121	195	106	121	299	384	152	193
Qatar	—	—	—	—	—	—	60	262
Saudi Arabia	128	143	—	—	5	9	509	583

See footnotes at end of table.

TABLE 5—Continued

U.S. EXPORTS OF IRON OXIDES AND HYDROXIDES, BY COUNTRY

Country	1989				1990			
	Pigment grade		Other grade		Pigment grade		Other grade	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quanitiy (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Singapore	164	$537	202	$408	651	$2,015	747	$1,324
South Africa, Republic of	44	65	854	693	43	97	1,679	1,496
Spain	116	190	10	11	47	49	155	321
Sweden	—	—	1	4	—	—	238	144
Switzerland	12	46	—	—	6	36	872	301
Taiwan	200	223	66	136	46	59	1,227	1,559
Thailand	680	426	33	57	1,168	781	601	1,438
Trinidad	99	50	1,046	132	—	—	67	403
Tunisia	—	—	—	—	—	—	10	22
U.S.S.R.	200	139	3	20	—	—	—	—
United Kingdom	355	571	1,828	3,315	653	1,362	4,486	4,693
Venezuela	(2)	5	33	31	—	—	547	452
Yugoslavia	—	—	—	—	—	—	60	79
Zaire	—	—	—	—	—	—	215	161
Other	—	—	9	33	3	10	39	236
Total [3]	9,966	15,700	34,631	54,567	9,510	18,533	198,631	110,732

[1]Reported data from Bureau of the Census, under review for accuracy.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.
Source: Bureau of the Census.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF SELECTED IRON OXIDE PIGMENTS, BY TYPE

Type	1989		1990		Sources, 1990 (metric tons)
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	
Natural:					
Earth colors	[1]2,135	$999	1,205	$576	Cyprus 1,030; Federal Republic of Germany, Western states 155; Spain 20.
Umber	(2)	(2)	400	125	Cyprus 342; Federal Republic of Germany, Western states 58.
Vandyke brown	(2)	(2)	76	66	Federal Republic of Germany, West Germany 76.
Micaceous	2,826	355	178	225	Austria 90; Spain 58; China 17; Netherlands 8; Japan 3; Canada 1; United Kingdom 1.
Total[3]	4,961	1,354	1,859	991	
Synthetic:					
Black	7,550	11,441	8,380	15,298	Canada 4,013; Japan 2,743; Federal Republic of Germany, Western states 1,407; New Zealand 135; China 36; Mexico 20; Australia 18; United Kingdom 5; Federal Republic of Germany, Eastern states 3.
Red	11,599	4,675	11,127	7,124	Canada 4,494; Federal Republic of Germany, Western states 3,060; Mexico 1,145; Sweden 800; China 598; Spain 440; Japan 230; Brazil 226; Netherlands 108; Venezuela 15; Belgium 6; Colombia 2; United Kingdom 2.
Yellow	10,681	8,594	11,492	10,803	Federal Republic of Germany, Western states 3,400; Canada 2,615; Mexico 1,949; United Kingdom 1,186; Brazil 990; China 783; Spain 495; Venezuela 17; Hungary 16; Hong Kong 15; Colombia 10; Netherlands 9; Australia 8; Switzerland 1.
Other[4]	1,878	4,476	1,141	2,693	Federal Republic of Germany, Western states 664; Japan 197; Canada 137; Mexico 63; India 31; Australia 24; Italy 15; United Kingdom 7; Spain 3; Finland 1.
Total	31,708	29,186	[3]32,141	35,918	
Grand total	36,669	30,540	[3]34,000	[3]36,909	

[1]Includes finished and crude natural ocher, sienna, umber, vandyke brown, and other natural oxides.
[2]Included with earth colors.
[3]Data do not add to totals shown because of independent rounding.
[4]Includes synthetic brown oxides, transparent oxides, and magnetic and precursor oxides.
Source: Bureau of the Census.

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF IRON OXIDE AND IRON HYDROXIDE PIGMENTS, BY COUNTRY

Country	Natural				Synthetic			
	1989		1990		1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quanitiy (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	—	—	—	—	—	—	50	$74
Austria	92	$91	90	$93	102	$24	—	—
Belgium-Luxembourg	20	13	—	—	74	221	6	66
Brazil	—	—	—	—	781	603	1,216	971
Canada	2,418	156	1	2	12,693	3,564	11,258	5,035
China	—	—	17	9	66	32	1,416	716
Colombia	—	—	—	—	—	—	12	10
Cyprus	1,772	382	1,372	305	—	—	—	—
Dominican Republic	—	—	—	—	21	29	—	—
France	40	25	—	—	—	—	—	—
Germany, Federal Republic of	317	550	289	454	8,180	6,720	8,530	9,711
Hong Kong	—	—	—	—	—	—	15	18
Hungary	—	—	—	—	—	—	16	27
India	—	—	—	—	—	—	31	129
Italy	—	—	—	—	—	—	15	18
Japan	1	7	3	85	3,702	13,152	3,171	13,530
Korea, Republic of	—	—	—	—	—	—	—	—
Mexico	—	—	—	—	3,855	3,020	3,177	3,009
Netherlands	—	—	8	11	116	101	117	44
New Zealand	—	—	—	—	—	—	135	256
Nigeria	6	22	—	—	—	—	—	—
Peru	(1)	31	—	—	—	—	—	—
Spain	294	71	78	25	405	311	938	710
Sweden	—	—	—	—	362	115	800	159
Switzerland	—	—	—	—	1	6	1	11
United Kingdom	1	7	1	7	1,251	1,199	1,201	1,335
Venezuela	—	—	—	—	101	90	33	54
Other	—	—	—	—	—	—	3	34
Total[2]	4,961	1,354	1,859	991	31,708	29,186	32,141	35,918

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.
Source: Bureau of the Census.

steel products, but it also produces synthetic iron oxide pigment. According to the developer, the process can be used to treat the pollution-plagued problem of steel-plant waste streams.

BASF AG announced intentions to invest in the production, most likely in Europe, of 150 tons per year of iron oxide-coated aluminum flake. The pigment, Paliocrom Gold, produces a metallic gold sheen that varies with the viewing angle by the different ways incident light is affected. Some of the light is reflected by the flake and some by the coating. Furthermore, the coating partially absorbs incident light rays. The pigment was developed at BASF's laboratory in Ludwigshafen, Federal Republic of Germany.[1]

OUTLOOK

The long-term outlook for the U.S. iron oxide pigment industry is expected to be one of continued growth despite decreases of mine production and finished pigment sales in 1990. Principal factors are the popularity of earth-toned colors, resurgence of growth in construction activities, and continued market development in paints and coatings and specialty oxides. The innocuous nature of iron oxide pigments may accelerate growth in this industry as heavy metal-bearing pigment usage wanes. However, declines in residential and commercial construction starts may have a greater impact and, therefore, hold back generally expected growth. The need for infrastructure improvements in the United States has been established, and, when implemented,

TABLE 8

NATURAL IRON OXIDE PIGMENTS: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Argentina	1,027	1,022	815	578	600
Austria	11,730	10,807	9,938	10,924	11,000
Brazil	5,474	5,803	5,223	[r e]5,500	5,500
Canada[e]	2,000	2,000	2,000	2,000	2,000
Chile	4,404	8,145	8,542	23,653	10,000
Cyprus	10,000	12,500	10,060	8,534	9,000
France[e]	15,000	15,000	15,000	15,000	15,000
Germany, Federal Republic of:					
Western states[3]	11,365	10,003	8,143	[r e]6,000	6,000
India	98,668	145,245	151,781	173,366	180,000
Iran[e 4]	4,300	4,300	4,300	4,300	4,300
Italy[e]	875	850	850	[r e]850	850
Pakistan (ocher)	608	1,792	1,040	2,394	2,400
Paraguay[e]	250	285	250	250	250
South Africa, Republic of	1,501	768	2,070	1,327	1,350
Spain:[e]					
Ocher	10,500	10,500	10,500	10,500	10,500
Red iron oxide	20,000	20,500	20,500	20,500	20,500
United States	30,744	31,816	30,747	36,661	[5]32,421
Yugoslavia	1,419	1,061	444	853	[5]1,212
Zimbabwe	207	[e]200	363	287	300

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through Apr. 15, 1991.

[2]In addition to the countries listed, a considerable number of others undoubtedly produce iron oxide pigments, but output is not reported, and no basis is available for formulating estimates of output levels. Such countries include (but are not limited to) China and the U.S.S.R. Because unreported output is probably substantial, this table is not added to provide a world total.

[3]Includes Vandyke brown.

[4]Iranian calendar year (Mar. 21 to Mar. 20), beginning in the year stated.

[5]Reported figure.

established, and, when implemented, could help sustain construction-related consumption, especially in concrete products and coated steels.

The near-term view is expected to closely resemble the overall economic climate, with the major sectors (concrete products and paints and coatings) being affected more than minor market niches (brake linings, magnetic inks, ferrites, and various product colorants).

[1]Industrial Minerals (London). Iron Oxide Paints a Golden Picture. No. 278, Nov. 1990, p. 91.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

IC,s 8771 and 8813; Iron Oxide Pigments

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2. Natural Iron Oxide Pigments – Location, Production, and Geological Description.

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IRON AND STEEL

By Anthony T. Peters

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Iron and steel are vital to the United States for both national security and economic well-being. They are the basic metals of any industrial society. Although there are technically acceptable substitutes for many of their small-scale uses, there are no practical substitutes on a large scale because of the cost and lack of availability of alternative materials.

Companies involved in iron and steel include ferrous foundries, steel mills, and the ferrous scrap industry. Foundries pour molten cast iron or steel into molds to produce castings with approximate shapes of the final products. Steel mills cast relatively simple steel shapes that the mills roll or hammer into finished products, such as sheet, bar, or structural shapes. Steel mills can be divided into integrated mills, which produce pig iron from ore and refine the pig iron to steel, and nonintegrated mills that use scrap as their primary raw material.

During the remainder of the century, growth of demand for iron and steel in the industrialized countries is expected to be slow compared with that in the 1950's and 1960's. Factors causing the lower growth include a shift of the industrialized economies toward services and manufacturing industries that use little iron and steel, more efficient use of materials in manufacturing and construction, substitution of other materials for iron and steel, and imports of manufactured products from developing countries.

The production of raw steel in 1990, 89.7 million metric tons (98.9 million short tons), was almost exactly 1 million tons higher than that of the previous year. Steel shipments were valued at approximately 40 billion dollars.

All companies reported sharply reduced profits, with a few actually incurring losses. There are many reasons for this apparent contradiction. As the economic downturn continued during the year, steel demand dropped, but the steelmakers continued to produce steel in expectation of an imminent upturn; this trend became strong when consumer confidence dropped to very low levels at the start of the war in the Persian Gulf in September.

Furthermore, the trend to make steel ahead of orders was supported by the general expectation of a strike at the U.S. Steel Corp. that did not materialize. Large amounts of steel were shipped on generous credit terms, reflected in frequently sharp increases in accounts receivable.

Improvements in technology, such as a further increase of the proportion of steel cast continuously to more than 67%, reduced operating costs but increased labor costs and provisions for the shutdown of unprofitable operations, or costs of severance of a number of employees, were often greater than the savings. Furthermore, the increased inventories caused price wars of unprecedented severity—discounts from nominal or "list" prices of up to 30% became common.

Imports were roughly the same as those in 1989, 15.7 million metric tons (17.3 million short tons); the major exporters, Japan, the European Community, and Canada, shipped a little less, but the other, smaller exporters shipped, in general, a little more. Exports, 3.9 million metric tons (4.3 million short tons), were 0.3 million less than in 1989.

Declared steelmaking capacity increased slightly during the year, from 105.1 to 105.8 million metric tons (115.9 to 116.7 million short tons). This, however, was the result of process improvements and restarting a small shuttered minimill rather than of any "greenfield" construction. Plans to construct at least two minimills with a combined capacity of more than 2 million metric tons were announced during the year.

Overall performance data are shown in table 1 and highlights of technical improvements in table 2.

DOMESTIC DATA COVERAGE

Data regarding the domestic production of iron and steel are those developed by the American Iron and Steel Institute (AISI). The members of this organization produce about 85% of domestic steel. Nonmembers informally notify AISI of their production numbers; hence, the data reported here can be regarded as complete.

Numbers referring to imports and exports of steel and its products were developed from information obtained from the Bureau of the Census. Other data were obtained from company reports and the trade press.

BACKGROUND

Integrated Steel Producers

Integrated steel producers are those that smelt iron ores, usually in the form of pellets, to crude liquid iron in blast furnaces and refine the iron, with some scrap, in basic open-hearth or basic oxygen furnaces, producing liquid steel. This is mostly cast into semifinished sections in continuous casting machines, although 34% of production was poured (cast) into ingots that were rolled into slabs or blooms.

The product mix of the integrated producers consists predominantly of flat products, sheet and strip, some of which is coated, galvanized, or tin plated. Some plates are made as well, but not many shape products, bars, and structurals. This field has been taken over by the nonintegrated producers.

Nonintegrated Steel Producers

The nonintegrated producers melt scrap in electric arc furnaces and cast the steel in continuous casting machines. The definition includes the well-known "minimills." However, the meaning of this expression changed within the past few years. It used to be accepted that a minimill produces only low-quality, nonalloy steel as simple bars and structural shapes, such as reinforcing bars, wire rods, angles, tees, and small channels, in furnaces with not more than a

TABLE 1

SALIENT IRON AND STEEL STATISTICS

(Thousand short tons unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Pig iron:[1]					
Production	44,287	48,308	55,745	55,873	54,750
Shipments:					
Steel production	43,312	47,413	54,833	55,299	54,081
Other uses[2]	398	365	912	713	669
Steel:[1]					
Production of raw steel:[3]					
Carbon	71,413	77,976	86,823	86,231	86,590
Stainless	1,689	2,028	2,199	1,926	2,037
All other alloy	8,505	9,147	10,902	9,786	10,279
Total	[4]81,606	89,151	99,924	97,943	98,906
Capacity utilization, percent[5]	63.8	79.5	89.2	84.5	84.7
Net shipment of steel mill products	72,737	80,646	88,391	84,100	84,981
Annual average composite price for steel mill products[6]	24.8	25.4	25.4	r26.3	26.3
Exports of major iron and steel products[7]	1,201	1,419	2,576	4,578	4,303
Imports of major iron and steel products[7]	22,145	21,534	22,310	17,333	17,162
Profits or (loss), million dollars	(4,149.9)	1,017.3	[8]2,300	1,478	(220)
World production:[9]					
Pig iron	r546,179	r562,281	592,233	p602,790	e593,699
Raw steel	r785,609	r812,740	856,978	p862,268	e850,982

eEstimated. pPreliminary. rRevised.

[1]American Iron and Steel Institute (AISI).

[2]In-plant foundries, exports, etc.

[3]Raw steel defined by AISI as steel solidified from liquid state.

[4]Data do not add to total shown because of independent rounding.

[5]Raw steel production capacity defined by AISI as the tonnage capability to produce raw steel for sustained full order book.

[6]Iron Age, cents per pound, nominal.

[7]Bureau of the Census.

[8]558.9 after special charges and unusual expenses.

[9]Source: U.S. Bureau of Mines and the International Iron and Steel Institute.

TABLE 2

EFFICIENCY TRENDS OF U.S. STEEL PRODUCTION

Year	Raw steel			Average steel[1] product yield (percent)	Work force[2] input (hours per shipped ton)
	Capacity (thousand short tons)	Utilization (percent)	Continuous cast (percent)		
1979	155,300	87.8	16.9	73.5	8.9
1980	153,700	72.8	20.3	75.0	9.0
1981	154,300	78.3	21.6	73.2	8.5
1982	154,020	48.4	29.0	82.6	8.5
1983	150,600	56.2	32.1	79.9	7.0
1984	135,300	68.4	39.6	79.7	6.4
1985	133,600	66.1	44.4	82.6	5.7
1986	127,000	63.8	55.2	86.1	5.1
1987	112,200	79.5	59.8	86.0	4.6
1988	112,200	89.2	61.3	84.0	5.7
1989	115,900	84.5	64.8	86.4	r4.3
1990	116,700	84.7	67.8	85.9	4.1

rRevised.

[1]100 times shipped tons divided by raw steel tons.

[2]Hourly and salaried hours combined.

Sources: American Iron and Steel Institute and Bureau of Labor Statistics.

91-metric-ton (100-short-ton) capacity and that the total mill output is at the most 910,000 metric tons (1 million short tons) per year. Almost all of these operations were closely held by a few investors.

This situation is still valid in many cases, but exceptions are too numerous to be disregarded. Many mills tap heats exceeding 100 tons; actually, Northwestern Steel and Wire Co. has the biggest furnaces in the world, making 365-metric-ton (400-short-ton) heats. Several mills exceeded the 1 million yearly tons figure; two corporations running several mills, Nucor Co. and North Star Steel Corp., have outputs exceeding those of the two or three smaller integrated producers. All minimills make high-strength low-alloy steels where the alloy content, usually columbium or vanadium, seldom exceeds one-quarter of 1%; many make also the traditional alloy steels, those with alloy contents not exceeding 5%. Several mills make higher quality grades, up to "forging quality," that are subject to severe testing and performance guarantees. Three roll only plates, two of them, high-quality grades. The Nucor Co. pioneered in the concept of "thin slab casting" and produced close to 1 million short tons per year of hot-rolled sheet and coil in its Crawfordsville, IN, mill. The larger and more advanced mills are sometimes called "market mills," but this term is not well defined and thus not widely used.

Alloy Steel Producers

The definition of alloy steels is quite straightforward: an alloy steel must contain up to 5% of intentionally added alloying elements (the lower limits are different for each element, varying from 0.05% in the case of molybdenum to 0.35% for chromium). High-alloy steels are those containing more than 5% alloys, but must have at least 50% iron to be classified as steels. Stainless and hot-work or high-speed tool steels are the best known examples of high-alloy grades. High-alloy steels are made only by specialized producers, who often make simpler alloy steels and occasionally plain carbon grades.

The often used expression "specialty steel" is vague in that almost any steel may be called special if made to some unusual or very demanding customer requirements. For instance, there is nothing special in a low-carbon steel for deep drawing, but the same grade vacuum degassed and with nitrogen stabilized by an almost undeterminably low addition of boron is very spe-

cial. Also, a plate containing 1% manganese is not special at all unless it is made, for instance, to meet stringent impact resistance requirements at subfreezing temperature.

Substitutes

Iron, as steel or cast iron, is the most widely used metal in the entire world. The reason is the 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

The legislation most affecting the industry was the passage of the Clean Air Act Amendments of 1990. A study by the U.S. Bureau of Mines (to be published) indicated that a number of older coke batteries owned by integrated steel mills would probably be uneconomical to upgrade to the mandated air purity standards and would be closed down. As a consequence, coke imports would increase from a range of 2 to 3 million to 6 to 8 million short tons per year.

The most-favored-nation customs status was given to Czechoslovakia, Hungary, and Poland. The practical effect of this change is a sharp lowering of customs duties; for instance, in the case of Czechoslovakia, the average duty would drop from 29% to about 6%.

The Department of Energy (DOE) contracted with Surface Combustion Inc. to construct and evaluate a commercial-sized installation to preheat scrap before charging it into electric arc furnaces. The project was based on a pilot plant developed by Surface Combustion.

The DOE also partly financed two trials by the Bethlehem Steel Corp.: a project to study coals involved in direct injection of coal powders into blast furnaces in the Burns Harbor mill costing $31 million and an ongoing project to upgrade an older coke battery in the Sparrows Point works to the proposed Clean Air Act pollution limits.

The direct steelmaking joint project between DOE and the AISI, mostly financed by the DOE, continued, and the contract was extended from 1 to 3 years. The project involved eight steelmaking companies. The total expected cost was $30 million with about $23 million coming from DOE.

With the pending expiration in March 1992 of the Voluntary Restraint Agreements (VRA's) of steel imports to the United States, talks were initiated by the U.S. Trade Representative with the major steel exporters to the United States in April 1990. The talks intended to convert the bilateral agreements regarding "unfair trade supports, especially almost all subsidies," into a multilateral agreement to be extended worldwide. Following the broad agreements reached in informal talks with Brazil, Japan, Mexico, and the European Community, the subject was introduced at the final session of General Agreement on Trade and Tariffs (GATT) in Brussels. Since the collapse of the talks owing to the disagreement about European agricultural subsidies, the talks reverted in December 1990 to individual signatories of the respective VRA's, and it appeared that a major international agreement may be in the offing.

Unfortunately, in November, AISI presented a study that showed that many countries continue to subsidize their steel industries, often in a modified form, such as taking over steel companies' debts by central state banks, guaranteeing loans for expansions, etc. Also, many countries continued the practice of dumping steel in the U.S. market. This study could interfere with the negotiations.

In accordance with the provisions of the Trade and Tariff Act of 1984, the U.S. International Trade Commission (ITC) determined whether domestic steel companies with a positive cash-flow actually reinvested profits, retrained displaced workers and, in general, adjusted to international competition. The ITC certified, and the President accepted the findings, that all nine major steel companies had an aggregate cash-flow of $1.1 billion during the first 9 months of the budget year (October 1, 1989, through September 30, 1990), while steel-related expenditures were $1.5 billion. The ITC also certified that during the last quarter of the year, expenditures would exceed the cash-flow. In every case, expenditures for retraining workers displaced by modernization exceeded 1% of net cash-flow.

A study by the Congressional Office of Technology Assessment indicated that about $1 trillion may be needed to reconstruct and upgrade the existing but deteriorating U.S. infrastructure—the roads, bridges, sewage plants, schools, and post offices, etc. Out of this sum, steel would represent about $16 billion. These numbers included supporting structures, such as office buildings, and the needed construction equipment. However, since this sum would have to come out of taxes, the chance of this rebuilding actually occurring in the near future was not considered by industry analysts to be high. The Office of Technology Assessment expressed an opinion that local initiatives on a smaller scale would have a better chance of success.

One unusual example supported this suggestion. During the primary elections in California, the voters approved a measure that would double the gasoline taxes by 1994. The proceeds from this increase were explicitly earmarked for the rebuilding and construction of roads and other transit projects. This outcome may signal the beginning of new willingness of voters to approve such expenditures.

Production

Integrated Steel Production.—The 13 integrated steel companies ran at yearend 46 blast furnaces, 3 open-hearth shops with 15 operable furnaces, and 25 basic oxygen shops with 58 furnaces. Also, one producer of high-alloy steels used basic oxygen furnaces but charged them with iron obtained by remelting pig iron and scrap in large electric induction furnaces.

The last remaining three open-hearth shops are expected to be closed and replaced with basic oxygen furnaces within the next few years. One was actually slated for replacement in 1991.

The year started out moderately well, but the general slump of economic activity in the country began to be felt by late spring. The beginning of the war in the Persian Gulf in September depressed consumer confidence, resulting in sharp drops of sales of goods that use large amounts of flat products, such as automobiles, appliances, and furniture. Construction, especially new housing starts, dropped sharply as well.

As a result, by yearend, several companies showed losses, and the profits of the others were much lower than those in 1989.

For the first time in many years, three blast furnaces and one basic oxygen shop were shut down toward yearend for lack of orders. Overall operating rates dropped from about 85% to a range of 65% to 70% of nominal capacity.

No capacity increases were planned, although some steelmaking capacity increases were the result of improved operating practices and further extensions of continuous casting. Most of the capital expenditures were directed toward the middle and finishing operations, hot- and cold-rolling mills, aiming at improvements in quality and productivity rather than outputs. More galvanizers were planned as joint ventures with Japanese steel companies.

Important structural changes took place during the year. The USX Corp. announced a plan to issue separate stock for Marathon Oil Co. and U.S. Steel Corp. This would make it easier to sell all or a part of the steel operations. U.S. Steel Corp. reached an agreement on a new labor contract with the United Steelworkers. The contract contained an unusual feature, a guarantee that senior workers would retain their benefits regardless of whether the plant where they work was to be sold or not. This was generally regarded as a hindrance to selling unprofitable operations.

Armco Steel Co. L. P., 45% owned by Kawasaki Steel Corp., reached an agreement with its employees in line with the U.S. Steel contract lasting 4 years but containing a no-strike pledge valid for 8 years.

Sharon Steel Corp. was split into two parts, the steel mill and the nonferrous interests, with the secured creditors agreeing to take over the steel mill in payment of their debts, while the unsecured creditors took over the nonsteel properties. This agreement was accepted by the bankruptcy court, effectively clearing the way for Sharon Steel to emerge out of bankruptcy.

The second largest steel producer, Bethlehem Steel Corp., announced spinning off the shape products operations to form a wholly owned subsidiary. This included the Johnstown, PA, works where a new caster was planned, the Bethlehem mill, and the rolling shops in Lackawanna (steelmaking there was closed several years ago). Toward yearend, a plan was announced to enter into a 50-50 joint venture with the British Steel Corp. to produce rails and shape products. The plan called for expanding the Steelton works near Harrisburg, PA, and abandoning steelmaking at Bethlehem, PA, which would become a finishing facility. Both developments were subject to receipt of concessions from the United Steelworkers regarding work rules. Resolution of this problem was expected to be lengthy and expensive: Bethlehem Steel wrote down $550 million as the cost of restructuring these facilities, shipbuilding, and other operations. The result of these charges was a $433 million loss reported for 1990.

National Intergroup Inc. sold for $147 million another 20% of National Steel to its half-owner, the NKK Corp. The future sale of another 20% was agreed on, leaving the American company with a nominal 10% ownership. The new Japanese owners announced the construction of a new, large coke battery with a capacity of 850,000 tons per year using the latest Japanese technology.

Inland Steel Co. announced its decision to build at least one coke battery using a modification of the design of the Sun Coal Co., a modern version of the old beehive ovens. All byproducts are burnt in the oven resulting in absence of pollution owing to the negative pressure in the oven obtained by the strong suction from the exhaust. Steam, used for power production, is the only coproduct. The drawback of the design was the large amount of space required.

National Steel Corp. started its degasser at the Granite City, IL, mill; so did the Bethlehem Steel Corp. at its Burns Harbor, IN, plant. The Armco Steel Co. L. P., upgraded its degasser in Middletown, OH. All these are expected to contribute to the quality of the highest grades of flat rolled steel.

The expansion of continuous casters progressed rapidly. Geneva Steel Corp. in Provo, UT, decided to install a caster that was designed to cast slabs of medium thickness, 152 millimeters (6 inches), but may be modified to thin slab casting, 50 millimeters (2 inches), if the technique, pioneered by the Nucor Corp., would prove satisfactory. This would save Geneva a part of the replacement cost of its combination plate and hot strip mill, which, although upgraded, dated back to 1943. This caster will be fed by a Q-BOP (Basic Oxygen Process) steelmaking shop, a version of the basic oxygen furnace process. Geneva bought the entire melt shop from the South Chicago plant of the U.S. Steel Corp., had it dismantled and shipped to Utah, and was reerecting it there. The total cost of this expansion was stated to be $226 million, including other minor developments. The open-hearth shop would be closed.

Weirton Steel Corp. expanded its slab caster to handle 2.8 million short tons per year from 1.8 million. This made Weirton a 100% cast-steel mill. The Granite City, IL, plant of National Steel also started to use its second slab caster. Gulf States Steel Inc. added a ladle metallurgy station to its recently started slab caster. The caster was originally owned, but not installed, by a Spanish steel company that was closed as one of the conditions for Spain entering the European Community; thus, Gulf Steel bought it for a fraction of its cost, reportedly for $42 million.

The United States Steel Corp. started the construction of a large slab caster at its Edgar Thomson Works in the Mon Valley in central Pennsylvania. When this caster and the slab caster under construction at the Gary Works in Indiana are completed, U.S. Steel Corp. will double its continuous casting capability, which at present is 42%, much below the national average of 66%, including minimills. The cost of the Mon Valley project was estimated to be $256 million.

The expansion of continuous casters diminished the need for ingot molds. As a result, the Shenango Group Corp. closed its blast furnace and ingot mold foundry in Neville Island, PA; this was the last "merchant" blast furnace left in the United States not associated with a steel mill.

Construction of a large number of new galvanizing plants was announced. Inland Steel Co. and Nippon Steel Corp. started the construction of a galvanizing plant next to the recently started continuous cold-rolling mill; toward yearend this mill started to ship class I products but had problems with synchronizing its many process computers. Bethlehem Steel Corp. announced plans to build galvanizing lines in its Burns Harbor, IN, and Sparrows Point, MD, mills; these will be partly financed by Japanese banks. The Wheeling-Pittsburgh Steel Corp. and the Nissan Steel Co. started to build a second line at their jointly owned facility. Armco Steel Co. L. P., and its partner, Kawasaki Steel Corp., decided to build a third line in their Middletown, OH, mill. Kobe Steel Corp. and USX Co. jointly started to build a large galvanizing plant in Leipsic, OH. All these were to be hot-dip operations. No firm cost or capacity data were announced.

Nonintegrated Steel Production.—The nonintegrated producers make about 25% of all the steel produced in the United States and keep their output up even in times of low demand by lowering prices or increasing the discounts from list prices. Not

all companies publish price lists, and few bother to keep them up to date. This resulted in a severe erosion of profits in 1990. Many producers showed in their stockholders' reports profits of under $10 per short ton and the lowest selling prices in many years (e.g., reinforcing bars in standard sizes could be bought for $280 per short ton).

Nevertheless, these producers kept updating their operations and, in many cases, expanding their production facilities. However, one company, the 118-year-old Colorado Fuel and Iron Corp., formerly an integrated producer, asked the local court for protection from creditors under the terms of chapter 11 of the Bankruptcy Act. The reason for this failure was the inability of the company to make the legally required contribution to its pension fund. The Birmingham Steel Corp. closed its melt shop in Norfolk, VA, and supplied the rolling mill with billets made in the much updated and expanded Kankakee, IL, plant. Also, Birmingham closed its small Emeryville, CA, operation because it was uneconomical, especially with respect to the high value of the ground it occupied. This company announced a plan to buy the obsolescent Seattle Steel Corp. and combine its output with that of its own mill nearby, in Kent, WA, retaining only one melt shop. The company's California customers would be served from this location and in the future from the announced new mill near Phoenix, AZ.

Birmingham Steel backed out of the earlier announced plan to build a flat products mill in Texas, with a scrap preparer, Proler Corp., and an Italian engineering company as partners. The reason given was the heavy capital outlay required, much higher than the original estimates.

The Nucor Co., following the success of its aforementioned Crawfordsville, IN, flat products mill, announced a plan to build another similar operation close to its beam mill in Arkansas. The expected cost was in excess of $300 million. This mill will have no pickling, oiling, or cold-rolling facilities because independent final processors are nearby. However, it will be sized to handle 27-metric-ton (30-short-ton) coils, rather than 18-metric-ton coils used at Crawfordsville. It will roll thinner gage steel than the other mill, thus enlarging the product range.

The Nucor-Yamato mill rolling beams in Blythesville, AR, mentioned previously, had a ladle furnace built at a cost of $4 million. The objective was to reduce costs by improving the quality of the steel, incidentally obtaining increase of the rated capacity of 650,000 product tons. A further expenditure of $14 million could raise the plant capacity by 30%.

As the result of the startup of Crawfordsville and the improvements in Blytheville and other mills, Nucor became the largest nonintegrated steel company in the United States, having made in 1990 3.15 million metric tons (3.46 million short tons). This output surpassed the output of three integrated mills owned by Rouge Steel, Weirton Steel, and Wheeling-Pittsburgh Steel Co.

The market for structural shapes and especially for wide flange beams, affected by the entry of the Nucor-Yamato plant, got a further jolt when the new plant of Northwestern Steel Co. near Houston, the former shape products plant of Armco Inc. that was considerably expanded and updated by its new owners, entered the market. Its capacity was declared to be about 540,000 metric (600,000 short) product tons. Additionally, Chaparral Steel Corp. was building another mill for structural products, including beams up to 24 inches wide, rated tentatively at 450,000 metric (500,000 short) product tons per year. The costs of this product should be low because it will start with a dog-bone-shaped cast beam blank, close to the required final shape, and thus will require very little rolling.

As a response to severe price competition, Inland Steel Co. announced that it would cease its structural production in early 1991. The USX Co. made continued production of beams at the South Chicago mill contingent upon the United Steelworkers accepting changes of work rules that would increase productivity. If this mill closed, it would mark the end of production of structural products from integrated steel operations and the closure of the 90-year-old south Chicago mill.

Northwestern had the distinction of receiving the Japanese Industrial Standards Certificate from Japan's Ministry of International Trade and Industry, being only the second U.S. steel company to receive this award, after the Chaparral Steel Corp. This quality award is necessary for bidding on construction projects in Japan that use any governmental funds.

One-half of Georgetown Steel Corp. in Georgetown, SC, was sold to Unimètal Co., a branch of the French Usinor Sacilor Groupe, the second largest steel corporation in the world after Japan's Nippon Steel Corp. Unimètal already was the largest foreign supplier of wire rod to the United States. Shortly afterward, in November 1990, it was announced that the new company would install a 550,000-metric-ton (600,000-short-ton) billet caster intended mainly for the production of high grades of wire, such as tire and piano wire.

The NS Group announced the startup of a continuous caster in its Newport works, which makes mainly welded pipe; also, a new reheating furnace was installed. The group bought the shuttered works of Koppel Steel, owned by Babcock and Wilcox Corp., in Koppel and Ambridge, PA. Koppel Steel produced seamless tubing and special quality bars before it was closed in 1988, a result of the collapse of the oil tubing market. The capacity of Koppel is 360,000 metric (400,000 short) raw steel tons per year; Ambridge is the finishing operation.

The nonintegrated steel producers use scrap as their raw material. This results in the retention in the steel of large amounts of "residual elements" contained in the scrap, mainly copper and tin, that cannot be refined out of a steel bath, and chromium and others that can be only partially removed. The effect of these elements is often detrimental, especially for some high-quality steel products.

A recognized substitute for scrap that does not carry any residual elements is direct-reduced iron (DRI). In the United States, it is made only by Georgetown Steel Corp. for its own internal use. The use of DRI dilutes the residuals to the point where they cease to have a measurable influence on the steel properties. Nucor's Crawfordsville plant is known to use up to 30% of the charge as DRI; other steelmakers are known to use it for specific applications.

In midyear, Oregon Steel Corp., a plate and tube maker, announced that it was entering into a joint venture with the Venezuelan CVG Co. to build a DRI plant near the rich iron ore mines in the Orinoco River basin. The plant was to cost $220 million; it was to use the Midrex process. Oregon Steel would finance up to 80% of the venture and have a claim on up to 75% of the 750,000 metric tons (825,000 short tons) of the DRI briquettes produced per year.

Alloy Steel Production.—Production of alloy steel in 1990 was 9.3 million metric tons (10.3 million short tons); that of stainless grades was 1.8 million metric tons (2.0 million short tons). Alloy steels are being partially replaced by the high-strength low-alloy grades that are reported as plain carbon steel. Production of stainless steels remained steady for several years, but is expected to show an increase owing to in-

creased activity in the pollution controls industry. Almost exactly 50% of stainless but only 37% of alloy grades were cast continuously. This was probably due to the fact that orders for alloy steels are usually small, not conducive to making long strings of continuous casts, or the fact that many of these grades are difficult to cast continuously and are better made as small ingots that are forged (hammered) or pressed after reheating to a high temperature.

The same situation exists in stainless steels. While the bulk of production is concentrated in only three grades, the balance is split between many uncommon specifications made in small quantities.

Significant ownership changes took place in the stainless steel sector. The second largest producer of flat products and plate, the J&L Specialty Products Corp., was sold by its owners, the Specialty Metals Corp., to the French Ugine ACG Corp., a unit of the Government-owned Usinor Sacilor Groupe. The price was reported as $570 million, including J&L's debt taken over by the purchaser. J&L was rebuilding its continuous caster at the Midland, PA, melt shop from 1,295 millimeters (51 inches) to 1,600 millimeters (63 inches) wide.

The French company also bought three steel service center chains, which handle both carbon and stainless steels: Edgecomb Metals Corp., Techalloy Corp., and Alloy and Stainless Co. Together they represent more than 30 outlets nationwide. Furthermore, Usinor-Sacilor entered into an agreement with the Bethlehem Steel Corp. to modernize its large rollmaking operation.

Consumption

The domestic steel mills shipped 77.1 million metric tons (85.0 million short tons), the highest amount since 1981. This includes 4.3 million short tons that was exported, little changed since the previous year. Also, 15.7 million metric tons (17.3 million short tons) of steel products was imported, the lowest number since 1985 and a little less than that in 1989.

The distributor stocks increased by 0.3 million tons. Hence, the total apparent consumption was 88.6 million metric tons (97.7 million short tons). The distribution of shipments by domestic mills is shown in table 6.

The consumption per person was 351 kilograms (774 pounds). The trend toward reduced consumption started in the 1960's with the invention of high-strength low-alloy steels. This reduced steel consumption in many applications, such as automobiles. Downscaling autos, as was done in the 1970's, accounted for approximately 23 kilograms (50 pounds) of reduction; reduction of steel reinforcements in concrete, wide replacement of steel cans with aluminum, and increased use of long-lasting, abrasion-resisting rails, etc., contributed to the overall trend.

Stocks

The stocks at distributor yards increased by 0.3 million tons to 6.1 million metric tons (6.7 million short tons) at yearend. This represents approximately 4 months of shipments, a normal number under normal circumstances, a little high in times of slack demand.

Stocks at the steel mills increased, but an exact number cannot be determined because there is no clear demarcation between stocks rolled against future deliveries and awaiting shipments; stocks rolled ahead of order receipts in expectation of these repeat orders to arrive in due course; and semifinished stock made for inventory. Normal inventory level is about 10 to 12 million short tons or 6 weeks of shipments. In the face of the slowdown of demand toward the end of the year, the stocks were higher than normal, as no mill pulls back production as fast as the decline of orders is actually occurring.

Markets and Prices

The destination of about 58.2 million metric tons (64 million short tons), 76% of

TABLE 3

MATERIALS CONSUMED IN BLAST FURNACES AND PIG IRON PRODUCED

(Thousand short tons)

Material	1986	1987	1988	1989	1990
Iron oxides:[1]					
Ores	2,087	2,972	5,682	3,539	2,733
Pellets	48,072	54,564	67,268	67,967	66,703
Sinter[2]	14,574	15,895	17,082	15,062	13,477
Total	64,733	73,431	90,032	86,568	82,913
Scrap[3]	2,079	3,389	3,007	3,362	e3,100
Miscellaneous[4]	1,502	1,703	e1,900	e2,100	e2,300
Coke	22,573	24,031	29,442	29,175	27,503
Fluxes[5]	2,247	2,131	e2,100	e2,000	e2,000
Pig iron produced	44,287	48,308	55,745	55,873	54,750

eEstimated.
[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]Mainly briquetted turnings and borings, shredded scrap, etc.; scrap produced at blast furnaces and remelted not included.
[4]Mainly revert materials not sintered.
[5]Includes fluxes used in sintering at the steel plant, but excludes fluxes consumed in agglomeration at the iron ore mine.

TABLE 4

U.S. STEEL PRODUCTION, BY TYPE OF FURNACE PROCESS

Year	Basic oxygen		Basic open hearth		Basic electric arc		Total (thousand short tons)
	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	Quantity (thousand short tons)	Percent	
1985	51,885	58.8	6,428	7.3	29,946	33.9	88,259
1986	47,885	58.7	3,330	4.1	30,390	37.2	[1]81,606
1987	52,496	58.9	2,666	3.0	33,989	38.1	89,151
1988	57,960	58.0	5,118	5.1	33,846	36.9	99,924
1989	58,348	59.6	4,442	4.5	35,154	35.9	[1]97,943
1990	58,741	59.1	3,496	3.5	36,669	37.4	98,906

[1]Data do not add to total shown because of independent rounding.

TABLE 5

U.S. CONSUMPTION OF SCRAP AND PIG IRON IN STEEL PRODUCTION, BY TYPE OF STEELMAKING FURNACE[1]

(Thousand short tons)

Year	Basic oxygen		Basic open hearth		Basic electric arc		Total	
	Scrap	Iron	Scrap	Iron	Scrap[2]	Iron	Scrap	Iron
1985	15,339	44,515	2,411	4,737	32,252	503	50,002	49,755
1986	14,753	41,582	1,556	2,325	31,166	313	47,475	44,220
1987	15,230	47,525	992	2,057	32,009	304	r48,231	r49,886
1988	17,484	52,446	978	3,858	34,345	248	52,807	56,552
1989	16,680	51,626	1,020	2,105	30,981	730	48,681	54,461
1990	16,712	51,992	947	1,744	30,277	345	47,936	54,081

rRevised.
[1]Pig iron mainly as liquid in basic oxygen and open-hearth furnaces.
[2]Consumption of scrap appears to be underreported.
Source: American Iron and Steel Institute.

the total 77.1 million metric tons (85.0 million short tons) shipped by domestic steel mills, is known. Based on the known shipments, the distribution of markets in 1990 was as follows: service centers and distributors took 24.8%, 3% more than in the previous year; automobile manufacturers accounted for 13.1%, the same as that in 1989; contractors and builders took 14.3%, about 3% more than in the previous year, although this demand slackened toward the yearend; manufacturers of containers' demand was unchanged at 5.3%; and machinery builders accounted for 2.8%, having been overtaken by the oil country tubular goods, which took 3.5%.

In general, market patterns in the United States remained fairly steady for several years, occasionally affected by localized factors within one industry. Decreased demand for automobiles and increased need for pipe and tube indicated previously were examples of normal distribution changes.

The destination of imports, 15.7 million metric tons (17.3 million short tons), is not known; neither is that of the 24% shipped as "unclassified." The ultimate use of the 21.6% shipped to distributors and service centers is not known, but the typical shipping patterns of these organizations indicate that approximately 50% went into construction, 25% into automotive replacement parts, and 25% into many other uses.

The nominal, finished steel base "list" price index as quoted by the Iron Age magazine was $512 at the beginning of 1990 and $525 near the end, an increase of 2.5%. However, this number is simply a compilation of list prices and biased toward the integrated producers' products. In the marketplace, steel is sold by negotiation and almost always at significant discounts from list prices. Some producers do not bother to keep updating their lists; a few minimills do not have any.

Prices at the beginning of the year were not heavily discounted except for 20% or even higher discounts for oil country tubular goods and some common stainless steels in common sizes. This led in the spring to a number of announced nominal increases or across-the-board reduction in published discounts. Up to about September, the fluctuation in announced prices showed its usual variations—increases followed by partial decreases, reduced or increased discounts, etc. USX Corp. made the unusual announcement of price increases 4 months before their effective dates, in effect inviting orders to be made and delivered before the price rises.

The general lowering of the economic activity eliminated all these gyrations. The only direction of price movements was then downward. Oil country tubular goods, some plates, and tinplate were the only exceptions, which held their level. Toward the end of the year some minimill products, like rebars, could be bought for less than $300 per ton, barely covering the production cost. Hot-rolled coil reputedly exchanged hands at less than $330 per short ton and cold-rolled prime at less than $400. This was the result of the reduced demand: Automobile production dropped by 15%, 20 out of 43 assembly plants were partly closed by December, the appliance market became stagnant, and construction activity dropped to the lowest level in years.

A new trend appeared late in the year, reputedly started by the major automobile producers. These corporations buy large amounts of steel parts from subcontractors who usually buy their steel on their own. The automakers started to insist on their subcontractors placing steel orders with the automobilemakers. They, in turn, would order the steel from the steel mills, insisting on their usual large volume discounts.

The price erosion, followed late in the year by sharply reduced production levels, resulted in most steel producers either showing much reduced profits or, in some cases, actual losses. These were followed by cuts or suspensions of dividends.

Contrary to some earlier experiences, imported steel did not affect the market to any unusual degree. This was caused by the weak dollar making import prices not particularly attractive. Actually, owing to cost increases abroad, some foreign exporters accepted lower than usual profit standards in order to sell their excess production at all.

Foreign Trade

Exports.—Not much change occurred in exports either. The drop to 3.9 million metric tons (4.3 million short tons) from 4.6 million short tons of the previous year can be mostly accounted for by reduction of exports to countries with difficulties in making dollar payments, such as China, Eastern Europe, and the U.S.S.R.

Imports.—Imports of 15.7 million metric tons (17.3 million short tons) showed little change from those of the previous year. Imports from the major exporters were under the restrictions of the VRA's shown in table 9, but several countries did not fill their quotas: Japan increased its exports to the Pacific rim countries while shipping more than 10% less than in 1989, Canada had a major steel strike, and the European Community shipped a little less than in the past. Increased imports from the Federal Republic of Germany and from Italy were still smaller than decreased shipments from the other members.

Imports from Eastern Europe, usually not large, decreased following the drop of its production.

Overall, the import picture did not change to any great extent from that of the previous year.

TABLE 6

DISTRIBUTION OF SHIPMENTS OF STEEL MILL PRODUCTS, BY PERCENT

	1986	1987	1988	1989	1990
Total shipments thousand short tons	72,737	80,646	88,391	84,100	84,981
Shipments by steel type:					
Carbon steel	88.9	89.0	92.7	93.4	92.7
Alloy steel	9.3	9.0	5.3	4.9	5.5
Stainless steel	1.8	2.0	2.0	1.7	1.8
Shipments by products:					
Wire rods	4.9	5.0	4.8	5.0	5.1
Structural shapes, 3 inches and more	6.0	6.3	5.8	6.0	6.7
Plates	5.1	5.3	8.7	8.6	9.3
Bars	8.2	7.9	7.7	10.8	11.1
Reinforcing bars	6.0	6.4	6.1	6.3	6.2
Pipe and tubing	4.2	4.7	5.3	4.8	5.5
Hot-rolled sheet and strip	18.2	17.9	16.4	16.6	16.6
Cold-rolled sheet and strip	20.2	19.3	17.6	17.4	16.5
Tinplate	3.7	3.6	3.3	3.3	3.3
Galvanized sheet and strip:					
Hot dipped	10.3	10.0	9.2	10.1	9.3
Electrolytic	1.3	1.9	2.5	2.6	2.4
All others	11.9	11.7	12.6	8.5	8.0
Shipments by markets:					
Service centers and distributors	24.9	25.9	25.1	24.7	24.8
Construction	15.1	14.4	14.4	13.7	14.3
Automotive	16.9	14.8	15.0	14.0	13.1
Machinery	10.0	9.7	9.6	2.6	2.8
Containers	5.9	5.7	5.3	5.3	5.3
All others	27.2	29.5	30.6	39.7	39.7

Source: American Iron and Steel Institute.

TABLE 7

U.S. MAIN STEEL PRODUCTS IMPORT AND EXPORT PARTNERS, BY COUNTRY

(Thousand short tons)

Country	1986		1987		1988		1989		1990	
	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports
Brazil	1,098	19	1,103	16	1,369	7	1,380	29	1,472	15
Canada	3,203	216	3,670	414	3,173	494	2,975	638	2,873	1,472
France	1,206	2	1,088	3	1,244	26	1,176	15	1,151	41
Germany, Federal Republic of	2,012	8	1,776	12	1,880	14	1,543	1,880	1,578	16
Japan	4,422	32	4,321	13	4,290	212	3,653	578	3,115	454
Korea, Republic of	1,525	16	1,296	24	1,307	45	993	725	1,328	307
All others	7,226	636	7,160	647	7,628	1,271	5,600	713	5,646	1,998
Total	20,692	929	20,414	1,129	20,891	2,069	17,320	4,578	[1]17,162	4,303

[1]Data do not add to total because of independent rounding.

Source: American Iron and Steel Institute.

TABLE 8

U.S. EXPORTS OF MAJOR IRON AND STEEL PRODUCTS[1]

	1989		1990	
	Thousand short tons	Thousand metric tons	Thousand short tons	Thousand metric tons
Steel mill products:				
Semifinished sections	391	355	497	451
Wire rods	36	33	107	97
Structural shapes	181	164	308	279
Steel piling	5	5	7	6
Plates, cut lengths	137	124	193	175
Plates in coils	494	448	291	264
Rails and track accessories	17	15	63	57
Bars, hot-rolled	87	79	268	243
Bars, concrete reinforcing	88	80	119	108
Bars, cold-finished	41	37	54	49
Tool steel	18	16	7	6
Standard pipe	23	21	32	29
Oil country goods	320	290	195	177
Line pipe	28	25	73	66
Pipe, other	1	1	6	5
Pipe and tubing, stainless	8	7	13	12
Tubing, not stainless	63	57	156	142
Wire	31	28	70	64
Blackplate	—	—	2	2
Tinplate	188	171	148	134
Tin, free-coated steel	30	27	26	24
Sheets, hot-rolled	1,156	1,049	685	621
Sheets, cold-rolled	499	453	358	325
Sheets and strip, hot-galvanized	333	302	199	181
Sheets, electrogalvanized	111	101	87	79
Sheets, coated	103	93	104	94
Sheets, electrical	55	50	45	41
Strip, hot-rolled	44	40	71	64
Sheets, cold-rolled	89	81	118	107
Total steel mill products	4,578	4,152	4,303	3,904
Fabricated steel products:				
Structural shapes	125	113	233	211
Wire rope	3	3	4	4
Wire strand	7	6	15	14
Wire springs	37	34	30	27
Nails and staples	10	9	12	11
Industrial fasteners	136	123	181	164
Pipe and tube fittings	14	13	17	15
All other fabricated products	188	171	206	187
Total fabricated steel products	520	472	698	633
Total, all steel products	5,098	4,625	5,001	4,537
Iron products:				
Tubes, pipes, and fittings	73	66	101	92
Castings	47	43	30	27
Total iron products	120	109	131	119

[1]Product grouping based on Harmonized Tariff Schedule; data may not add to totals shown owing to independent rounding.
Source: American Iron and Steel Institute.

TABLE 9

STEEL IMPORT VOLUNTARY RESTRAINT AGREEMENTS (VRA's)

(Percent of U.S. steel apparent consumption in 1990)

Country	VRAI	First period[1]	Second period[1]	Third period[1]
Australia	0.26	0.39	0.49	0.59
Austria	.24	.25	.25	.25
Brazil	1.35	1.80	2.10	2.10
China	.08	.08	.09	.09
Czechoslovakia	.04	.04	.04	.04
European Community	6.94	7.00	7.00	7.0
Finland	.24	.25	.25	.25
Germany, Federal Republic of	.11	.10	.10	.10
Hungary	.03	.05	.05	.05
Japan	6.19	5.00	5.30	5.30
Korea, Republic of	1.92	2.45	2.62	2.62
Mexico	.49	.95	1.10	1.10
Poland	.09	.13	.13	.13
Romania	.11	.11	.11	.11
Trinidad and Tobago	.04	.12	.13	.15
Venezuela	.21	.33	.33	.33
Yugoslavia	.02	.05	.05	.05
Total	18.36	19.10	20.14	20.26

[1]Numbers are approximate because some VRA's were negotiated for two 15-month periods, and others were negotiated for other combinations totaling 30 months. Market shares are based on 1989 apparent consumption.

Source: U.S. International Trade Commission.

TABLE 10

U.S. IMPORTS OF PIG IRON, BY COUNTRY

(Short tons)

Country	1986	1987	1988	1989	1990
Brazil	143,154	118,736	496,916	341,933	241,451
Canada	112,607	209,898	145,366	132,935	137,721
South Africa, Republic of	32,944	—	—	—	—
Other	6,252	26,078	10,273	13,307	3,564
Total	294,957	354,712	652,555	488,175	382,736

Source: Bureau of the Census.

TABLE 11

U.S. IMPORTS OF MAJOR IRON AND STEEL PRODUCTS[1]

(Thousand short and metric tons)

	1989		1990	
	Short tons	Metric tons	Short tons	Metric tons
Steel mill products:				
Semifinished sections	2,198	1,994	2,365	2,145
Wire rods	1,108	1,005	960	871
Structural shapes	1,509	1,369	826	749
Steel piling	86	78	90	82

See footnotes at end of table.

TABLE 11—Continued

U.S. IMPORTS OF MAJOR IRON AND STEEL PRODUCTS[1]

(Thousand short and metric tons)

	1989		1990	
	Short tons	Metric tons	Short tons	Metric tons
Steel mill products—Continued				
Plates, cut lengths	938	851	959	870
Plates, in coils	500	454	614	557
Rails and track accessories	157	142	133	121
Bars, hot-rolled	776	704	770	699
Bars, concrete reinforcing	234	212	148	134
Bars, cold-finished	189	171	162	147
Tool steel	91	83	60	54
Standard pipe	806	731	952	864
Oil country goods	r430	390	381	346
Line pipe	527	478	696	631
Pipe, other	10	9	14	13
Pipe and tubing, stainless	37	34	47	43
Tubing, other	r663	601	492	446
Wire	494	448	432	392
Blackplate	145	132	146	132
Tinplate	337	306	314	285
Tin, free-coated	115	104	114	103
Sheets, hot-rolled	1,898	1,722	2,282	2,070
Sheets, cold-rolled	1,877	1,703	2,049	1,859
Sheets and strip, hot-galvanized	1,297	1,177	1,263	1,146
Sheets, electrogalvanized	328	298	386	350
Sheets, coated	236	214	192	174
Sheets, electrical	85	77	76	69
Strip, hot-rolled	111	101	96	87
Strip, cold-rolled	140	127	139	126
Total steel mill products	17,321	15,713	17,162	15,569
Fabricated steel products:				
Structural shapes	185	168	105	95
Wire rope	117	106	93	84
Wire strand	196	178	168	152
Wire springs	239	217	235	213
Nails and staples	391	355	376	341
Industrial fasteners	752	682	722	655
Pipe and tube	125	113	139	126
All other fabricated products	373	338	394	357
Total fabricated steel products	2,378	2,157	2,232	2,025
Total, all steel products	19,699	17,870	19,394	17,594
Iron products:				
Tubes, pipes, and fittings	65	59	53	48
Castings	199	180	176	160
Total iron products	264	239	229	208

rRevised.

[1]Product grouping based on Harmonized Tariff Schedule; data may not add up to totals shown owing to independent rounding.

Source: American Iron and Steel Institute.

TABLE 12

U.S. IMPORTS OF STAINLESS STEEL[1]

(Short tons)

Product	1986	1987	1988	1989	1990
Semifinished	17,623	56,723	62,407	62,121	60,821
Plate	16,415	11,117	15,848	17,414	20,650
Sheet and strip	151,571	129,294	118,584	141,008	154,342
Bars and shapes	37,889	37,991	40,726	43,417	44,526
Wire and wire rods	36,038	37,394	39,861	43,016	41,453
Pipe and tube	33,274	26,446	36,752	37,257	47,219
Total	292,810	298,965	314,178	344,233	369,011

[1]Numbers for 1989 and 1990 are included in table 11. Numbers for 1986-88 are based on Tariff Schedule of the United States.

Source: U.S. International Trade Commission.

TABLE 13

PIG IRON[1] AND DIRECT-REDUCED IRON:[2] WORLD PRODUCTION, BY COUNTRY[3]

(Thousand short tons)

Country[4]	1986	1987	1988	1989[p]	1990[e]
Algeria	1,343	1,499	[r e]1,320	[e]1,210	990
Argentina:					
Pig iron	1,791	1,931	1,759	2,320	2,130
Direct-reduced iron	1,031	1,139	1,176	1,284	1,140
Australia	6,492	6,139	6,316	[e]6,720	6,610
Austria	3,692	3,804	4,040	4,214	4,245
Belgium	8,876	9,087	10,083	9,770	10,320
Brazil:					
Pig iron	22,107	23,487	25,757	26,856	[5]23,333
Direct-reduced iron	325	223	215	284	[5]287
Bulgaria	1,760	1,821	1,584	[r e]1,545	1,545
Burma:					
Pig iron	3	[r]1	1	4	1
Direct-reduced iron	33	22	22	22	22
Canada:					
Pig iron	10,195	10,713	10,470	13,421	13,340
Direct-reduced iron	760	801	823	791	825
Chile	651	680	855	748	760
China[e]	[r]55,820	[r]60,660	[r]62,880	63,700	68,120
Colombia	349	359	341	327	[5]356
Czechoslovakia	10,552	10,789	10,699	10,925	[5]10,598
Egypt:					
Pig iron[e]	220	220	[5]146	140	140
Direct-reduced iron	33	520	771	[e]760	760
Finland	2,190	2,274	2,396	2,518	2,520
France	15,412	16,305	15,130	16,994	16,535
Germany, Federal Republic of:					
Eastern states[6]	3,018	3,037	3 ,071	[r e]2,975	2,205
Western states:					
Pig iron	31,987	31,435	35,773	36,130	33,070
Direct-reduced iron	187	220	300	[e]390	390
Greece[e]	180	180	180	180	180
Hungary	2,264	2,323	2,307	2,154	2,095

See footnotes at end of table.

TABLE 13—Continued

PIG IRON[1] AND DIRECT-REDUCED IRON:[2] WORLD PRODUCTION, BY COUNTRY[3]

(Thousand short tons)

Country[4]	1986	1987	1988	1989[p]	1990[e]
India:					
Pig iron	11,584	12,007	12,936	13,316	13,780
Direct-reduced iron	187	209	209	375	830
Indonesia: Direct-reduced iron	1,460	1,013	1,080	1,391	1,430
Iran:[e]					
Pig iron	276	276	276	276	276
Direct-reduced iron	—	—	—	44	44
Iraq: Direct-reduced iron	—	—	22	[e]220	110
Italy	13,135	12,495	12,510	12,964	12,675
Japan	82,289	80,929	87,408	88,402	[5]88,437
Korea, North[e]	6,400	6,400	7,200	7,200	7,200
Korea, Republic of	9,940	12,188	13,865	16,365	[5]16,908
Libya: Direct-reduced iron	—	—	—	[e]100	100
Luxembourg[6]	2,921	2,541	2,779	2,960	[5]2,916
Malaysia: Direct-reduced iron	640	651	500	628	660
Mexico:					
Pig iron	4,119	4,092	4,054	3,560	[5]4,040
Direct-reduced iron	1,565	1,710	1,858	2,368	[5]2,783
Morocco[e]	17	17	17	17	17
Netherlands	5,101	6,035	5,505	5,691	[5]5,467
New Zealand:[e]					
Pig iron	220	220	220	220	220
Direct-reduced iron	90	—	—	—	—
Nigeria: Direct-reduced iron	121	154	160	[e]160	154
Norway	617	408	405	[re]265	—
Pakistan	983	[r]989	1,028	1,100	1,100
Paraguay	—	[r]55	69	69	77
Peru:					
Pig iron	238	204	223	250	250
Direct-reduced iron	61	56	54	[e]55	55
Poland	11,626	11,548	11,314	10,459	10,360
Portugal	473	480	491	416	420
Qatar: Direct-reduced iron	548	520	488	585	584
Romania	10,283	9,560	[e]9,400	[e]9,100	9,040
Saudi Arabia: Direct-reduced iron	1,290	1,450	1,080	[e]1,330	1,325
South Africa, Republic of:					
Pig iron	6,365	6,963	6,802	7,212	6,900
Direct-reduced iron	870	930	805	926	950
Spain	[r]5,363	[r]5,295	5,114	6,307	6,105
Sweden	2,897	2,666	2,749	2,907	[5]3,016
Switzerland[e]	[5]87	77	77	77	77
Taiwan	[e]4,100	[e]4,300	6,256	6,371	6,030
Trinidad and Tobago: Direct-reduced iron	229	524	659	675	[5]768
Tunisia[e]	165	165	165	165	165
Turkey	4,041	4,892	5,419	4,458	6,060
U.S.S.R.:					
Pig iron	124,781	124,837	126,278	[e]125,700	121,250
Direct-reduced iron	830	1,390	1,764	[e]1,870	1,870

See footnotes at end of table.

TABLE 13—Continued

PIG IRON[1] AND DIRECT-REDUCED IRON:[2] WORLD PRODUCTION, BY COUNTRY[3]

(Thousand short tons)

Country[4]	1986	1987	1988	1989[p]	1990[e]
United Kingdom	10,676	13,246	14,392	13,931	13,560
United States:					
Pig iron	43,951	48,337	55,745	55,873	[5]54,750
Direct-reduced iron	176	231	320	320	400
Venezuela:					
Pig iron	[r]543	521	554	539	386
Direct-reduced iron	3,240	3,473	2,983	[e]3,060	[5]2,586
Yugoslavia	3,376	3,160	3,214	3,196	[5]2,550
Zimbabwe[e]	710	634	660	573	[5]574
Grand total	[r]559,855	[r]577,517	607,522	620,428	611,772
Of which:					
Pig iron	[r]546,179	[r]562,281	592,233	602,790	593,699
Direct-reduced iron	13,676	15,236	15,289	17,638	18,073

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Crude cast iron from the blast furnace or cupola furnace.

[2]Direct-reduced iron is obtained from ore by reduction of oxides to metal without melting. World direct-reduced-iron capacity is 27,680,000 short tons.

[3]Table excludes ferroalloy production except where otherwise noted. Table includes data available through June 21, 1991.

[4]In addition to the countries listed, Vietnam and Zaire have facilities to produce pig iron and may have produced limited quantities during 1986-90, but output is not reported, and available information is inadequate to make reliable estimates of output levels. Production is pig iron unless otherwise specified.

[5]Reported figure.

[6]Includes blast furnace ferroalloys.

TABLE 14

RAW STEEL:[1] WORLD PRODUCTION, BY COUNTRY[2]

(Thousand short tons)

Country[3]	1986	1987	1988	1989[p]	1990[e]
Albania[e]	140	140	140	130	120
Algeria[e]	1,540	[r]1,650	1,540	[r]1,430	1,100
Angola[e]	11	11	11	11	11
Argentina	3,566	4,005	3,995	4,270	[4]4,008
Australia	7,389	6,756	7,054	7,424	[4]7,348
Austria	4,731	4,741	5,027	5,201	[4]4,731
Bangladesh[5]	106	90	89	95	100
Belgium	10,770	10,788	12,370	12,068	[4]12,595
Brazil	23,406	24,505	27,046	27,578	[4]22,677
Bulgaria	3,268	3,357	3,169	3,196	[4]2,647
Canada	15,543	16,204	16,290	16,238	[4]15,983
Chile	778	800	1,002	882	880
China[e]	57,400	61,700	65,000	67,500	72,800
Colombia	697	759	831	778	[4]808
Cuba	454	443	346	370	[4]298
Czechoslovakia	16,658	19,927	16,886	17,047	[4]16,329
Denmark	697	668	717	689	[4]672
Dominican Republic	110	97	83	61	55
Ecuador	19	28	26	25	26
Egypt	1,102	1,764	1,874	1,543	1,540
El Salvador	10	14	12	17	14
Finland	2,850	2,942	3,084	3,220	3,150
France	19,427	19,540	20,947	21,259	[4]20,963

See footnotes at end of table.

TABLE 14—Continued

RAW STEEL:[1] WORLD PRODUCTION, BY COUNTRY[2]

(Thousand short tons)

Country[3]	1986	1987	1988	1989[p]	1990[e]
Germany, Federal Republic of:					
Eastern states	8,782	9,086	8,963	8,630	[4]6,159
Western states	40,933	39,957	45,220	45,275	[4]42,367
Greece	[r]1,113	[r]1,000	1,057	1,056	[4]1,087
Guatemala	19	23	25	25	25
Honduras[e]	8	8	8	8	8
Hong Kong[e]	[r]290	[r]310	[r]330	[r]350	390
Hungary	4,095	3,991	3,950	3,699	[4]3,265
India[6]	12,596	14,201	14,354	14,090	14,330
Indonesia	1,653	[r]1,602	[e]2,260	[e]2,200	2,310
Iran[e]	[r]940	[r]960	[r]1,080	[r]1,100	1,100
Ireland	229	243	299	357	[4]359
Israel	121	128	[e]130	[e]130	160
Italy	25,224	25,197	26,191	27,793	[4]28,042
Jamaica	12	21	28	[e]28	28
Japan	108,330	108,592	116,493	118,948	[4]121,628
Jordan	[e]150	[e]260	19	15	15
Korea, North[e]	7,200	7,200	8,800	8,800	8,800
Korea, Republic of	16,043	18,499	21,073	24,111	[4]25,491
Libya	—	—	—	—	[4]551
Luxembourg	4,084	3,639	4,033	4,102	[4]3,925
Malaysia[e]	830	[4]827	600	600	600
Mexico	7,964	8,424	8,575	8,654	[4]9,596
Morocco[e]	7	7	8	8	8
Netherlands	[r]5,827	5,602	6,083	6,262	[4]5,966
New Zealand	321	[r]451	507	670	[4]843
Nigeria	220	203	212	235	[4]243
Norway	922	923	1,000	707	[4]423
Pakistan[e]	880	[r]1,210	1,100	1,100	1,100
Paraguay	—	15	68	61	66
Peru	537	[r]554	530	442	440
Philippines[e]	276	280	[4]365	330	330
Poland	18,898	18,902	18,599	16,638	[4]14,940
Portugal	780	807	894	804	[4]746
Qatar	559	542	581	581	630
Romania	15,737	15,306	[e]15,400	15,890	15,400
Saudi Arabia	[e]1,200	1,505	1,779	1,995	[4]2,021
Singapore	430	465	455	546	[4]539
South Africa, Republic of	9,805	[r]9,911	9,741	10,546	[4]9,632
Spain	13,201	12,887	12,880	13,982	[4]14,005
Sweden	5,192	5,065	5,268	[e]5,200	[4]4,910
Switzerland	1,185	959	909	1,010	[4]1,069
Syria[e]	76	77	77	77	77
Taiwan	6,260	6,558	9,164	9,973	[4]10,531
Thailand	510	589	608	759	755
Trinidad and Tobago	359	398	399	324	390
Tunisia	200	216	165	214	[4]220
Turkey	[r]6,534	7,765	8,799	8,746	[4]10,417
U.S.S.R.	176,976	178,450	179,717	176,370	169,800

See footnotes at end of table.

TABLE 14—Continued

RAW STEEL:[1] WORLD PRODUCTION, BY COUNTRY[2]

(Thousand short tons)

Country[3]	1986	1987	1988	1989[p]	1990[e]
United Kingdom	16,326	19,208	20,958	20,738	[4]19,740
United States	81,606	89,151	99,924	97,943	[4]98,906
Uruguay	[r]34	33	32	52	44
Venezuela[6]	3,822	4,102	3,994	3,324	[4]2,951
Vietnam[e]	120	120	125	[r]125	132
Yugoslavia	4,981	4,814	4,946	4,960	[4]3,978
Zimbabwe	[e]540	[r]568	664	653	[4]639
Total	[r]785,609	[r]812,740	856,978	862,268	850,982

[e]Estimated. [p]Preliminary. [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 June 21, 1991.

[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]Data are for year ending June 30 of that stated.

[6]Includes steel castings.

OUTLOOK

Prediction of output and profits of the U.S. steel industry is equivalent to the prediction of steel demand, although another factor, change in accounting methods, has an influence on profits. This is the change in the "generally recognized accounting standards" for accounting for pensions and retirees' health insurance. While these were treated by almost all companies in the entire country as current expenses, the Internal Revenue Service (IRS) has determined that in the future they will have to be carried as accrued charges. This is likely to become a significant cost, possibly in the millions of dollars, for many steel companies. Profits will be affected correspondingly. This change was recommended by the Financial Accounting Standards Board, established by the accounting profession; the recommendations of this body carry strong weight with the IRS. Its adoption becomes mandatory in 1993, but some companies are doing it now.

Besides the overall level of economic activity, the steel industry is strongly affected by factors specific to steel, such as existence or elimination of the VRA's (of steel imports to the United States) that expire in March 1992 or contract negotiations with the United Steelworkers, also coming up the same year.

The VRA's affect steel imports, but an even stronger factor influencing international steel trade is the strength of the dollar against other currencies. A weak dollar discourages imports but encourages exports; a strong dollar has the opposite effect.

Production trends of the integrated steel mills may differ from those of minimills because of the different product mixes. The integrated companies make almost exclusively "flat products," sheet and strip, whether coated or not. These are affected by the strength of the consumer goods markets, mainly automotive and appliances. Since these are discretionary purchase items, they are strongly affected by general economic downturns. Toward the end of 1990, when consumer confidence collapsed in the face of the war in the Persian Gulf and the generally sluggish economy, the integrated mills suffered heavy losses and operated often at less than 70% of capacity. The slight upturn in oil country tubular goods consumption helped producers of these products but was not strong enough to exert a significant influence.

Minimills do not make (with one exception) flat products, although a few make plates and heavy structural sections. In general, they are restricted to the production of "shape" or "long" products, such as wire rods, structural shapes, and bars. Hence, they are largely dependent on the construction industry in the country, which was relatively inactive in the latter part of 1990. This resulted in a price war that virtually eliminated profits.

Thus it is clear that any reliable forecast of the future of the U.S. steel industry is exceptionally difficult, even for a short term. The year 1991 started poorly and the outlook was not good. In 1992, the possible extension or lapse of the VRA's and the labor contract negotiations, with the possibility of a strike, make predictions for this year very uncertain. Beyond this, predictions would be guesses because of the uncertainty of general economic activity.

Two economic trends may continue: as long as the dollar is weak, foreign steel companies may continue to invest in U.S. steel mills, as joint ventures or outright purchases. In the minimill sector, more consolidations of weaker companies into the stronger ones are possible. Some of the stronger companies will enter the flat products market using the thin slab casting technique. The Nucor Corp., which initiated this method, announced in late 1990 its plan to build another flat products minimill.

OTHER SOURCES OF INFORMATION

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IRON AND STEEL SCRAP

By Raymond E. Brown

Mr. Brown, a physical scientist with 35 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 Sarah P. Guerrino and Shirley M. Miller, Ferrous Data Section. International data tables were prepared by William L. Zajac, Chief, International Data Section. Tables 9 and 19 were prepared by the author.

Use of iron and steel scrap to produce new steel and ferrous castings, which are vital to the United States for both national security and economic well-being, represents significant energy, environmental, economic, and resource conservation benefits. Direct-reduced iron, pig iron, and iron carbide can be substituted for iron and steel scrap but are usually considered more expensive than scrap. Also, availability of these substitutes on a large scale is limited, and there are certain technical problems associated with the use of some of these substitute materials. However, these scrap alternatives have certain advantages, which include 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 1990 with 44.6 million short tons[1] of all types of ferrous scrap at a delivered value of approximately $4.71 billion, while exporting 12.8 million tons (excluding used rails for rerolling and other uses; and ships, boats, and other vessels for scrapping) valued at $1.64 billion. In 1989, domestic consumers received 43.6 million tons at a delivered value of approximately $4.63 billion; exports totaled 12.3 million tons valued at $1.75 billion. This represented tonnage increases of 2% for received quantities and 4% for exported quantities.

DOMESTIC DATA COVERAGE

Domestic production data for ferrous scrap were developed by the U.S. Bureau of Mines from voluntary monthly or annual surveys of U.S. operations. Of the operations to which a survey request was sent, 61% responded, representing an estimated 65% of the total consumption shown in table 2 for three types of scrap consumers. Consumption for the nonrespondents was estimated using prior reports adjusted by industry trends. An estimation error was also contained in the difference between the reported total consumption of purchased and home scrap and the sum of scrap receipts plus home scrap production, less scrap shipments and adjustments for stock changes. For scrap consumption data shown in table 2, this difference amounted to 0.5% for manufacturers of pig iron and raw steel and castings, 0.2% for manufacturers of steel castings, 5% for iron foundries and miscellaneous users, and 2% average for all types of manufacturers combined.

TABLE 1

SALIENT U.S. IRON AND STEEL SCRAP AND PIG IRON STATISTICS

(Thousand short tons and thousand dollars)

	1986	1987	1988	1989	1990
Stocks, Dec. 31:					
Scrap at consumer plants	4,344	4,844	4,554	4,644	4,598
Pig iron at consumer and supplier plants	188	281	207	304	170
Total	4,532	5,125	4,761	4,948	4,768
Consumption:					
Scrap	65,856	68,303	76,822	72,209	71,271
Pig iron	45,604	50,030	59,047	58,387	56,255
Exports:					
Scrap	11,704	10,367	10,098	12,290	12,765
Value	$1,053,849	$967,018	$1,351,955	$1,748,643	$1,635,218
Imports for consumption:					
Scrap (includes tinplate and terneplate)[1]	724	843	1,038	1,120	1,443
Value	$49,073	$82,016	$133,577	$149,109	$171,510

[1]Excludes used rails for rerolling and other uses and ships, boats, and other vessels for scrapping.

ANNUAL REVIEW

Legislation and Government Programs

On November 15, 1990, the President signed into law the Clean Air Act Amendments of 1990. The Clean Air Act of 1970 was last amended in 1977. The 1990 amendments, the most significant pollution control legislation in U.S. history, would greatly increase the U.S. Environmental Protection Agency's (EPA) influence over the location, design, and operation of industrial facilities such as iron and steel producers and scrap processors.

Environmental and other issues and legislation in 1990 that the 101st Congress considered included: the Resource Conservation and Recovery Act (RCRA), the Nation's primary recycling and disposal statute, which defined what is waste and determines which wastes are hazardous; limiting the export and import of "wastes" across State and international boundaries; the Toxic Substances Control Act (TSCA), which governed the use of toxic materials in manufactured articles, restricting their use when danger to the environment can be demonstrated; encouraging greater recycling; promoting markets for recycled goods; and increasing the duty on imported products containing U.S. processed scrap.

The U.S. Department of Energy (DOE) and Bethlehem Steel Corp. have signed an agreement for the engineering, construction, and operation of a blast furnace coal injection demonstration project at Bethlehem's Burns Harbor, IN, plant. Total cost of the project was $144 million.

A seminar on radioactivity and scrap metal was held in Washington, DC, in September. The purpose of the seminar was to provide a setting for the U.S. Nuclear Regulatory Commission (NRC), the Institute of Scrap Recycling Industries Inc. (ISRI), and the trade associations representing major consumers of scrap metals to meet and consider the problem of radioactivity related to both ferrous and nonferrous scrap.

DOE contracted with the Advanced Combustion Products Group of Surface Combustion Inc., Toledo, OH, to construct and evaluate a commercial-sized installation to preheat ferrous scrap metal before charging into electric arc melting furnaces. The scrap preheating system proposed by Surface Combustion was based on a pilot-scale system developed in the mid-1980's by Surface Combustion and the Natural Gas Industry. The pilot model was successful and reduced energy usage by as much as 20%.

At a Congressional hearing in June, the Executive Director and two members of ISRI testified before the House Small Business Subcommittee on Regulation, Business Opportunities, and Energy on the fate of more than 100 mothballed ships that belong to the National Defense Reserve Fleet. The aging ships were managed by the Maritime Administration (MARAD).

Available Supply, Consumption, and Stocks

Overall domestic demand for ferrous scrap in 1990 by the iron and steel and the ferrous castings industries, the major consumers of this raw material, was little changed from that of 1989. Because of continued strong worldwide demand for ferrous scrap in 1990, average annual prices for most grades, except for stainless steel scrap, remained high.

American Iron and Steel Institute (AISI) sponsored a symposium entitled "The Impact of Recycling and Resource Recovery on Steelmaking With High-Quality Scrap," in Pittsburgh, PA, in April. Conference cosponsors were the Steel Manufacturer's Association (SMA) and the Specialty Steel Industry of the United States (SSIUS). The symposium addressed three key issues the steel industry faces in response to the Nation's solid waste problems: recyclability of steel cans—how the commodity can be a source from curbside recovery, the retail-wholesale buyback, followed by processing; practical information about metallurgical considerations by experts involved in steelmaking; and a discussion of future prospects for detinning and dezincing.

Proler International Corp., Houston, TX, unveiled its new detinning plant in May. The facility was capable of recycling 180,000 tons of tin-plated cans and clippings per year. The plant joins two other Proler detinning plant operations in Seattle and Randolph, AZ.[2] AMG Resources Corp., Pittsburgh, PA, opened a 40,000-ton-per-year detinning plant in November. The plant, in St. Paul, MN, would process used steel cans obtained from that region's municipal waste stream. This detinning plant would be the first such facility to rely solely on used tin cans as its feedstock. Most detinning operations use what was commonly called skeleton scrap, consisting of tinplate scrap from canmaking operations.

ISRI had asked Congress to implement a "design for recycling" policy that would promote the design and manufacture of appliances, automobiles, and other consumer goods for safe and efficient recycling at the end of their useful lives. Additionally, ISRI officials gave speeches to world steel industry leaders and to the board of directors of AISI to promote the concept of designers engineering products that would meet higher standards for disassembly and recycling. ISRI had been promoting the "design for recycling" concept since the mid-1970's.

Horsehead Resource Development Co. Inc. (HRD), Palmerton, PA, would expand its two metal dust recycling facilities by the end of 1991 at a cost of $21 million. This would significantly increase the company's capacity for processing cadmium, lead, and zinc dust by 35% to more than 470,000 tons per year. The processing plants are in Palmerton, PA, and Rockwood, TN. The EPA had listed electric arc furnace (EAF) dust as hazardous waste and issued regulations requiring dust containing 15% or more zinc to be processed with "the best demonstrated available technology" after August 8, 1991. HRD, with support by the Gas Research Institute (GRI), developed its Flame Reactor process, which uses a gas-fired, high-temperature flash smelting burner to process EAF dust. The EPA designated high-temperature metals recovery (HTMR) technology, the method used by HRD, as the best demonstrated method available for processing high-metals content EAF dust.

A U.S. Bureau of Mines study revealed that iron casting compositions had changed with respect to a few tramp elements such as arsenic, chromium, cobalt, tin, and zinc over a 5¾-year period, from January 1981 to September 1986. Also, significant variations between zones within the United States were observed for aluminum, arsenic, chromium, cobalt, copper, and manganese. The Bureau study was in response to concerns expressed by foundries regarding the quality of ferrous scrap used to prepare iron castings.[3]

Auto shredders were introduced in the United States in the mid-1960's to upgrade the quality of ferrous scrap, decrease the volume of waste sent to landfills, and reduce the number of abandoned obsolete

automobiles and appliances that were scattered throughout the country. Tramp elements, such as copper, typically found in shredder feed material have been reduced dramatically. An analysis by the U.S. Bureau of Mines revealed that shredded scrap had been replacing lower quality No. 2 bundles as a raw charge material for iron and steel furnaces. For example, the ratio of consumer receipts for shredded scrap versus No. 2 bundled scrap increased from essentially 0:1 in 1967 to about 7:1 in 1988. However, since 1988, this ratio began to decline, and in 1990, it had dropped to approximately 5:1. This decline coincided with some shredder operations being forced to close and others voluntarily shutting down their operations in 1988 because of a crack-down by Federal and State officials on the disposal of shredder residue (waste). An increased supply of ferrous scrap for consumption in iron and steel furnaces, as a result of shredder processing, represented significant energy, economic, and environmental benefits and conserved natural resources.

The Ford Motor Co., Dearborn, MI, presented Q-1 awards to two scrap processors. Ford's Q-1 program was designed to recognize suppliers with products of outstanding quality. This was the first time that these awards were given to scrap recyclers. Twenty years ago, in response to the abandoned auto crisis, Ford took the lead in reusing old cars to make new components.[4] There has been a gradual decline in iron and steel content and growth in the use of aluminum, plastics, powder metals, and other materials in U.S.-built cars since 1984.[5] Auto shredder companies and others who handle vehicles containing either fired or unfired airbags should be aware of potential hazards associated with the mechanisms, according to the Greater Rochester Auto Craftsman Guild, a New York auto group. Because of the need for airbags to activate instantaneously upon impact, they are triggered by and contain certain highly reactive toxic chemicals. These, of course, should be avoided.[6]

Nucor Corp., Charlotte, NC, was spending approximately $2 million to clean up radioactive contamination and install sensitive radiation detectors in its steel mill at Plymouth, UT. The contamination occurred in March when a load of scrap steel containing a small amount of cesium 137 was accidently fed into the plant's electric furnace. The cesium was vaporized and drawn into the air cleaning system, where it was incorporated in the fly ash. Nucor planned to feed the furnaces at its new Crawfordsville, IN, flat-roll steel plant with direct-reduced iron on a trial basis. High-quality melting stock was critical to the success of Nucor's effort to bring a minimill operation into market for flat-rolled steel products that have been dominated by large integrated producers. Also, Nucor was installing new casting and rolling equipment at its Nucor-Yamato structural section mill in Blytheville, AR, to expand capacity by 30%. The improvements were expected to cost $14 million. Production was forecast to surpass 1 million tons per year.

Miller Compressing Co., Milwaukee, WI, a ferrous and nonferrous scrap processor, broker, and trader was honored for its help in combating the school dropout problem. The company was sponsoring a junior achievement program, "The Economics of Staying in School."

North Star Steel Co., Minneapolis, MN, the Nation's largest minimill steel producer, planned to build a greenfield minimill and industrial complex near Johnstown, PA. A 300,000-ton-per-year minimill operation in conjunction with two cogeneration electric plants would be part of the $500 million joint-venture complex.[7] Also, North Star has joined forces with Cleveland-Cliffs, Inc., Cleveland, OH, to evaluate the feasibility of iron carbide production. The technology involved reducing high-quality iron ore concentrate with reformed natural gas in a fluidized-bed reactor. Iron carbide produced in the reactor might be a better alternative to scrap as a raw material than direct-reduced iron, according to a spokesperson for Cleveland-Cliffs.

Unimetal, the long products division of Usinor Sacilor, a French steel group, had finalized the takeover of 50% of Georgetown Steel Corp., Georgetown, SC. Georgetown, which also produced direct-reduced iron, was one of the United States' largest wire rod producers. In 1989, Thomas Steel Corp., Lemont, IL, rebuilt two EAF's. Before rebuilding, tap-to-tap time for a 40-ton heat was 3½ hours. After rebuilding, that figure was slashed to 1½ hours in 1990. A computer management system, which cost in excess of $2 million, was installed in the melt shop during rebuilding and may make it possible for the steelmaker to achieve a tap-to-tap time of only 60 minutes. In essence, the system could spell out a scrap recipe depending on the customer's order, operate and regulate the furnaces, present spectrographic readings, and control when and for how long the furnace roof opens during a heat, as well as control the doors for the automatic alloying system.

Thousands of old household appliances that squander electricity and do little more than occupy space in basements were being auled away free of charge and recycled as scrap metal in a number of cities. Programs offering free pickup service and safe disposal were being sponsored by utility companies, local Government agencies, and private companies as a way to conserve energy and preserve the environment by keeping the bulky machines out of landfills. Programs varied from city to city, but took their lead from the Appliance Recycling Centers of America Inc. (ARCA), Minneapolis, MN. Local affiliates of the national organization worked through sponsoring organizations, which promoted the recycling programs and paid ARCA a subsidy for each appliance it handled. After collecting an item, ARCA stripped out the plastic and insulation plus parts containing hazardous materials, then sold the remaining shell to a scrap metal dealer. On average, each unit contained about 200 pounds of metal. ARCA paid particular attention to capacitors, which may have contained polychlorinated biphenyls (PCB's), chemicals that have been linked to cancer. Also requiring special handling were chlorofluorocarbon (CFC) refrigerants, which were recycled wihthout being vented into the atmosphere.

Imports of metallurgical-grade coke decreased 67% in 1990, to 765,000 tons, compared with that of 1989. Metallurgical coke imports represented 3% of domestic apparent consumption in 1990 compared with 7% in 1989. The United States continued as a net importer of metallurgical coke. Domestic coal consumption in coke plants decreased 4% in 1990 to 39.8 million tons. Domestic metallurgical coal exports decreased 3% in 1990 to 63.5 million tons compared with those of 1989.

Raw steel production was 98.9 million tons in 1990 compared with 97.9 million tons in 1989. The shares of raw steel produced by electric, basic oxygen, and open-hearth furnaces were, respectively, 37%, 59%, and 4% in 1990 and 36%, 60%, and 5% in 1989. Continuous steel production represented 67% of total raw steel production in 1990 compared with 65% in 1989. Raw steel capacity utilization was 85% in both 1989 and 1990. Raw steel production capability was 116.8 million tons in 1990 compared with 115.9 million tons 1989.

Net shipments of all grades of steel mill products were 85.0 million tons in 1990 and 84.1 million tons in 1989. Imports of steel mill products decreased slightly from 17.3 million tons in 1989 to 17.2 million tons in 1990. Exports of steel mill products decreased from 4.58 million tons in 1989 to 4.30 million tons in 1990. The apparent supply of steel mill products increased from 96.8 million tons in 1989 to 97.8 million tons in 1990. Imports of steel mill products, as a share of the U.S. market were 18% in both 1989 and 1990. Steel mill processing yields were 86% in both 1989 and 1990. Pig iron production decreased from 55.9 million tons in 1989 to 54.7 million tons in 1990.

Iron castings shipments totaled 8.6 million tons in 1990 compared with 9.26 million tons (revised) in 1989. Steel castings shipments totaled 1.14 million tons in 1990 compared with 1.18 million tons (revised) in 1989.

Steel mills accounted for 73% of all scrap received from brokers, dealers, and other outside sources; steel foundries received 5%; and iron castings producers and miscellaneous users received 22%. The apparent total domestic consumption of ferrous scrap in 1990, in million tons, was composed of 44.1 net receipts (total receipts minus shipments), 26.0 home scrap, and 0.1 withdrawals from stocks. The 1990 total was 70.2 million tons; the apparent total domestic consumption was 71.2 million tons in 1989. The total market for U.S. scrap (net receipts plus exports minus imports) was 55.4 million tons in 1990 compared with 57.2 million tons (revised) in 1989. Stocks of ferrous scrap held by steel mills and iron foundries decreased, but those held by steel foundries increased in 1990.

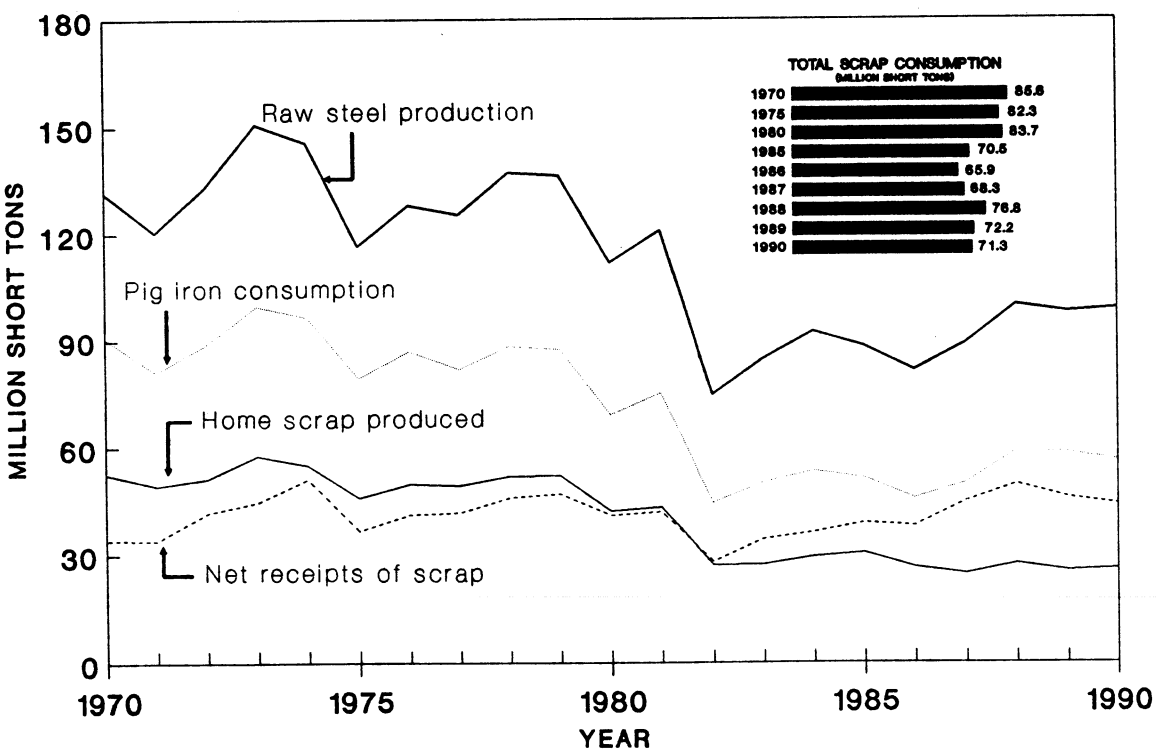
An analysis by the U.S. Bureau of Mines of iron and steel scrap consumption by domestic steel mills revealed that two key trends have emerged during the past 20 years. First, steelmakers have increased their use of electric arc furnaces, which use close to 100% scrap as a charge material to produce raw steel. Second, steel producers have extended their use of continuous casting—a more efficient forming technology than ingot casting—which has increased steel mill processing yields, but left progressively less "home" (internally generated) scrap available to the mills.

The study showed that the quantity of ferrous scrap consumed in the United States by integrated and minimill steel producers to produce 1 ton of raw steel had risen from about 0.51 ton in 1970 to 0.61 ton in 1990. The report also showed that of the ferrous scrap consumed by U.S. steel mills, about 60% consisted of home scrap in 1970 compared with only about 27% in 1990.

Additionally, the analysis demonstrated that the industry's reliance on purchased (new plus old) scrap had increased sharply over the past 20 years. Total ferrous scrap consumed by U.S. steel mills was composed of 16% new (prompt industrial) scrap and 24% old (obsolete) scrap in 1970 compared with 29% and 44%, respectively, in 1990. During this period, total raw steel production had fallen by about 25%, from 132 million tons in 1970 to 98.9 million tons in 1990. However, net shipments of steel mill products declined by only 6% during this timeframe, from 90.8 million tons in 1970 to 85.0 million tons in 1990.[8]

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



Prices

Based on average composite delivered quoted prices per long ton quoted weekly and monthly by the American Metal Market (AMM), No. 1 heavy melting steel scrap cost $107.15 in 1990, ranging from a low of $100.02 in March to a high of $114.33 in August. Based on Iron Age data, No. 1 heavy melting steel scrap cost $107.37 in 1990, ranging from $100.50 in March to $114.17 in August. The average composite price for No. 1 heavy melting steel scrap in 1990 was slightly lower compared with that of 1989, by less than 1% based on both AMM and Iron Age data. Based on prices quoted weekly by AMM 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 28%, from $1,281.53 per long ton in 1989 to $926.25 per long ton in 1990.

In 1990, 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 $128.10 per short ton compared with that of 1989, while that of total imports decreased 11% to $118.82 per short ton.

Foreign Trade

Foreign trade tables are based on the Harmonized Tariff Schedule (HTS), which became effective January 1, 1989. Additionally, valuation continued to be reported on a f.a.s. basis for exports and on a customs value basis for imports.

The trade surplus in 1990 for all classes of ferrous scrap (including used rails for rerolling and other uses and ships, boats, and other vessels for scrapping) was $1.46 billion in value and 11.2 million tons in quantity. This represented a decrease of 10% in value and less than 1% in quantity compared with the 1989 surplus of $1.62 billion (revised) in value and 11.3 million tons (revised) in quantity. The balance of trade for all U.S. merchandise [exports (f.a.s.) less imports (customs value)] showed a deficit of $102 billion in 1990, down from a deficit of $109 billion in 1989.

The quantity of total exports and the quantity and value of total imports reached record highs in 1990. The quantity and value of total imports in 1990 each increased by a larger percentage than the quantity of total exports compared with that of 1989. However, the value of total exports was lower in 1990 than that in 1989.

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 1990 went to 52 countries and totaled 12,162,845 tons valued at $1,361,366,675, which averaged $111.93 per ton. Six countries received 82% of the total quantity. The largest tonnages went to the Republic of Korea, 3,095,004 tons; Turkey, 3,028,137 tons; India, 1,838,004 tons; Canada, 884,702 tons; Mexico, 606,280 tons; and Taiwan, 502,086 tons. The value of scrap exports to these six countries was $1,089,323,462, 80% of the total value.

Total U.S. exports of stainless steel scrap in 1990 went to 31 countries and consisted of 256,797 tons valued at $212,367,918 averaging $826.99 per ton. Six countries received 87% of the total quantity. The largest tonnages went to the Republic of Korea, 81,236 tons; Japan, 71,247 tons; Canada, 23,219 tons; Spain, 21,635 tons; the Netherlands, 17,256 tons; and Belgium, 9,386 tons. The value of stainless steel scrap exports to these six countries was $186,754,977, 88% of the total value.

U.S. exports of alloy steel scrap (excluding stainless steel) in 1990 were shipped to 39 countries. The total comprised 345,138 tons valued at $61,483,696, which averaged $178.14 per ton. Six countries received 85% of the total quantity; the largest tonnages went to Canada, 126,888 tons; India, 55,846 tons; the Republic of Korea, 54,715 tons; Taiwan, 23,945 tons; Mexico, 17,033 tons; and Italy, 15,645 tons. The value of alloy steel scrap to these six countries was $47,490,050, 77% of the total value.

In 1990, based on tonnage of iron and steel scrap by customs district, New York, NY, was the leading customs district for exports, accounting for 17% of the total exports, followed by Los Angeles, CA, with 13%, and Philadelphia, PA, with 9%. San Juan, PR, was the leading customs district for reexports, accounting for 42% of the total reexports, followed by Detroit, MI, with 36%, and Providence, RI, with 17. Detroit, MI, was the leading customs district for imports, accounting for 43% of the total imports, followed by Seattle, WA, with 25%, and Buffalo, NY, with 8%. In 1989, again based on tonnage of ferrous scrap by customs district, New York, NY, was the leading customs district for exports, accounting for 16% of the total exports, followed by Los Angeles, CA, with 14%, and New Orleans, LA, with 9%. Providence, RI, was the leading customs district for reexports, accounting for 40% of the total reexports, followed by Detroit, MI, with 33%, and San Juan, PR, with 21%. Detroit, MI, was the leading customs district for imports, accounting for 38% of the total imports, followed by Seattle, WA, with 34%, and Buffalo, NY, with 12%. For more details, including tonnages and values, refer to published data in U.S. Bureau of Mines Mineral Industry Surveys on iron and steel scrap.[9]

Total U.S. imports for consumption of iron and steel scrap were supplied by 29 countries in 1990. They contained 9,356 tons of tinplate waste or scrap valued at $1,781,994.

World Review

World demand for iron and steel scrap decreased slightly in 1990. However, demand for ferrous scrap, on a percentage basis, increased in certain countries. These included industrialized countries such as Belgium, Italy, Japan, Turkey, and the United States; Asian countries such as China, India, the Republic of Korea, and Taiwan; and Latin American countries such as Mexico.

The United States continued to be the leading exporting country of iron and steel scrap. Canada, France, the Federal Republic of Germany, the Netherlands, the U.S.S.R., and the United Kingdom were also major exporters of ferrous scrap.

The Basel Convention, on the control of transboundary movements of hazardous waste and their disposal, had been signed by 53 countries, including the United States and the European Community (EC).[10] The Basel Convention was negotiated under the auspices of the United Nations Environment Program during an 18-month period and completed at Basel, Switzerland, on March 22, 1989. The intent of the agreement was to put an end to the rising number of incidents of dumping hazardous wastes in Third World nations where inadequate provisions exist for their safe disposal. It would become law within 3 months of its being ratified by a minimum of 20 countries.

The Bureau International de la Recuperation (BIR), Brussels, Belgium, criticized national governments and international organizations for failing to make a

distinction between the definitions of secondary raw materials and waste (SRM&W). The BIR had issued definitions of SRM&W to BIR member associations, BIR individual member firms, the specialized press, and related supranational organizations. The definitions were as follows: secondary raw materials are redundant goods, byproducts, or residues that have a value and are recycled for further use; and waste includes redundant goods, byproducts, or residues that have no value and must be disposed of at a cost. Also, BIR members had been especially critical of the Basel Convention, which would significantly limit international trade in secondary materials because it made no distinction between scrap and hazardous waste.

The Brazilian Government shut down 20 pig iron producers in May for not reforesting areas cut down to make charcoal. This action would significantly reduce pig iron export prospects unless other producers took up the slack. The U.S.S.R.'s Minister of Metallurgy had called for a cut in ferrous scrap exports to avoid domestic shortages. The Soviet steel industry had a scrap shortage of 5 million metric tons in 1990. Growing health concerns had led environmental authorities in Taiwan, one of the largest international markets for nonferrous scrap, to propose a ban on all scrap imports beginning in 1993. Any material that produced toxic substances when incinerated would be prohibited under that rule.

The EC launched a $26 million research program to identify new recycling technologies as part of its raw materials and recycling plan for the next 3 years. The program was established to enhance the competitiveness of the EC's mining and metallurgical industries. Also, a proposal to create markets for recycled products was made an integral part of an EC waste management strategy. Additionally, the Council of Environment Ministers had agreed to the scope and authority of the new European Environmental Agency. Its functions would be to accumulate and analyze relevant environmental statistics to assist the EC in making objective and scientific responses to current and future environmental problems. Changes in Eastern Europe probably would have little impact on the world's metal and scrap industries in the short term. However, for the long term, these changes most likely would have considerable influence. Ferrous scrap dealers in the Chugoku region of southern Japan had expressed concerns about electric steel mill expansions in that area. Demand for high-grade scrap was expected to soar but dealers did not have enough processing capacity or purchasing routes to meet the growth.

A study by the International Iron and Steel Institute (IISI), Brussels, Belgium, concluded that steel was and will remain the dominant and most cost-effective material for automotive applications. Also, IISI updated its statistics on energy in the steel industry.

The president of Ipsco Inc., Regina, Saskatchewan, Canada, was considering closing the only major steel plant in Western Canada and moving its operations to the United States because of persistent environmental protection and regulatory roadblocks that created problems in procuring raw materials. Environment Canada, a Canadian Federal regulatory agency, had proposed a new law that would force importers to post a bond for each cross-border shipment of hazardous waste and scrap. The Canadian Government was expected to revise the proposal so that white goods and auto wrecks would not be considered hazardous. Ipsco imports 50% of its scrap from the United States.

The public sector of the Turkish iron and steel industry was planning to install a thin slab continuous caster and cold-rolling plant at its Iskenderun Iron and Steel Works on the Mediterranean by the end of 1992. The works had an annual raw steelmaking capacity of 2 million metric tons. Turkey had to import about 1.5 million metric tons per year of flat products. Man Gutehoffnungshutte, Federal Republic of Germany, would build an electric arc furnace melt shop for the NTS Steel Groups Co., in Thailand, by the end of 1991. The order included technical help, engineering, and the main equipment, which consisted of a 75-metric-ton furnace capable of producing 400,000 metric tons of liquid steel per year. There would also be a ladle furnace, process controls, and handling equipment for scrap and ferroalloys. This project was part of an overall contract for a complete minimill steel plant for wire and reinforcing steel.

In the past decade, the volume of recycled scrap in China had been rising at an annual average of 8%, according to the Chinese Ministry of Materials. China had reclaimed more than 400 million metric tons of scrap iron and steel since the 1949 revolution. This resulted in the saving of significant quantities of iron ore and high-quality coal. The country also saved money that would have been spent on metal ore exploration, mine development, and steel mill construction.

The Federal Republic of Germany's tinplate producers had launched a new can recycling program, which would be funded with about $1.5 million per year to support public services in the collection and recycling of tinplate scrap. Short-term measures by tinplate producers to protect the environment included briefings with interested city and county authorities and the installation of new collection centers.

The total number of shredders in operation worldwide in 1990 was estimated at 633 (see table 19), 32 more than in 1989. Because of new shredder installations and upgrading of older equipment in 1990, total world power requirements and total world annual tonnage capacity increased by about 94,000 to 1.15 million horsepower and by 3.5 to 30 million metric tons compared with that of 1989. Globally, the average power requirements and the average annual tonnage capacity per shredder increased in 1990 by 60 to 1,810 horsepower and by 3,000 to 47,000 metric tons compared with that of 1989. The more efficient shredder operations scattered throughout the world resulted in lowering average energy requirements by 5%, from 0.040 horsepower per metric ton of annual capacity in 1989 to 0.038 in 1990. The total number of new units under construction and equipment being upgraded or in the planning stages in 1990 amounted to 30. The United States continued as the world's leading country in total shredder numbers, power, and tonnage capacity. Japan followed as the second leading country, with the United Kingdom third. The total number of shredders in Western Europe in 1990 was about equal to that of the United States. However, total power requirements, total annual tonnage capacity, average power requirements per shredder, and average annual tonnage capacity per shredder were significantly higher in the United States compared to that of Western Europe. Also, the data in table 19 indicated that the average shredder in the United States was more energy efficient than the average shredder in Western Europe. The most significant developments in 1990 were in France, where 34 existing shredders would be augmented by 9, and in Japan, where 145 shredders would be increased by 10.

Current Research

Researchers at the Argonne National Laboratory in Argonne, IL, developed a new three-step process to recover thermoplastics and other potentially marketable material from automobile shredder residue (fluff). The recovery process employed physical separation, solvent extraction, and solvent regeneration.[11]

Officials at Westinghouse Electric Corp., Pittsburgh, PA, reported that the company had successfully tested a system of plasma incineration of landfill material at its plasma-fired test cupola in Madison, PA. The company planned to apply this technology to auto shredder residue. Westinghouse had had a commercially operating plasma-fired cupola in place at a General Motors Corp. foundry in Defiance, OH, since late 1989.[12] Japan's Government Industrial Development Laboratory reportedly found a way to use fluff as a fuel for a waste gasification process that can generate 500 kilowatts per ton of fluff.

Carnegie Mellon's Center for Materials Production was doing a case study of cryogenic scrap preparation to determine if the process was worth looking at again. Cryogenic research was conducted in Belgium in the 1970's and 1980's.[13]

Metal Recovery Industries, Ontario, Canada, began operation of North America's first commercial dezincing line for steel scrap.[14] AISI established a task force to examine the recycling and future prospects of galvanized and tinned scrap. A new process, developed at Carnegie Mellon University, involved removing copper from solid steel scrap by putting the copper into solution as a sulfide matte. A large rotary kiln had been set up for this purpose at USX's pilot plant in Universal, PA.[15]

A number of modifications were planned for the AISI Direct Steelmaking Program. The most significant change that was being considered involved replacing the verticle basic oxygen furnace (BOF)-type converter with a horizontal design.[16] Development of direct steelmaking technology would eliminate the need for coke, as it would be replaced with coal. Professor Donald R. Sadoway, Department of Materials Science and Engineering, Massachusetts Institute of Technology (MIT), Cambridge, MA, was conducting research on a new direct steelmaking process that employs electrochemical processing of iron ore in nonaqueous media to extract pure iron. The process used technology similar to that perfected by Hall-Hroult for the electrolytic reduction of alumina to aluminum metal. With the MIT process, no carbon ends up in the iron.[17] The Electric Power Research Institute (EPRI), Palo Alto, CA, would sponsor a feasibility study on the process.

Nucor Corp., Charlotte, NC, planned to build a second sheet-producing minimill plant on the Mississippi River in Arkansas. The 1-million-ton-per-year facility was expected to come on-stream in 1993. This left Nucor as the only electric furnace sheet-producing mill in North America. Plans to use this new technology by Birmingham Steel Corp., Birmingham, AL; Co-Steel Inc., Toronto, Ontario, Canada; and New Jersey Steel Corp., Sayreville, NJ; had been put on hold. The president of Co-Steel stated that his company was concerned about the high cost and availability of low-residual scrap.

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 outlook for the total market for U.S. ferrous scrap is expected to be one of continued growth. The total market for U.S. scrap is forecast to range from 59 million tons to 68 million tons by the year 1995, representing an average annual growth rate ranging from 0.6% to 3.0%, respectively. It is probable that by 1995 the total market for U.S. ferrous scrap will be closer to the mid-range of this forecast, reaching 64 million tons, which represents an average annual growth rate of 1.9%. This optimistic forecast is based predominantly on a combination of favorable factors affecting the market, which primarily include continued world growth in the quantity of steel produced in scrap-based electric arc furnaces; an increase in the percentage of steel that is continuously cast; and an absence of excessive Government rules or restrictions on U.S. exports of scrap.

[1]All quantities are in short tons unless otherwise specified.

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[16]McAloon, T. P. Direct Steelmaking Changes Direction. Iron and Steelmaker, v. 18, No. 1, Jan. 1991, pp. 22-23.

[17]Sadoway, D. R. Metallurgical Electrochemistry in Nonaqueous Media. Paper in 1990 Elliott Symposium Proceedings (MIT, Cambridge, MA, June 10-13, 1990). pp. 189-196.

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Bureau International De La Recuperation (BIR).
Center for Materials Production (CMP).
Electric Power Research Institute (EPRI).
Gas Research Institute (GRI).
Institute of Scrap Recycling Industries Inc. (ISRI).
International Iron and Steel Institute (IISI).
Metal Bulletin.
Steel Can Recycling Institute (SCRI).
Steel Manufacturers Association (SMA).

TABLE 2

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF IRON AND STEEL SCRAP AND PIG IRON IN 1990, BY GRADE

(Thousand short 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 resulting from current operations	Obsolete scrap (includes ingot molds, stools, and scrap from old equipment, buildings, etc.)			
MANUFACTURERS OF PIG IRON AND RAW STEEL AND CASTINGS							
Carbon steel:							
Low-phosphorus plate and punchings	505	29	600	—	1,140	8	72
Cut structural and plate	1,206	136	298	—	1,596	23	118
No. 1 heavy melting steel	8,170	-1,667	7,155	351	13,654	457	905
No. 2 heavy melting steel	3,580	155	936	2	4,646	14	324
No. 1 and electric-furnace bundles	5,694	170	987	8	6,239	680	522
No. 2 and all other bundles	851	66	130	—	1,003	47	46
Electric furnace, 1 foot and under (not bundles)	15	240	(1)	—	254	—	12
Railroad rails	213	18	24	—	248	—	13
Turnings and borings	1,038	92	156	—	1,242	15	91
Slag scrap (Fe content 70%)	1,014	337	2,026	1	3,177	254	138
Shredded or fragmentized	2,997	1,481	99	—	4,666	7	309
No. 1 busheling	1,477	140	97	(1)	1,652	62	92
All other carbon steel scrap	3,711	-171	4,467	96	7,476	653	274
Stainless steel scrap	571	19	433	—	1,016	16	46
Alloy steel (except stainless)	96	131	672	—	874	12	113
Ingot mold and stool scrap	291	118	259	280	654	320	149
Machinery and cupola cast iron	—	-2	4	—	2	5	(1)
Cast-iron borings	106	1	1	(1)	92	14	7
Motor blocks	—	—	—	—	—	—	—
Other iron scrap	295	11	388	8	548	137	146
Other mixed scrap	618	93	67	(1)	775	27	58
Total[2]	32,448	1,397	18,800	747	[3]50,955	2,752	3,434
MANUFACTURERS OF STEEL CASTINGS							
Carbon steel:							
Low-phosphorus plate and punchings	596	24	106	(1)	743	—	42
Cut structural and plate	445	14	83	(1)	538	4	51
No. 1 heavy melting steel	207	—	92	—	264	1	29
No. 2 heavy melting steel	149	—	2	—	157	—	9
No. 1 and electric-furnace bundles	9	—	—	—	11	—	(1)
No. 2 and all other bundles	—	—	—	—	—	—	—
Electric furnace, 1 foot and under (not bundles)	63	—	9	—	74	—	5
Railroad rails	35	—	(1)	—	35	—	2
Turnings and borings	23	—	17	—	38	4	4
Slag scrap (Fe content 70%)	—	—	—	—	—	—	—
Shredded or fragmentized	58	—	2	—	57	—	(1)

See footnotes at end of table.

TABLE 2—Continued

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF IRON AND STEEL SCRAP AND PIG IRON IN 1990, BY GRADE

(Thousand short 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 resulting from current operations	Obsolete scrap (includes ingot molds, stools, and scrap from old equipment, buildings, etc.)			
MANUFACTURERS OF STEEL CASTINGS							
Carbon steel—Continued							
No. 1 busheling	87	—	—	—	82	—	13
All other carbon steel scrap	451	—	196	—	637	—	36
Stainless steel scrap	40	1	37	—	86	1	13
Alloy steel (except stainless)	97	2	186	—	276	5	84
Ingot mold and stool scrap	—	—	—	—	—	—	—
Machinery and cupola cast iron	44	—	12	—	54	—	14
Cast-iron borings	73	—	19	—	64	—	4
Motor blocks	(1)	—	—	—	(1)	—	—
Other iron scrap	29	—	73	—	92	2	14
Other mixed scrap	—	11	—	—	11	—	(1)
Total[2]	2,407	53	832	1	3,220	17	321
IRON FOUNDRIES AND MISCELLANEOUS USERS							
Carbon steel:							
Low-phosphorus plate and punchings	1,212	36	161	42	1,451	—	73
Cut structural and plate	1,151	12	107	(1)	1,278	1	67
No. 1 heavy melting steel	106	109	283	—	345	153	31
No. 2 heavy melting steel	182	—	139	—	254	77	5
No. 1 and electric-furnace bundles	199	218	57	—	474	—	6
No. 2 and all other bundles	211	—	—	—	187	—	25
Electric furnace, 1 foot and under (not bundles)	35	228	9	—	269	—	2
Railroad rails	273	—	2	—	283	2	15
Turnings and borings	442	1	20	—	465	3	41
Slag scrap (Fe content 70%)	34	—	1	—	34	1	2
Shredded or fragmentized	1,201	62	—	—	1,972	—	55
No. 1 busheling	481	80	12	—	641	—	13
All other carbon steel scrap	709	5	46	2	796	1	68
Stainless steel scrap	9	—	6	—	16	(1)	4
Alloy steel (except stainless)	27	—	11	—	39	(1)	14
Ingot mold and stool scrap	211	10	194	2	416	11	30
Machinery and cupola cast iron	1,140	225	427	29	1,808	27	139
Cast-iron borings	473	114	146	—	721	16	43
Motors blocks	474	53	689	—	1,225	16	46
Other iron scrap	650	30	2,790	—	3,398	77	97
Other mixed scrap	490	128	411	7	1,022	36	67
Total[2]	9,711	1,310	5,512	83	17,096	421	843
TOTAL—ALL TYPES OF MANUFACTURERS[2]							
Carbon steel:							
Low-phosphorus plate and punchings	2,313	88	868	42	3,335	8	188
Cut structural and plate	2,802	162	488	(1)	3,412	28	236
No. 1 heavy melting steel	8,482	-1,558	7,530	351	14,263	611	965
No. 2 heavy melting steel	3,911	155	1,077	2	5,057	91	338
No. 1 and electric-furnace bundles	5,901	387	1,044	8	6,723	680	529

See footnotes at end of table.

TABLE 2—Continued

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF IRON AND STEEL SCRAP AND PIG IRON IN 1990, BY GRADE

(Thousand short 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 resulting from current operations	Obsolete scrap (includes ingot molds, stools, and scrap from old equipment, buildings, etc.)			
TOTAL—ALL TYPES OF MANUFACTURERS—Continued							
Carbon steel—Continued							
No. 2 and all other bundles	1,062	66	130	—	1,189	0,047	0,071
Electric furnace, 1 foot and under (not bundles)	113	468	19	—	597	—	19
Railroad rails	522	18	27	—	566	2	30
Turnings and borings	1,504	93	192	—	1,745	22	136
Slag scrap (Fe content 70%)	1,048	337	2,026	1	3,211	255	140
Shredded or fragmentized	4,256	1,544	101	—	6,696	7	364
No. 1 busheling	2,046	220	109	(1)	2,375	62	117
All other carbon steel scrap	4,871	-167	4,708	98	8,909	654	378
Stainless steel scrap	620	21	476	—	1,118	17	63
Alloy steel (except stainless)	221	133	869	—	1,189	18	211
Ingot mold and stool scrap	502	129	453	282	1,071	331	179
Machinery and cupola cast iron	1,183	223	443	29	1,865	32	153
Cast-iron borings	652	114	165	(1)	878	30	53
Motor blocks	474	53	689	—	1,225	16	46
Other iron scrap	973	42	3,252	8	4,038	216	257
Other mixed scrap	1,108	232	478	7	1,809	63	126
Grand total	44,566	2,759	25,144	830	[3]71,271	3,190	4,598

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.
[3]Internal evaluation indicates that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 9.6 million short tons.

TABLE 3

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF PIG IRON AND DIRECT-REDUCED IRON IN 1990

(Thousand short tons)

	Receipts	Production	Consumption	Shipments	Stocks, Dec. 31
MANUFACTURERS OF PIG IRON AND RAW STEEL AND CASTINGS					
Pig iron	2,124	53,825	54,809	1,389	70
MANUFACTURERS OF STEEL CASTINGS					
Pig iron	28	—	27	W	6
IRON FOUNDRIES AND MISCELLANEOUS USERS					
Pig iron	1,499	—	1,420	45	95
TOTAL—ALL TYPES OF MANUFACTURERS					
Pig iron[1]	3,651	53,825	56,255	1,435	170
Direct-reduced or prereduced iron	1,837	—	1,725	W	40

W Withheld to avoid disclosing company proprietary data.
[1]Data may not add to totals shown because of independent rounding.

TABLE 4

CONSUMPTION OF IRON AND STEEL SCRAP AND PIG IRON IN THE UNITED STATES IN 1990, BY TYPE OF FURNACE OR OTHER USE

(Thousand short tons)

Type of furnace or other use	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]	2,827	—	—	—	—	—	2,827	—
Basic oxygen process[3]	16,515	53,015	—	—	—	—	16,515	53,015
Open-hearth furnace	717	1,360	—	—	—	—	717	1,360
Electric furnace	[4]30,327	15	2,937	27	7,885	1,061	41,148	1,104
Cupola furnace	33	49	284	—	9,052	337	9,368	386
Other (including air furnace)[5]	536	—	—	—	158	21	695	21
Direct castings[6]	—	370	—	—	—	—	—	370
Total[1]	50,955	54,809	3,220	27	17,096	1,420	[4]71,271	56,255

[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 9.6 million short tons.
[5]Includes vacuum melting furnaces and miscellaneous uses.
[6]Includes ingot molds and stools.

TABLE 5

PROPORTION OF IRON AND STEEL SCRAP AND PIG IRON USED IN FURNACES IN THE UNITED STATES IN 1990

(Percent)

Type of furnace	Scrap	Pig iron
Basic oxygen process	23.8	76.2
Open-hearth furnace	34.5	65.5
Electric furnace	97.4	2.6
Cupola furnace	96.0	4.0
Other (including air furnace)	97.1	2.9

TABLE 6

IRON AND STEEL SCRAP SUPPLY[1] AVAILABLE FOR CONSUMPTION IN 1990, BY REGION AND STATE

(Thousand short tons)

Grade	Receipts of scrap		Production of home scrap		Total new supply[2]	Shipments of scrap[3]	New supply available for consumption[2]
	From brokers, dealers, and other outside sources	From other own-company plants	Recirculating scrap resulting from current operations	Obsolete scrap (includes ingot molds, stools, and scrap from old equipment, buildings, etc.)			
New England and Middle Atlantic:							
Connecticut, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island	1,576	84	416	3	2,080	39	2,042
Pennsylvania	5,833	293	3,961	76	10,162	659	9,503
Total[2]	7,409	377	4,377	79	12,242	698	11,545
North Central:							
Illinois	4,753	766	2,183	11	7,714	103	7,610

See footnotes at end of table.

TABLE 6—Continued

IRON AND STEEL SCRAP SUPPLY[1] AVAILABLE FOR CONSUMPTION IN 1990, BY REGION AND STATE

(Thousand short tons)

Grade	Receipts of scrap		Production of home scrap		Total new supply[2]	Shipments of scrap[3]	New supply available for consumption[2]
	From brokers, dealers, and other outside sources	From other own company plants	Recirculating scrap resulting from current operations	Obsolete scrap (includes ingot molds, stools, and scrap from old equipment, buildings, etc.)			
North Central—Continued							
Indiana	5,318	-1,577	6,208	4	9,953	833	9,120
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	3,528	238	1,402	(4)	5,167	1	5,166
Michigan	3,550	443	2,021	13	6,027	168	5,859
Ohio	6,860	452	3,284	613	11,210	895	10,315
Total[2]	24,009	322	15,098	641	40,071	2,000	38,070
South Atlantic:							
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	4,109	528	2,012	23	6,672	157	6,516
South Central:							
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	6,199	1,487	2,763	57	10,508	329	10,180
Mountain and Pacific:							
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	2,841	45	890	28	3,804	7	3,796
Grand total	44,566	2,759	25,144	830	73,299	3,190	70,190

[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]Data may not add to totals shown because of independent rounding.
[3]Includes scrap shipped, transferred, or otherwise disposed of during the year.
[4]Less than 1/2 unit.

TABLE 7

U.S. CONSUMPTION OF IRON AND STEEL SCRAP AND PIG IRON[1] IN 1990, BY REGION AND STATE

(Thousand short 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	1,066	4	60	(3)	912	89	2,038	93
Pennsylvania	7,970	5,039	174	4	1,331	582	9,475	5,626
Total[2]	9,036	5,043	234	4	2,243	671	11,513	5,719
North Central:								
Illinois	5,750	2,813	209	—	1,674	83	7,632	2,897
Indiana	7,797	18,923	394	5	948	94	9,139	19,022
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	2,104	(3)	454	5	2,619	143	5,176	146
Michigan	3,203	5,887	29	—	2,804	154	6,036	6,041
Ohio	7,797	11,019	464	10	2,099	162	10,360	11,191
Total[2]	26,651	38,642	1,550	20	10,144	636	38,343	39,297
South Atlantic:								
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	5,433	5,061	14	(3)	1,209	31	6,656	5,092

See footnotes at end of table.

TABLE 7—Continued

U.S. CONSUMPTION OF IRON AND STEEL SCRAP AND PIG IRON[1] IN 1990, BY REGION AND STATE

(Thousand short 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
South Central:								
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	7,176	4,701	640	1	2,421	64	10,237	4,768
Mountain and Pacific:								
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	2,658	1,360	785	1	1,080	16	4,524	1,376
Grand total[2]	[4]50,955	54,809	3,220	27	17,096	1,420	[4]71,271	56,255

[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 9.6 million short tons.

TABLE 8

U.S. CONSUMER STOCKS OF IRON AND STEEL SCRAP AND PIG IRON, DECEMBER 31, 1990, BY REGION AND STATE

(Thousand short tons)

Region and State	Carbon steel (excludes rerolling rails)	Stainless steel	Alloy steel (excludes stainless)	Cast iron (includes borings)	Other grades of scrap	Total scrap stocks[1]	Pig iron stocks
New England and Middle Atlantic:							
Connecticut, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island	117	5	55	34	8	219	21
Pennsylvania	433	33	62	104	7	639	13
Total[1]	550	38	117	138	15	859	33
North Central:							
Illinois	380	—	13	45	8	445	11
Indiana	454	2	11	162	4	633	46
Iowa, Kansas, Minnesota, Missouri, Nebraska	191	(3)	2	16	30	240	17
Michigan	159	2	5	52	10	227	11
Ohio	494	11	31	61	1	598	13
Wisconsin	13	3	—	14	—	31	5
Total[1]	1,691	19	61	350	53	2,173	103
South Atlantic:							
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	387	4	1	67	9	468	15
South Central:							
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	692	—	12	93	14	811	18
Mountain and Pacific:							
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	190	2	21	40	35	288	2
Grand total[1]	3,509	63	211	689	126	4,598	170

[1]Data may not add to totals shown because of independent rounding.
[2]Less than 1/2 unit.

TABLE 9

U.S. AVERAGE MONTHLY PRICE AND COMPOSITE PRICE FOR NO. 1 HEAVY MELTING STEEL SCRAP IN 1990, WITH ANNUAL AVERAGES FOR 1989 AND 1990

(Per long ton)

Month	Chicago	Pittsburgh	Philadelphia	Composite price[1]
January	$104.00	$99.82	$104.41	$102.74
February	102.29	100.58	106.00	102.96
March	98.00	98.23	103.84	100.02
April	109.43	103.33	105.40	106.05
May	114.55	109.75	108.50	110.93
June	111.67	104.50	106.79	107.65
July	108.50	102.00	106.60	105.70
August	116.00	118.50	108.50	114.33
September	113.76	115.50	108.50	112.59
October	112.50	113.28	106.11	110.63
November	107.73	108.35	105.90	107.33
December	105.00	105.50	104.00	104.83
Annual average:				
1990	108.62	106.61	106.21	107.15
1989	108.33	106.80	106.76	107.30

[1]American Metal Market, composite price, Chicago, Pittsburgh, and Philadelphia.

TABLE 10

U.S. EXPORTS[1] OF IRON AND STEEL SCRAP, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1986		1987		1988		1989[2]		1990[2]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Canada	365	$31,436	331	$30,516	628	$62,367	1,033	$106,296	1,035	$109,220
China	340	28,506	249	23,423	31	5,010	49	11,129	72	11,372
Italy	286	26,177	175	15,675	89	12,926	162	27,446	187	26,297
Japan	1,725	170,015	986	123,051	649	148,362	478	139,245	530	119,866
Korea, Republic of	2,989	247,055	2,630	213,550	2,358	271,155	2,987	404,815	3,231	409,677
Mexico	318	29,981	501	48,278	916	101,785	574	63,585	626	72,186
Spain	673	51,771	417	42,503	404	108,067	658	119,784	260	35,685
Taiwan	667	74,387	426	46,629	669	89,021	407	64,386	530	71,761
Turkey	1,417	115,334	2,254	195,971	1,985	230,853	3,225	393,503	3,029	335,781
Venezuela	483	36,673	150	10,273	258	26,109	82	8,166	50	5,243
Other	2,441	242,514	2,247	217,149	2,112	296,298	2,636	410,288	3,215	438,130
Total[3]	11,704	1,053,849	10,367	967,018	10,098	1,351,955	12,290	1,748,643	12,765	1,635,218

[1]Excludes used rails for rerolling and other uses and ships, boats, and other vessels for scrapping.
[2]U.S. exports were shipped to 60 countries in 1990 compared with 63 in 1989.
[3]Data may not add to totals shown because of independent rounding.

TABLE 11

U.S. EXPORTS AND IMPORTS FOR CONSUMPTION OF IRON AND STEEL SCRAP, BY CLASS

(Thousand short tons and thousand dollars)

Country	1986		1987		1988		1989		1990	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Export:										
No. 1 heavy melting scrap	2,922	$230,519	2,446	$200,980	2,400	$255,370	2,789	$308,485	2,733	$297,504
No. 2 heavy melting scrap	797	58,879	579	45,994	691	68,102	1,050	109,101	886	91,587
No. 1 bundles	155	13,876	167	14,890	74	8,852	103	12,990	173	19,596
No. 2 bundles	301	21,095	366	23,623	371	31,567	462	41,505	375	32,489
Stainless steel scrap	165	90,066	172	94,025	243	239,807	292	320,683	257	212,368
Shredded steel scrap	3,495	293,040	3,314	298,259	2,910	343,188	3,854	486,999	4,050	482,465
Borings, shovelings, turnings	731	43,955	528	28,835	515	36,230	743	55,765	272	20,442
Other steel scrap[1]	2,048	209,094	2,033	195,197	2,042	277,281	1,774	276,420	2,676	322,550
Iron scrap	1,091	93,325	762	65,217	852	91,557	1,224	136,694	1,343	156,217
Total[2]	11,704	1,053,849	10,367	967,018	10,098	1,351,955	12,290	1,748,643	12,765	1,635,218
Ships, boats, and other vessels for scrapping	212	16,475	246	20,264	330	43,548	126	16,698	25	3,842
Used rails for rerolling and other uses[3]	78	11,302	57	8,863	42	7,330	r61	r20,062	53	14,385
Total exports[2]	11,994	1,081,626	10,670	996,145	10,470	1,402,833	r12,477	r1,785,403	12,843	1,653,445
Imports for consumption:										
Iron and steel scrap	724	49,073	843	82,016	1,038	133,577	1,120	149,109	1,443	171,510
Used rails for rerolling and other uses[3]	—	—	—	—	—	—	r98	r14,844	170	25,148
Total imports[2]	724	49,073	843	82,016	1,038	133,577	1,218	163,953	1,614	196,658

rRevised.

[1]Includes terneplate and tinplate.

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

[3]Totals in 1989 and 1990 contain mixed (used plus new) rails. For 1989, exports contained 1,313 short tons valued at $8,664,660; imports contained 4,050 short tons valued at $1,065,953. For 1990, exports contained 6,591 short tons valued at $4,439,351; imports contained no mixed rails.

TABLE 12

U.S. EXPORTS OF USED RAILS FOR REROLLING AND OTHER USES, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1986		1987		1988		1989[1]		1990[1]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Canada	(2)	$44	1	$170	1	$134	4	r$774	7	$3,966
Korea, Republic of	—	—	(2)	8	—	—	—	—	(2)	49
Mexico	77	11,186	45	7,346	40	6,794	r53	r14,569	39	8,810
Turkey	—	—	10	1,111	—	—	—	—	(2)	6
Other	(2)	72	1	228	1	401	4	r4,719	7	1,553
Total[3]	78	11,302	57	8,863	42	7,330	r61	r20,062	53	14,385

rRevised.

[1]Exports in 1989 and 1990 contained mixed (used plus new) rails. For 1989, exports contained 1,313 short tons valued at $8,664,660. For 1990, exports contained 6,591 short tons valued at $4,439,351.

[2]Less than 1/2 unit.

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

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF IRON AND STEEL SCRAP,[1] BY COUNTRY

Country	1989		1990	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Austria	18	$27	—	—
Canada	951,063	121,454	1,194,662	$134,150
France	29,508	207	130	258
Germany, Federal Republic of	3,747	1,215	1,026	791
Japan	65,794	5,885	73,979	7,170
Mexico	56,863	13,217	70,112	18,732
Netherlands	3,573	1,512	895	97
Sweden	90	211	9,731	43
U.S.S.R.	—	—	289	2,741
United Kingdom	357	905	31,250	1,347
Other	8,508	4,477	61,365	6,181
Total[2]	1,119,521	149,109	1,443,439	171,510

[1]Includes tinplate and terneplate, excludes used rails for rerolling and other uses, and ships, boats, and other vessels for scrapping.
[2]Data may not add to totals shown because of independent rounding.

TABLE 14

U.S. IMPORTS FOR CONSUMPTION OF IRON AND STEEL SCRAP,[1] BY CLASS

(Short tons and U.S. dollars)

Class	1989		1990	
	Quantity	Value	Quantity	Value
No. 1 heavy melting scrap	40,071	$4,090,945	56,438	$5,411,578
No. 2 heavy melting scrap	11,618	1,162,945	11,741	1,093,062
No. 1 bundles	71,173	8,130,056	154,967	16,207,757
No. 2 bundles	6,111	725,792	14,245	1,450,614
Stainless steel scrap	58,742	29,826,184	112,595	31,284,356
Shredded steel scrap	61,805	12,361,167	50,844	6,296,095
Borings, shovelings, turnings	16,771	1,388,505	31,740	2,959,970
Other iron and steel scrap	746,704	77,711,456	840,172	87,700,496
Cast iron scrap	106,526	13,711,619	170,697	19,106,205
Total	1,119,521	149,108,669	1,443,439	171,510,133

[1]Excludes used rails for rerolling and other uses and ships, boats, and other vessels for scrapping.

Source: Bureau of the Census.

TABLE 15

U.S. IMPORTS FOR CONSUMPTION OF USED RAILS FOR REROLLING AND OTHER USES,[1] BY COUNTRY

(Short tons and U.S. dollars)

Class	1989		1990	
	Quantity	Value	Quantity	Value
Australia	—	—	7	$7,234
Canada	88,318	$13,521,929	167,418	23,421,711
France	—	1,599	—	—
Germany, Federal Republic of	5	4,881	2,689	1,641,592
Japan	28	15,202	174	77,265
United Kingdom	6	10,674	—	—
U.S.S.R.	9,875	1,290,199	—	—
Total	98,232	14,844,484	170,288	25,147,802

[1]Imports in 1989 contained 4,050 short tons of mixed (used plus new) rails valued at $1,065,953.

Source: Bureau of the Census.

TABLE 16

IRON AND STEEL SCRAP CONSUMPTION IN SELECTED COUNTRIES[1]

(Thousand short tons)

Continent, country group, and country	1985	1986	1987	1988	1989
North America:					
Canada[2]	8,967	8,627	9,039	9,400	9,800
United States[3 4]	70,493	65,856	68,303	76,822	72,209
Latin America:[5]					
Argentina	1,264	1,253	1,444	1,462	1,550
Brazil	7,714	7,934	8,068	8,461	8,600
Chile	241	152	241	320	290
Colombia	433	491	593	619	610
Ecuador	21	20	30	28	20
Mexico	3,413	3,253	2,844	3,772	2,780
Peru	257	292	343	304	250
Trinidad and Tobago	80	152	169	280	260
Uruguay	51	41	40	41	45
Venezuela	1,195	996	1,284	1,423	1,325
Central America, not further detailed	111	152	151	137	120
Europe:					
European Community:[6]					
Belgium[7]	3,430	2,956	3,009	r3,420	3,167
Denmark[8]	656	776	714	719	696
France[9 10]	7,109	7,128	7,398	7,544	7,608
Germany, Federal Republic of[9]	20,517	18,795	17,813	20,445	13,870
Greece	300	1,220	1,116	r1,187	1,181
Ireland	254	256	271	r300	374
Italy	17,133	16,144	16,407	17,143	18,562
Luxembourg	1,761	1,644	r1,443	r1,625	1,560
Netherlands	1,658	1,436	1,442	r1,319	1,220
Portugal	600	420	435	516	508
Spain	11,152	9,548	9,405	9,904	10,137
United Kingdom	7,712	7,341	7,783	r8,488	8,746
European Free Trade Association:					
Austria[7]	1,681	1,615	1,624	r1,616	1,660
Finland[7]	838	837	1,606	1,434	1,500
Norway[7 10]	597	600	697	762	530
Sweden[3 7 10]	3,380	3,240	3,255	3,297	3,200
Switzerland[e]	915	1,100	1,100	1,200	900
Council for Mutual Economic Assistance:					
Bulgaria	850	850	950	1,000	2,194
Czechoslovakia[3 9 10]	8,471	8,422	r9,054	8,958	8,469
German Democratic Republic[3 7 9 10]	5,593	5,516	5,642	r5,588	5,623
Hungary	2,754	2,912	2,723	2,465	2,224
Poland[7]	9,490	10,070	10,214	r9,952	8,750
Romania[e]	4,280	4,300	4,500	4,700	4,000
U.S.S.R.	66,139	77,200	78,200	79,400	70,000
Other: Yugoslavia[7 9 10]	2,447	2,523	1,596	r1,741	1,750
Africa: South Africa, Republic of[e 3]	3,300	3,500	3,500	3,750	4,000
Asia:					
China[e]	11,700	12,500	13,500	14,000	14,500
India[e]	4,300	4,400	4,400	4,500	5,000
Japan[9]	48,685	44,378	r44,777	47,373	48,400

See footnotes at end of table.

TABLE 16—Continued

IRON AND STEEL SCRAP CONSUMPTION IN SELECTED COUNTRIES[1]

(Thousand short tons)

Continent, country group, and country	1985	1986	1987	1988	1989
Asia—Continued					
Korea, Republic of[e]	3,700	3,800	4,000	4,500	5,100
Taiwan[e 11]	1,700	1,800	2,000	2,250	2,350
Turkey[12]	2,127	2,200	2,500	2,750	2,700
Oceania:					
Australia	2,100	2,000	r1,717	r1,505	1,590
New Zealand[e]	150	150	150	160	200
Total	351,719	r350,796	r357,490	r378,580	360,128

[e]Estimated. [r]Revised.

[1]Unless otherwise noted, figures represent reported consumption of iron and steel scrap utilized in the production of pig iron, ferroalloys, crude steel, foundry products, and rerolled steel, as well as other unspecified uses in the steel industry and by other unspecified industries as reported by the United Nations Economic Commission for Europe in its Annual Bulletin of Steel Statistics for Europe, 1989, v. 17, New York, 1990, 28 pp., which is the source of all reported data unless otherwise noted. All estimates are by the U.S. Bureau of Mines.

[2]Source: Canadian Foundry Association as reported by Energy, Mines, and Resources Canada.

[3]Excludes scrap consumed by steel rerollers.

[4]Source: U.S. Bureau of Mines.

[5]Reported data are from Instituto Latino Americano del Fierro y el Acero. Statistical Yearbook of Steel Making and Iron Ore Mining in Latin America, 1989, Santiago, 1990, 231 pp. Source does not provide details on what is included; presumably figures include total steel industry ferrous scrap consumption but exclude scrap used outside the steel industry.

[6]Portugal and Spain became members of the European Community on Jan. 1, 1986.

[7]Excludes scrap consumed in iron foundries.

[8]Includes scrap used in production of steel castings in shipyards but excludes scrap, if any, used in production of pig iron and that used in iron foundries.

[9]Excludes scrap consumed outside the steel industry.

[10]Excludes scrap consumed within the steel industry for purposes other than the manufacture of pig iron, ferroalloys, crude steel, foundry products, and rerolled steel (details on use not available).

[11]Excludes a substantial tonnage derived from shipbreaking, possibly in the order of several million tons annually, for electric-furnace-equipped steel mills.

[12]Source: Organization for Economic Cooperation and Development. The Iron and Steel Industry in 1985, Paris, 1987, 52 pp.; The Iron and Steel Industry in 1986, Paris, 1988, 52 pp.; The Iron and Steel Industry in 1987, Paris, 1988, 52 pp.; and The Iron and Steel Industry in 1988, Paris, 1989, 52 pp.

TABLE 17

IRON AND STEEL SCRAP EXPORTS, BY SELECTED COUNTRIES[1]

(Thousand short tons)

Continent, country group, and country	1985	1986	1987	1988	1989
North America:					
Canada	968	2 1,016	2 1,198	2 1,854	2 992
United States[2 3]	10,060	11,782	10,424	10,140	12,351
Latin America:					
Cuba[4]	129	122	165	67	e 100
Mexico[2]	24	24	25	52	e 30
Europe:					
European Community:[5]					
Belgium[6]	811	725	829	1,008	2 1,157
Denmark	298	202	246	328	308
France	4,366	3,484	3,558	4,070	2 4,696
Germany, Federal Republic of	3,756	3,768	4,650	5,067	5,343
Greece	1	1	2 2	2 3	2 3
Ireland	55	45	29	35	37
Italy	11	8	18	31	33
Netherlands	2,023	2,192	2,474	2,921	3,057
Portugal	18	12	8	14	2 23
Spain	1	1	18	66	32
United Kingdom	4,982	4,230	3,950	r3,995	3,599
European Free Trade Association:					
Austria	35	24	101	52	106
Finland	11	—	—	—	2 1

See footnotes at end of table.

TABLE 17—Continued

IRON AND STEEL SCRAP EXPORTS, BY SELECTED COUNTRIES[1]

(Thousand short tons)

Continent, country group, and country	1985	1986	1987	1988	1989
Europe—Continued					
European Free Trade Association—Continued					
Iceland	7	3	11	[2]5	4
Norway	10	9	13	23	22
Sweden	24	32	49	106	[2]156
Switzerland	110	[2]67	[2]96	[2]86	[2]74
Council for Mutual Economic Assistance:					
Bulgaria	42	4	39	40	35
Czechoslovakia[4]	155	112	110	180	184
German Democratic Republic[4]	29	8	12	[r]17	[e]20
Hungary	30	7	118	166	[e]160
Poland[2]	88	81	107	382	485
U.S.S.R.	[2]3,655	[2]4,506	[2]4,299	3,562	3,012
Other: Yugoslavia	191	174	405	399	251
Africa:					
Algeria[2]	93	164	166	157	[e]175
Morocco[2]	89	57	69	101	106
South Africa, Republic of[4]	74	161	78	60	[e]75
Asia:					
Bahrain[e]	10	10	10	10	10
Brunei[e]	[2]9	10	10	10	10
China[4]	24	3	[2]110	[2]756	[e]800
Cyprus	16	15	5	18	37
Hong Kong[2]	332	304	353	409	456
India[e]	20	20	20	25	35
Indonesia[2]	1	7	3	6	1
Japan	183	508	416	459	647
North Korea[4]	2	28	[r]23	27	[e]30
Korea, Republic of[2]	82	79	46	45	21
Kuwait[e]	100	100	100	100	100
Malaysia[2]	24	51	49	89	[e]95
Philippines[2]	1	1	1	2	[e]2
Saudi Arabia[e]	35	35	50	[2]137	[2]154
Singapore[2]	184	100	172	293	263
Taiwan[2]	428	310	108	83	57
Thailand[2]	4	6	5	5	[e]5
Turkey	[2]4	5	6	8	[e]10
United Arab Emirates[e]	10	10	10	10	10
Vietnam[4]	61	101	93	144	[e]150
Oceania:					
Australia[2]	555	623	965	12	61
New Zealand[2]	[e]2	4	3	2	[e]2
Total	34,233	35,351	[r]35,825	[r]37,637	39,583

[e]Estimated. [r]Revised.

[1]Unless otherwise noted, source is United Nations Economic Commission for Europe. Annual Bulletin of Steel Statistics for Europe, 1989, v. 17, New York, 1990, 38 pp.

[2]Source: Official trade returns of subject country.

[3]Includes rerolling material.

[4]Partial figure; compiled from import statistics of trading partner country.

[5]Portugal and Spain became members of the European Community on Jan. 1, 1986.

[6]For 1985 - 1987, Belgium-Luxembourg combined, data not available to separate; 1988 and 1989 data for Belgium only.

TABLE 18

IRON AND STEEL SCRAP IMPORTS, BY SELECTED COUNTRIES[1]

(Thousand short tons)

Continent, country group, and country	1985	1986	1987	1988	1989
North America:					
Canada	974	[2]827	[2]858	1,269	[2]1,610
United States[2 3]	611	724	843	1,038	1,120
Latin America:					
Argentina[2]	1	1	1	1	[e]1
Brazil[2]	35	541	161	[e]165	[e]165
Chile	[e]10	[2]19	[e]25	[e]20	[e]20
Colombia[2]	[e]50	[e]50	[e]50	173	[e]175
Cuba[4]	109	98	[e]100	[e]100	[e]100
Mexico[2]	926	475	512	920	[e]1,000
Peru[e]	20	20	20	20	[e]20
Venezuela[2]	547	[e]550	[e]550	[e]700	[e]700
Europe:					
European Community:[5]					
Belgium[6]	1,642	1,347	1,746	2,097	[2]2,177
Denmark	53	133	98	129	116
France	508	389	572	883	[2]959
Germany, Federal Republic of	1,776	1,517	1,311	1,551	1,359
Greece	345	502	[2]720	[2]470	[2]472
Ireland	150	134	164	198	243
Italy	6,368	5,232	5,413	5,578	6,332
Netherlands	646	936	1,148	848	1,221
Portugal	116	114	101	198	[2]164
Spain	6,776	4,784	4,702	4,966	4,952
United Kingdom	55	52	[2]80	[r]114	122
European Free Trade Association:					
Austria	263	127	76	112	97
Finland	125	71	60	18	[2]37
Norway	12	7	35	[r]181	67
Sweden	976	769	870	876	[2]689
Switzerland	265	[2]357	[2]150	[2]94	[2]168
Council for Mutual Economic Assistance:					
Czechoslovakia	[4]49	[4]47	2	2	[e]2
German Democratic Republic	[4]977	[4]1,087	995	[e]1,000	[e]850
Hungary	15	9	15	6	[e]5
Poland[2]	6	6	7	3	3
U.S.S.R.	[6]28	[6]49	[e]50	49	49
Other: Yugoslavia	804	718	759	822	712
Africa:					
Egypt[2]	2	2	2	13	[e]10
Morocco[2]	2	4	2	2	(7)
South Africa, Republic of	[4]8	50	25	30	20
Asia:					
Bahrain[e]	3	3	3	3	3
China[4]	547	716	[2]548	[2]170	[e]200
Hong Kong[2]	22	37	48	95	84
India[e]	[r]1,600	[r]1,750	[r]2,000	[r]2,225	1,860
Indonesia[2]	210	524	508	645	792
Japan	3,587	3,554	2,599	1,974	1,275

See footnotes at end of table.

TABLE 18—Continued

IRON AND STEEL SCRAP IMPORTS, BY SELECTED COUNTRIES[1]

(Thousand short tons)

Continent, country group, and country	1985	1986	1987	1988	1989
Asia—Continued					
Korea, Republic of[2]	2,640	3,434	3,879	4,290	4,478
Malaysia[2]	37	5	244	524	e500
Pakistan[2]	169	162	647	e700	e550
Philippines[2]	1	94	120	103	e100
Saudi Arabia	e1	21	e200	2596	2211
Singapore[2]	72	230	140	201	217
Syria[e]	15	15	15	15	15
Taiwan[2]	766	1,351	1,040	1,384	1,700
Thailand[2]	725	612	996	1,277	e1,500
Turkey	21,323	21,983	3,121	3,348	e3,300
Oceania:					
Australia	1	1	e1	e1	e5
New Zealand[2]	3	6	e6	e4	e4
Total	r36,972	r36,226	r38,338	r42,201	42,531

[e]Estimated. [r]Revised.
[1]Unless otherwise noted, source is United Nations Economic Commission for Europe. Annual Bulletin of Steel Statistics for Europe, 1989, v. 17, New York, 1990, 38 pp.
[2]Source: Official trade returns of subject country.
[3]Excludes scrap imported for consumption by steel rerollers.
[4]Partial figure; compiled from export statistics of trading partner countries.
[5]Portugal and Spain became members of the European Community on Jan. 1, 1986.
[6]For 1985 - 1987, Belgium-Luxembourg combined, data not available to separate; 1988 and 1989 data for Belgium only.
[7]Partial figure; compiled from incomplete returns of subject country and export statistics of trading partner countries.
[8]Less than 1/2 unit.

TABLE 19

SHREDDER PROCESSING CAPACITY IN SELECTED COUNTRIES IN 1990[1]

Country	Total number of shredders in operation, including mills	Total power requirements (horsepower)	Total annual capacity and/or output[2] (thousand metric tons)	Number of new plants under construction	Average power requirements per shredder (horsepower)	Average annual capacity and/or output per shredder (thousand metric tons)	Average power requirements of annual capacity and/or output (horsepower per metric ton)
North America:							
Canada	22	60,000	1,500	—	2,700	68	0.040
Mexico	4	6,600	e145	—	1,700	e36	e.046
United States	e210	e560,000	e15,000	4	e2,700	e71	e.037
Geographic area	e236	e626,600	e16,645	4	e2,700	e71	e.038
South America:							
Argentina	1	2,000	e43	—	2,000	e43	e.047
Brazil	3	5,000	e126	—	1,700	e42	e.040
Colombia	3	5,000	e109	—	1,700	e36	e.046
Venezuela	1	4,000	e86	—	4,000	e86	e.047
Geographic area	8	16,000	e364	—	2,000	e45	e.044
Western Europe:							
Austria	6	e7,500	120	—	e1,250	20	e.063
Belgium-Luxembourg	10	13,750	375	—	1,370	37	.037
Denmark	5	6,400	100	—	1,300	20	.064
Finland	3	e5,750	e90	1	e1,900	e30	e.064
France	34	45,790	1,400	9	1,350	41	.033

See footnotes at end of table.

TABLE 19—Continued

SHREDDER PROCESSING CAPACITY IN SELECTED COUNTRIES IN 1990[1]

Country	Total number of shredders in operation, including mills	Total power requirements (horsepower)	Total annual capacity and/or output[2] (thousand metric tons)	Number of new plants under construction	Average power requirements per shredder (horsepower)	Average annual capacity and/or output per shredder (thousand metric tons)	Average power requirements of annual capacity and/or output (horsepower per metric ton)
Western Europe—Continued							
Germany, Federal Republic of	44	56,760	1,570	—	1,290	36	.036
Ireland	1	1,250	30	—	1,250	30	.042
Italy	e15	e21,400	e750	e1	e1,430	e50	e.029
Netherlands	10	11,300	450	—	1,130	45	.025
Norway	3	2,900	112	—	970	37	.026
Portugal	2	e2,250	e47	—	e1,100	e24	e.048
Spain	12	14,500	e310	1	1,200	e26	e.047
Sweden	4	e9,750	e210	1	e2,400	e53	e.046
Switzerland	4	e5,000	e110	—	e1,250	e27	e.045
Turkey	1	2,000	e43	—	2,000	e43	e.047
United Kingdom	55	110,000	e2,100	1	2,000	e38	e.052
Geographic area	209	e316,300	e7,817	14	e1,500	e37	e.040
Eastern Europe:							
Czechoslovakia	2	5,000	e100	—	2,500	e50	e.050
German Democratic Republic	2	e3,750	e81	—	e1,900	e41	e.046
U.S.S.R.	6	e11,300	e240	—	e1,900	e41	e.047
Yugoslavia	1	1,250	e27	—	1,250	e27	e.046
Geographic area	11	e21,300	e448	—	e1,900	e41	e.048
Africa:							
South Africa, Republic of	5	e9,250	e277	1	e1,850	e55	e.033
Geographic area	5	e9,250	e277	1	e1,850	e55	e.033
Far East:							
Japan	145	e121,100	e3,633	10	e840	e25	e.033
Singapore	1	1,400	e42	—	1,400	e42	e.033
Taiwan	1	1,230	e37	—	1,230	e37	e.033
Geographic area	147	e123,730	e3,712	10	e840	e25	e.033
Middle East:							
Abu Dhabi	1	e1,250	e27	—	e1,250	e27	e.046
Iraq	1	e1,250	e27	—	e1,250	e27	e.046
Kuwait	1	e2,000	e43	1	e2,000	e43	e.047
Libya	1	e1,250	e27	—	e1,250	e27	e.046
Qatar	1	e1,500	e32	—	e1,500	e32	e.047
Saudi Arabia	2	e4,500	e98	—	e2,300	e49	e.046
Geographic area	7	e11,750	e254	1	e1,700	e36	e.046
Oceania:							
Australia	9	e20,700	e440	—	e2,300	e49	e.047
New Zealand	1	e2,000	e43	—	e2,000	e43	e.047
Geographic area	10	e22,700	e483	—	e2,300	e48	e.047
World total	e633	e1,147,630	e30,000	30	e1,810	e47	e.038

eEstimated.

[1]Unless otherwise specified, source for figures developed by the U.S. Bureau of Mines is from the Institute of Scrap Recycling Industries, Inc., the Bureau International de la Recuperation (BIR), manufacturers of shredders, or shredder operators.

[2]Assumed shredders were operated 8 hours per day, 5 days per week, 11 months per year (to allow for downtime, holidays, and planned maintenance), at 70% capacity.

KYANITE AND RELATED MATERIALS

By Michael J. Potter

Mr. Potter, a physical scientist with 24 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for kyanite since 1975. Domestic survey data were prepared by Joe Daniels, mineral data assistant; and international data table was prepared by Virginia Woodson, international data coordinator.

Kyanite, andalusite, and sillimanite are anhydrous aluminum silicate minerals of the same composition represented by the chemical formula $Al_2O_3 \cdot SiO_2$. Related materials include synthetic mullite, dumortierite, and topaz, also classified as aluminum silicates, although the last two additionally contain substantial proportions of boron and fluorine, respectively. The largest end use of kyanite group minerals and mullite is in the manufacture of high-alumina, high-performance refractories, including brick and shapes and monolithic refractory applications such as for high-temperature mortars or cements, ramming mixes, and castable refractories. U.S. production of kyanite was estimated to have decreased slightly compared with that of 1989 owing to flat or decreased activity in the iron and steel industry and other industries in which refractories were used. Domestic synthetic mullite output decreased compared with that of the previous year. Data have not been published to maintain company proprietary data. Imports of andalusite in 1990 were approximately 17,000 metric tons compared with the past few years when imports were in the 10,000-ton-per-year range.

DOMESTIC DATA COVERAGE

There are two known domestic kyanite mine-and-mill operations, but data are not known and would not be publishable because of company proprietary data. Of the three known synthetic mullite producers, all responded to the voluntary domestic survey. However, data cannot be published because of possible revealing of company proprietary data.

BACKGROUND

Definitions, Grades, and Specifications

Kyanite, andalusite, and sillimanite are a closely related trio of aluminum silicate minerals, differing slightly in physical properties and crystallographic characteristics, but sharing the same chemical composition, which can be represented as $Al_2O_3 \cdot SiO_2$. When heated, kyanite begins to break down to a noticeable extent at 1,315° C (andalusite at 1,382° C and sillimanite at 1,549° C) to form a mixture of mullite, $3Al_2O_3 \cdot 2SiO_2$, and vitreous silica, SiO_2. The mullite so produced usually consists of an aggregation of interlocking, acicular crystals and remains dimensionally and chemically stable until the temperature is raised to at least 1,810° C. These properties enable mullite to serve to advantage as a component in refractory shapes and furnace linings for a wide range of industrial applications. Above 1,810° C, mullite dissociates slowly with little change in volume into corundum (Al_2O_3) and silica, which recombine to form mullite at a lower temperature.

Topaz, $Al_2SiO_4(F,OH)_2$, and dumortierite, $Al_7(BO_3)(SiO_4)_3O_3$, are also often classed as members of the kyanite group of minerals. Upon firing, topaz loses fluorine and dumortierite loses boron, yielding refractory residues consisting essentially of mullite. A number of other substances—fire clay, siliceous bauxite, and kaolin, for example—owe their ability to perform satisfactorily in some refractory applications to the fact that, when heated, a least part of the aluminum silicate they contain is converted to mullite.

There are three types of synthetic mullite. Low-temperature sintered synthetic mullite is made by sintering siliceous bauxite or mixtures of bauxite and kaolin above 1,549° C. High-temperature sintered synthetic mullite is prepared by sintering mixtures of alumina and kaolin, bauxite and kaolin, or alumina, kaolin, and kyanite above 1,749° C. Fused synthetic mullite is made by melting Bayer process alumina and silica or bauxite and kaolin in an electric furnace at about 1,900° C.

All domestic kyanite ore is ground to permit separation and recovery by froth flotation of the mineral particles from accompanying gangue. The flotation-concentrate product is graded for sale to consumers in five particle-size ratings: 35, 48, 100, 200, and 325 mesh. Kyanite concentrates may contain from 56% to 60% alumina, from 38% to 44% silica, and from 0.2% to 0.9% iron oxide. Lump kyanite from India, ranging in size from pea to boulders, was formerly imported into the United States. Indian reserves are limited, however, and material is no longer being exported.

Products for Trade and Industry

Kyanite and related materials are consumed in the manufacture of high-alumina or mullite-class refractories and in lesser quantities as ingredients in ceramic compositions. U.S. kyanite is marketed either in raw form or after heat treatment as mullite. In the 35- to 48-mesh range, kyanite is used in monolithic refractory applications such as high-temperature mortars or cements, ramming mixes, and castable refractories or

with clays and other ingredients in refractory compositions for making kiln furniture, insulating brick, firebrick, and a wide variety of other articles. More finely ground material, minus 200 mesh, is used in body mixes for sanitary porcelains, wall tile, investment-casting molds, and miscellaneous special-purpose ceramics.

Data on the properties of finished refractory products are available from the producing firms. However, selection of the best refractory available for a specific application can sometimes be made only by testing under actual operating conditions. Load-bearing capacity, slag resistance, spalling characteristics, and other factors are often of prime importance.

Zircon sand containing some kyanite, sillimanite, and/or staurolite is used for foundry and refractory sand.

Technology

Both mines of the one U.S. kyanite producer are open pit, hard-rock quarrying operations. Blasted material is reduced to manageable size by drop-ball breaking and trucked to the processing plants where it is crushed to minus 1-inch size in jaw and cone crushers and then ground in rod mills to minus 35 mesh or finer. Two stages of flotation with alkaline-fatty acid or acid-petroleum sulfonate collectors produce an intermediate kyanite concentrate, which after being freed from iron by high-intensity magnetic treatment, becomes a salable product. Some kyanite is calcined at about 1,593° C and sold as mullite.

Byproducts and Coproducts

Quartzitic waste tailings from kyanite concentrators may be marketed locally as construction sand, but transportation costs limit the shipping radius of this byproduct.

Andalusite occurs in pyrophyllite ores that are mined by a company for ceramic and refractory purposes in North Carolina. A zircon-refractory heavy-mineral sand produced in Florida contains a small amount of aluminum silicates (kyanite, sillimanite, and staurolite) and is used for foundry and refractory sand.

Substitutes

Substitute and alternative materials for kyanite-group and mullite products in refractories include fire clay, calcined bauxite, and alumina. Other materials such as magnesite, chromite, silicon carbide, and zircon are interchangeable for specific end uses and conditions. Local availability of refractory raw materials is an important factor in choosing refractory products because transportation costs may prohibit use of alternative technically superior materials.

ANNUAL REVIEW

Legislation

The allowable depletion rates for kyanite, established by the Tax Reform Act of 1969 and unchanged through 1990, were 22% for domestic production and 14% for foreign operations.

Issues

Andalusite continued to be imported into the United States in 1990 as one of several minerals and metals that were exempt under a section of the Comprehensive Anti-Apartheid Act. The exemption list included strategic minerals for which the quantities essential for the economy or defense of the United States were unavailable from reliable and secure suppliers.

Production

Kyanite was produced at two open pit mines by Kyanite Mining Corp.: the Willis Mountain and East Ridge Mines in Buckingham County, VA. The company also operated beneficiation plants and calcining facilities for conversion of kyanite to mullite.

High-temperature sintered mullite was produced by C-E Minerals Div. of Combustion Engineering Inc. at Americus, GA, and Didier Taylor Refractories Corp. at Greenup, KY. Electric-furnace-fused mullite was produced by Washington Mills Electro Minerals Corp. at Niagara Falls, NY.

C-E Minerals was sold to Imetal SA by Asea Brown Boveri Ltd. (ABB) of Switzerland after ABB purchased C-E's parent company, Combustion Engineering Inc.[1]

Consumption and Uses

The U.S. Bureau of Mines does not collect data on end uses of kyanite and synthetic mullite. However, refractories for the iron and steel industries were probably the major end use of kyanite-mullite, consuming an estimated 55% of the quantity produced. Nonferrous metallurgical operations were believed to be the next largest use, estimated at 20%. A third category, estimated at 15%, consisted of glassmaking furnaces, ceramic kilns, boilers, petroleum-processing equipment, etc. Nonrefractory uses were estimated to make up the remaining 10%.

In the iron and steel industries, mullite is important in critical areas of blast furnace stoves and stacks, reheat furnaces, steel degassing chambers and soaking pits, and many types of auxiliary pouring and handling equipment. In the nonferrous metal industry, an end-use example is in refractory linings of alumina reduction cells.

Other miscellaneous uses include kiln furniture, blown aluminum silicate high-temperature insulation, brake linings, foundry mold facings, glass additions for alumina contents, ceramic tile, pyrometer tubes, high-tension insulators, spinnable mullite fibers, shell castings, ceramic honeycomb, mortars, grinding media, whitewares, extrusion dies, and welding rod coatings.

Prices

Prices at yearend 1990, in British pounds, from Industrial Minerals (London) were unchanged from the previous year. Price increases for 1990 in table 1 represent a stronger British pound against the U.S. dollar than in 1989.

Foreign Trade

Shipments of U.S. kyanite, mullite, and synthetic mullite were believed to have been made to foreign destinations, including Europe and Asia. Imports of andalusite from the Republic of South Africa were 17,350 metric tons with a customs value of $2,805,000, according to the U.S. Department of Commerce.

World Review

Capacity.—Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and

TABLE 1

PRICE OF KYANITE AND RELATED MATERIALS

(Dollars per metric ton)

	1989	1990
Andalusite, Transvaal, 57% Al_2O_3, bulk, c.i.f. main European port	144–160	171–190
Andalusite, Transvaal, 60% Al_2O_3, c.i.f. main European port	208	247
Sillimanite, South African, 70% Al_2O_3, bags, c.i.f. main European port	304	361
U.S. kyanite, 59% to 62% Al_2O_3, 35–325 Tyler mesh, raw and/or calcined, 18-ton lots, c.i.f. main European port	144–248	171–295
U.S. kyanite, f.o.b. plant, carlots:		
Raw	70–137	70–137
Calcined	123–172	123–172

Source: Industrial Minerals (London). Dec. 1989, No. 267, p. 75, and Dec. 1990, No. 279, p. 79.

TABLE 2

U.S. IMPORT DUTIES

Tariff item	No.	Most favored nation (MFN) Jan. 1, 1991	Non-MFN Jan. 1, 1991
Kyanite, sillimanite, andalusite, and dumortierite	2508.50	Free	Free
Mullite	2508.60	4.9% ad valorem	30% ad valorem

plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

The data in table 3 are rated capacity for mines and refineries as of December 31, 1990. Capacity data for Japan, the Republic of South Africa, and Sweden were obtained from literature sources. For other countries, recent peak production or estimated production was considered to be equal to rated capacity.

China.—Although kyanite ore bodies usually contain only 15% to 20% kyanite, development and utilization of the mineral, as well as andalusite and sillimanite, has taken place in the past several years. Processing of kyanite minerals has been achieved by flotation and magnetic separation. Producers were working on improving product quality and finding opportunities to export abroad.[2]

A 3,000-ton-per-year andalusite plant began operation in Xixia County, Hunan Province. The andalusite source for the plant was a deposit with proven reserves of 7.8 million tons.[3]

India.—The Indian Bureau of Mines developed beneficiation steps to obtain refractory-grade kyanite from the country's low-grade, mica-quartz-bearing kyanite deposits. Ore reserves are 175 million tons, with 90 million tons in Bihar and 80 million tons in Andhra Pradesh. A representative sample from the Lapsoburu deposit, Singhbhum district, Bihar, contained an estimated 35% kyanite, 50% quartz, 10% mica, and 5% other minerals such as rutile, staurolite, iron oxides, amphiboles, etc. Two-stage froth flotation of the sample followed by wet high-intensity magnetic separation yielded a product containing about 95% kyanite, 1% quartz, 1% mica, and 3% other minerals with a kyanite recovery of 73%. Further research work successfully produced dense and volume-stable aggregates out of the beneficiated kyanite concentrate and thus established its suitability for making refractory brick.[4]

Ireland.—Navan Resources PLC continued with plans to obtain capital resources to conduct a full-scale evaluation and feasibility study of its Tomduff

TABLE 3

WORLD KYANITE AND RELATED MINERALS CAPACITY, DECEMBER 31, 1990

(Thousand metric tons)

	Capacity
North America:	
United States:	
Kyanite	W
Synthetic mullite	W
Total	W
South America:	
Brazil: Kyanite[e]	5
Europe:	
France: Andalusite	60
Germany, Federal Republic of:	
Synthetic mullite[e]	10
Italy: Synthetic mullite[e]	5
Spain: Andalusite	5
Sweden: Kyanite	25
United Kingdom:	
Synthetic mullite	10
Other countries[e]	200
Total	315
Africa:	
South Africa, Republic of:	
Andalusite[e]	320
Sillimanite[e]	3
Zimbabwe: Kyanite	2
Total	325
Asia:	
China: Unspecified	3
India:	
Kyanite	38
Sillimanite	15
Total	56
Japan:	
Synthetic mullite[e]	30
Total	89
Oceania:	
Australia:	
Kyanite[e]	1
Sillimanite[e]	1
Total	2
World total[1 2]	740

[e]Estimated. W Withheld to avoid disclosing company proprietary data.
[1]Excludes U.S. kyanite and synthetic mullite.
[2]Data do not add to total shown because of independent rounding.

TABLE 4

KYANITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2] and commodity	1986	1987	1988	1989	1990[e]
Australia:					
Kyanite	768	1,079	[e]500	[e]500	750
Sillimanite[3]	133	77	64	[e]70	100
Brazil: Kyanite	950	510	[e]1,000	[e]1,000	1,000
China: Unspecified[e]	2,500	2,500	2,500	2,500	2,500
France: Andalusite	50,900	50,000	[e]50,000	[e]50,000	50,000
India:					
Andalusite	732	122	—	—	—
Kyanite	32,394	39,959	[r]35,773	[r]39,489	39,000
Sillimanite	14,905	12,756	[r]15,377	[r]16,117	16,000
Kenya: Kyanite[e]	1	1	1	1	1
Korea, Republic of	[r]33	[r]85	[r]112	[r]19	20
South Africa, Republic of:					
Andalusite	181,466	194,373	259,556	[r]284,048	270,000
Sillimanite	1,330	1,243	781	[r]170	300
Spain: Andalusite	[r]3,304	[r]3,916	[r]3,360	[r e]3,500	3,600
Sweden: Kyanite[e]	5,000	5,000	5,000	5,000	5,000
United States:					
Kyanite	W	W	W	W	W
Mullite, synthetic[e]	W	W	W	W	W
Zimbabwe: Kyanite	1,851	1,834	1,795	[r]1,869	1,800

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.

[1]Owing to incomplete reporting, this table has not been totaled. Table includes data available through Apr. 2, 1991.

[2]In addition to the countries listed, a number of other nations produce kyanite and related materials, but output is not reported quantitatively, and no reliable basis is available for estimation of output levels.

[3]In addition, about 7,000 metric tons of sillimanite clay (also called kaolinized sillimanite) is produced annually containing 40% to 48% Al_2O_3.

andalusite project in County Carlow. Initial studies revealed a mineralized zone 5 kilometers by 200 meters to 300 meters with a 9% to 25% andalusite content. The company believed that the property could support a production capacity of 50,000 tons per year producing a material 2.8 millimeters to 10 millimeters.[5] In late 1990, Navan announced taking a Swiss joint-venture partner, Realstate AG, to continue the evaluation of the andalusite project.[6]

OUTLOOK

The iron and steel industry has been the dominant consumer of refractories, including those based on kyanite and mullite. Steel output has been static in some countries but has shown growth in other regions such as China and Latin America.[7] In Eastern Europe, the refractories in use are the cheaper, less efficient fireclays. This region may be a potential growth market for conversion to alumino-silicate refractories, which have a higher alumina content and are more efficient.[8]

More severe operating conditions in iron and steel and other industries have required refractories that give longer service life. This has resulted in a reduction in overall refractory consumption. However, kyanite usage has been stable because of newer and more recent applications and uses.[9]

[1]Chemical Marketing Reporter. ABB Plans Sale of C-E Minerals Unit. V. 237, No. 22, p. 27.

[2]Guanghuan, W. Chinese Resources and Processing Technology for Kyanite Minerals. Ind. Miner. (London), No. 270, Mar. 1990, pp. 95, 97, 98.

[3]Industrial Minerals (London). Mineral Notes. No. 275, Aug. 1990, p. 61.

[4]Amanullah, S., G. M. Rao, and K. Satyanarayuna. Beneficiation of Mica-Quartz-Bearing Kyanite. Paper in Processing Developments (Proc. 9th "Ind. Min." Int. Congr., Sydney, Australia, Mar. 25–28, 1990). Met. Bull. J., 1990, pp. 24–25, 27–29.

[5]Industrial Minerals (London). Fillers and Extenders. No. 277, Oct. 1990, p. 97.

[6]———. World of Minerals. No. 279, Dec. 1990, p. 9.

[7]Roskill Information Services Ltd. (London). The Economics of Kyanite Group Minerals 1990, 6th ed., 110 pp.

[8]McMichael, B. Alumino-Silicate Minerals. Ind. Miner. (London), No. 277, Oct. 1990, p. 43.

[9]Kay, C. Kyanite. Min. Eng., v. 42, No. 6, June 1990, pp. 566-567.

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LEAD

By William D. Woodbury

Mr. Woodbury, a physical scientist with the U.S. Bureau of Mines, Branch of Metals, had 25 years of mining and civil works geotechnical experience upon becoming the Bureau's lead specialist in 1982. Domestic survey data were prepared by Eraina Dixon and Lisa Conley, mineral data assistants; and international data were prepared by Audrey A. Wilkes, international data coordinator.

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 aluminum, copper, and zinc. In some applications, lead can be toxic, however; its pervasive use in the water distribution system of ancient Rome is theorized by some historians to have contributed to that city's downfall through disorientation from poisoning. However, bridge abutment pads and structural dowelling still standing from that era attribute to its benefits; buildings built in Europe more than four centuries ago still stand under their original lead roofs. For this application lead is still widely used in England on modern structures. Today's worldwide major use of lead is in storage batteries that are used for a multiplicity of functions, including on-line voltage regulation against power surges (for computers), power grid load-leveling, and traditional transportation and communication uses. Other major uses are in soundproofing and radiation shielding, which includes transportation and storage of radioactive materials.

In the first quarter of 1990, reflecting the demand growth that started in the second quarter of 1987, the world cash price for lead on the London Metal Exchange (LME) briefly achieved, in mid-March, a price of 59.8 cents per pound, the same as the alltime record monthly price established in October 1979. Some domestic quotations in mid-March of 65 cents per pound delivered were only 2 cents below the December 1979 price, the highest ever recorded for the United States. However, owing primarily to record battery inventories at yearend 1989, which were not worked down by the end of 1990, demand and prices did not hold up as most of the world appeared headed into a recessionary period. Nevertheless, the year on average was quite profitable for the lead industry as the LME cash price achieved the highest annual level since 1980, and the third highest ever, in spite of increasing metal stocks.

World refined lead output, in spite of record-high U.S. secondary production, was about the same as that of 1989. World demand declined by almost 3%, mostly in the fourth quarter, after 7 years of spectacular growth, but was still the second highest ever. The world secondary sector, responding to environmental challenges, produced at a record level of 46% of world demand, but mine production leveled off and metal stocks rose for the first time since 1987. However, U.S. mine production increased by 15% primarily because the huge new Red Dog Mine in Alaska neared planned capacity output, and the United States was a significant net exporter of lead concentrates for the second consecutive year and for only the second year ever.

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 230 consuming companies to which a survey request was sent, 201 responded, representing 96% of the total U.S. lead consumption shown in tables 1, 10, 11, 12, and 13. Of the 49 companies producing secondary lead, exclusive of copper base, to which a survey request was sent, 42 responded, representing 93% of the total refinery production of secondary lead, not including that from copper base scrap, shown in tables 1, 7, 8, and 9. Production and consumption for the nonrespondents were estimated using prior-year levels adjusted for general industry trends.

ANNUAL REVIEW

Legislation and Government Programs

There were two significant Federal administrative actions affecting the U.S. lead industry in 1990 by the Environmental Protection Agency (EPA). In midyear, EPA's "third-third" rule became effective for landfilled process wastes under the Resource Conservation and Recovery Act (RCRA), as amended. This rule requires pretreatment for most secondary smelter slags, an item of significant cost to smelters. However, the smelters won a 2-year temporary reprieve to a less strict interim standard on appeal. In October, EPA proposed the "final" lead in drinking water standard, in which an "action level" of 10 parts per billion triggers various corrosion control options. The application of this rule could eventually translate into an 80% further reduction of lead in process effluents and discharges at considerable expense to lead producers and some consumers, especially battery plants. After 2 years of intense study, EPA also completed a comprehensive, multimedia (air-land-water) pollution prevention strategy that encompasses both the "old" lead problems in cities and perceived "new" lead problems. This strategy will result in

TABLE 1

SALIENT LEAD STATISTICS

(Metric tons unless otherwise specified)

		1986	1987	1988	1989	1990
United States:						
Production:						
Domestic ores, recoverable lead content		339,793	311,381	384,983	410,915	473,992
Value	thousands	$165,150	$246,720	$315,222	$356,476	$480,917
Primary lead (refined):						
From domestic ores and base bullion		348,217	336,471	371,348	379,034	385,637
From foreign ores and base bullion		22,071	37,139	20,739	17,421	18,020
Secondary lead (lead content)		624,769	710,067	736,401	r891,341	922,911
Exports (lead content):						
Lead ore and concentrates		4,380	8,764	20,902	[1]57,038	[1]56,600
Lead materials, excluding scrap		19,778	13,586	29,077	[1]43,837	[1]76,749
Imports for consumption:						
Lead in ore and concentrates		4,604	873	20,606	r [1]2,939	[1]7,790
Lead in base bullion		142	10,827	4,046	[1]5,782	[1]2,713
Lead in pigs, bars, reclaimed scrap		143,511	192,260	155,893	[1]116,358	[1]90,919
Stocks, Dec. 31:						
Primary lead[2]		20,400	21,608	15,398	15,623	25,525
At consumers and secondary smelters		83,824	88,586	89,865	r82,355	86,503
Consumption of metal, primary and secondary		1,125,521	1,230,373	1,245,170	r1,277,604	1,275,233
Price: Metals Week average, delivered, cents per pound		22.05	35.94	37.14	39.35	46.02
World:						
Production:						
Mine	thousand metric tons	r3,345.2	r3,424.6	3,429.8	p3,367.8	e3,367.2
Refinery[3]	do.	r3,190.9	r3,193.7	3,246.0	p3,284.5	e3,214.0
Secondary refinery	do.	r2,360.5	r2,524.1	2,604.4	p2,702.1	e2,727.7
Price: London Metal Exchange, pure lead, cash average, cents per pound		18.43	26.99	29.73	30.63	37.05

eEstimated. pPreliminary. rRevised.

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export categories for 1989 and 1990 are not necessarily comparable with those in previous years.

[2]American Bureau of Metal Statistics Inc.

[3]Primary metal production only. Includes secondary metal production where inseparably included in country total.

the imposition of significantly stricter multimedia regulations on producers and consumers over the next several years. Immediate consequences of the regulations, to be felt in 1991, will be strict enforcement of existing laws and regulations.

In State actions, mandatory lead-acid battery recycling laws became effective in 13 States during 1990, and, in 7 others, laws were passed to become effective on January 1, 1991. These were in addition to nine other States whose recycling laws became effective in 1989, and one in 1988.

Issues

Domestically, the year 1990 was one of furious legislative activity relative to lead as several bills were introduced into both houses of the Congress to deal with various aspects of lead pollution and epidemiology. The primary concern addressed was urban soil and household dust contamination from old, flaking lead-base paint and solid residues from leaded gasoline exhaust emissions. Also addressed were mandatory Federal lead-acid battery recycling and/or minimum required content of secondary lead in batteries, and source reduction by severely reducing lead content of solders and eliminating lead from all food packaging and containers. In addition, taxation of primary lead and economic incentives for secondary production to reduce environmental "loading" and comprehensive documentation of existing uses, with mandatory new product approvals, was being considered. Extensive yearlong hearings were held at committee and subcommittee levels, but no floor votes were taken, and various amended and combined versions of all proposals were expected to be reintroduced in 1991.

With the exception of the "old lead problem" (primary concern aforementioned), the issue of concern emerging publicly for the first time on a grand scale was that with no proven effective "environmental sink" for heavy metals, they simply move from media to media (air-land-water). In doing so it is postulated that they continuously expose the populace more often and in ever-increasing dosages as "virgin" (i.e., newly mined heavy metals) are added to the cycle. However, this hypothesis is dependent on the assumption that dissipative end uses grow proportionately with the overall population and demand, and/or that exposures to both dissipative and nondissipative uses cannot be technologically reduced.

This is a rebuttable presumption illustrated simplistically by the continuously

evolving U.S. lead supply-demand pattern itself. From the peak demand year of 1977 (table 2), primary demand has dropped by 370,000 tons mostly because the major dissipative use of lead in gasoline additives has decreased by 200,000 tons, replaced in the market by highly recyclable electrical and transportation uses, which have increased by 200,000 tons. This is reflected in the old scrap production levels for 1990 versus 1977, an increase of 240,000 tons. There has also been a 100,000-ton drop in overall demand, 90% of which was in the chemicals and other miscellaneous use categories, much of which was dissipative.

Net imports from worldwide, generally less environmentally regulated sources than our domestic facilities have declined by about 200,000 tons from the primary supply side. Projections for the future (see Outlook section) indicate that this overall decreasing exposure and "loading" trend will continue in the domestic supply-demand pattern. With the establishment of the lead-acid battery as a "fungible," marketable commodity due to a generally more environmentally conscious populace (30 States had mandatory battery recycling laws at yearend) and continuing advances in recycling technology, this scenario will improve even more during the rest of the century, continuing to reduce exposure and the attendant epidemiological effects. Technologic advances in lead-acid batteries, resulting in even longer life, will also continue to contribute to limiting use of lead and exposure thereto.

Production

Primary.—The increase in domestic mine production of lead in 1990 was attributed primarily to the coming on-stream in February of Cominco Alaska Inc.'s huge Red Dog open pit zinc-lead-

TABLE 2

LEAD SUPPLY-DEMAND RELATIONSHIPS[1]

(Thousand metric tons)

	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Mine production (Pb in concentrates):														
United States	240	270	285	310	300	340	480	540	545	585	570	625	587	576
Rest of world	2,285	2,260	2,415	2,550	2,580	2,680	2,775	2,875	2,875	2,815	2,940	2,815	2,868	2,792
Total	2,525	2,530	2,700	2,860	2,880	3,020	3,255	3,415	3,420	3,400	3,510	3,440	3,455	3,368
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY														
Components of U.S. supply:														
Refinery production:														
Domestic ore	226	275	283	299	243	334	481	489	534	531	527	535	483	520
Foreign ore	141	141	103	111	110	107	113	126	70	94	97	85	96	76
Old scrap	[e]424	426	450	440	433	428	468	459	444	452	489	545	512	564
Imports—Metal, excluding scrap	202	193	202	260	331	307	253	222	175	223	162	107	90	129
Industry stocks, Jan. 1, pigs and bars	214	160	137	122	102	117	85	138	210	161	166	136	185	195
Government stockpile releases	4	36	49	58	25	26	20	11	9	41	191	241	6	—
Total U.S. supply	[e]1,211	1,231	1,224	1,290	1,244	1,319	1,420	1,445	1,442	1,502	1,632	1,649	1,372	1,484
Distribution of U.S. supply:														
Industry stocks, Dec. 31, pigs and bars	160	137	122	102	117	85	138	210	161	166	136	185	195	157
Exports—Metal, excluding scrap	1	9	7	5	6	8	4	7	5	8	60	56	19	5
Industrial demand	[e]1,050	1,085	1,095	1,183	1,121	1,226	1,278	1,228	1,276	1,328	1,436	1,408	1,158	1,322
U.S. DEMAND PATTERN														
Ammunition	45	51	52	71	71	75	72	66	79	77	74	79	68	67
Construction	130	131	122	118	108	112	105	90	90	80	79	69	63	65
Electrical	78	80	84	93	88	85	84	80	117	116	122	120	70	75
Gasoline additives	175	203	204	225	225	238	246	253	240	253	249	227	189	218
Oxides and chemicals	90	94	99	109	94	100	93	90	74	82	100	106	72	96
Transportation	440	430	430	460	440	520	580	560	590	630	720	715	625	705
Other	92	96	104	107	95	96	98	89	86	90	92	92	71	96
Total U.S. demand	[e]1,050	1,085	1,095	1,183	1,121	1,226	1,278	1,228	1,276	1,328	1,436	1,408	1,158	1,322
Total U.S. primary demand (Industrial demand less old scrap)	626	659	645	743	688	798	810	769	832	876	947	863	646	758
PRICES														
Average annual (cents per pound)	11.1	13.6	16.0	15.2	14.0	13.2	14.9	15.7	13.9	15.0	16.3	22.5	21.5	23.1
Average annual, based on constant 1987 dollars, (cents per pound)	40.4	48.6	55.7	50.9	45.9	41.3	44.1	44.0	36.8	38.0	38.8	49.1	42.6	43.2

See footnotes at end of table.

TABLE 2—Continued

LEAD SUPPLY-DEMAND RELATIONSHIPS[1]

(Thousand metric tons)

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Mine production (Pb in concentrates):														
United States	560	552	547	573	459	530	466	335	424	353	319	394	420	495
Rest of world	2,808	2,843	2,925	2,897	2,907	2,918	2,891	2,934	3,007	2,992	3,106	3,036	2,948	2,872
Total	3,368	3,395	3,472	3,470	3,366	3,448	3,357	3,269	3,431	3,345	3,425	3,430	3,368	3,367
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY														
Components of U.S. supply:														
Refinery production:														
Domestic ore	490	504	532	509	443	465	464	324	423	348	336	371	379	386
Foreign ore	62	64	46	39	55	52	55	65	71	22	37	21	17	18
Old scrap	637	650	673	581	578	521	452	586	570	575	658	691	842	874
Imports—Metal, excluding scrap	231	227	183	82	100	95	177	163	133	142	188	152	122	97
Industry stocks, Jan. 1, pigs and bars	157	135	143	199	181	203	171	154	142	178	104	110	105	98
Government stockpile releases	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total U.S. supply	1,577	1,580	1,577	1,410	1,357	1,336	1,319	1,292	1,339	1,265	1,323	1,345	1,465	1,473
Distribution of U.S. supply:														
Industry stocks, Dec. 31, pigs and bars	135	143	199	181	203	171	154	142	178	104	110	105	98	112
Exports—Metal, excluding scrap	9	8	11	164	23	56	20	7	27	13	10	14	34	64
Industrial demand	1,433	1,429	1,367	1,065	1,131	1,109	1,145	1,143	1,134	1,148	1,203	1,226	1,333	1,297
U.S. DEMAND PATTERN														
Ammunition	62	56	53	49	49	44	44	48	50	44	47	53	57	58
Construction	75	60	50	37	37	40	44	43	39	34	31	32	31	34
Electrical	90	88	86	70	74	75	80	93	120	143	138	132	149	143
Gasoline additives	211	178	187	128	111	119	89	79	46	29	W	W	W	W
Oxides and chemicals	91	92	91	78	80	61	69	77	73	70	68	63	58	57
Transportation	795	855	815	640	720	720	770	755	760	785	850	875	980	950
Other	109	100	85	63	60	50	49	48	46	43	69	71	58	55
Total U.S. demand	1,433	1,429	1,367	1,065	1,131	1,109	1,145	1,143	1,134	1,148	1,203	1,226	1,333	1,297
Total U.S. primary demand (Industrial demand less old scrap)	796	779	694	484	553	588	693	557	564	573	545	535	491	423
PRICES														
Average annual (cents per pound)	30.7	33.7	52.7	42.4	36.5	25.5	21.7	25.6	19.1	22.0	35.9	37.1	39.4	46.0
Average annual, based on constant 1987 dollars, (cents per pound)	53.7	54.9	78.9	58.2	45.6	30.1	24.5	27.9	20.2	22.8	35.9	35.9	37.8	44.2

[e]Estimated. W Withheld to avoid disclosing company proprietary data, included in "Other."
[1]1964-83 revised from previous editions of Mineral Facts and Problems.

silver mine in the Kotzebue region. However, small increases were also realized at virtually all producing zinc-silver and/or zinc-gold mines in Colorado, Idaho, and Montana where lead is a coproduct and/or byproduct. A slight increase in lead output was also recorded in Missouri, which represented 78% of domestic producion (table 3); Alaska and the other three aforementioned States accounted for 18% of the total. Of those mines listed in table 5, the top 15 produced more than 99% of the total or all but 3,800 tons. In terms of corporate ownership, three companies, Doe Run, ASARCO Incorporated, and Cominco, accounted for 90% of the total. On the basis of lead in concentrates, The industry performed at only 62% of capacity (table 17), the same as in 1989, because of decreasing primary demand, both domestic (table 2) and worldwide (table 16).

During 1990 in southeastern Missouri, the Doe Run Co. of St. Louis, MO, the Nation's largest integrated lead producer, operated three mine and mill divisions, Buick, Fletcher, and Viburnum, consisting of six mines and four mills, which had an aggregate daily capacity of 26,300 tons of ore according to parent company Fluor Corp.'s annual SEC Form 10-K. In May 1990, Fluor Corp. purchased Homestake Lead Co. of Missouri's 42.5% interest in Doe Run for $125 million in cash and are now sole owners. On a fiscal year basis ending October 31, 1990, Doe Run mined and milled 4.78 million tons of ore grading 5.36% lead compared with 4.35 million tons grading 5.58% in 1989, an increase in contained lead of just less than 6%. This resulted in metal production at Doe Run's integrated smelter-refinery in Herculaneum, MO, of about 231,000 tons of refined lead for the calendar year 1990 compared with about 224,000 tons of refined lead for

1989, an increase of 3%. In addition, Doe Run produced and sold 45,000 tons of copper concentrate and 44,000 tons of zinc concentrate in its fiscal year 1990 from its mines. As of October 31, 1990, these mines had proven ore reserves of approximately 76.8 million tons with an average grade of approximately 4.84% lead, according to Fluor's SEC Form 10-K. Approximately 65% of Doe Run's ore is on properties under Federal mineral leases for terms of 10 to 20 years, renewable for 10 years, for which the company pays the Bureau of Land Management a royalty of 5% of the gross value of concentrates produced.

Asarco operated two mine and mill complexes in southern Missouri, which together produced 82,500 tons of lead in concentrates, the same as in 1989, according to the company's first quarter 1991 special report of "Statistical Data for Securities Analysts." This represented about 72% of the refined lead production from Asarco's integrated smelter-refinery at Glover, MO, in 1990 compared with 75% in 1989. That plant produced 112,000 tons of refined lead in 1990 and 108,000 tons in 1989, according to the report. Asarco purchased Cominco American Inc.'s 50% share of the Magmont Mine production in Iron County, MO, to supplement Glover's feed. Asarco's refinery at Omaha, NE, which receives the lead bullion output of the East Helena, MT, custom smelter, produced 61,000 tons of refined lead in 1990 compared with 65,000 tons in 1989. Asarco also received a 50% share and 37.5% share, respectively, of the production from the Leadville and Galena mines shown on table 5. Asarco's total lead metal production in 1990 was 45% from its own mines, 48% custom, and 7% toll, but at yearend it was estimated that the company had an approximately 85% captive domestic capability if its own mine production were fully optimized.

The Magmont Mine at Bixby, MO, a 50-50 joint venture of Cominco American Inc., the operator, and Dresser Industries Inc., continued to be the Nation's third largest producer, in spite of being only about 3 years from exhaustion. Surface drilling during the year revealed two minor extensions of the ore body, which partially replaced the ore extracted. Ore recovery from the major 1986 groundfall area was completed in 1990, with recovery and pillar extraction exceeding that from other areas of the mine. According to parent company Cominco Ltd.'s (Canada) annual stockholders report, Magmont milled 984,000 tons of ore grading 7.1% compared with 962,000 tons grading 6.8% in 1989. This yielded 87,000 tons of concentrate grading 78.0% lead compared with 81,000 tons at 77.9% concentration in 1989. The mine also produced 8,000 tons of zinc in concentrate from 1.0% ore and 800 tons of copper from 0.3% ore. Cominco Alaska's Red Dog Mine, about 90 miles north of Kotzebue in northwest Alaska, officially opened in February after some initial startup problems that arose in late 1989. However, operations continued to improve through the year, and the mill processed 904,000 tons of ore, which graded 26.5% zinc, 8.5% lead, and 3.6 troy ounces per short ton of silver. Lead concentrate production was 51,400 tons at 55.1% lead compared with 306,000 tons of zinc concentrate at 56.9% zinc and 3% lead. The mill also produced a bulk concentrate of 45,000 tons grading 31.7% zinc and 22.9% lead. Ultimate average production levels are projected at 70,000 tons of contained lead and 325,000 tons of contained zinc per year from measured reserves of 67 million tons estimated to average 5.4% lead and 18.5% zinc, according to Cominco Ltd.

Secondary.—Domestic secondary production increased for the fifth consecutive year, setting a new record, as the industry continued to perform at 90% of capacity, estimated to be 1.03 million tons per year at yearend. In spite of the closure, for environmental reasons, of Exide Corp.'s Dixie Metals Co. plant in Dallas, TX, and the Alco Pacific Inc. plant in Carson, CA, at yearend, there was a net increase in domestic capacity of about 100,000 tons for the year. This was the result, primarily, of expansions and improvements at several larger plants, mostly by RSR Corp., GNB Inc., and Schuylkill Metals Corp. The latter was acquired by a Citicorp investor group during the year, which allowed for a recapitalization of its two plants. At yearend, the industry was represented by 15 companies that operated 22 battery breakers-smelters with capacities of 6,000 to 110,000 tons per year. Also operating were six smaller operations (including Asarco's Omaha, NE, refinery and Doe Run's Boss, MO, smelter), with plant capacities of 6,000 to 10,000 tons per year that did not process batteries. In addition,

TABLE 3

MINE PRODUCTION OF RECOVERABLE LEAD IN THE UNITED STATES, BY STATE

(Metric tons)

State	1986	1987	1988	1989	1990
Idaho	9,951	W	W	W	W
Missouri	319,900	W	353,194	366,931	372,383
Montana	W	W	8,266	W	W
Nevada	—	—	W	—	830
New Mexico	10	W	W	W	W
South Dakota	—	—	—	4	—
Total[1]	339,793	311,381	384,983	410,915	473,992

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Includes, for at least some of the years 1986-90, Alaska, Arizona, Colorado, Illinois, New York, and Tennessee.

TABLE 4

MINE PRODUCTION OF RECOVERABLE LEAD IN THE UNITED STATES, BY MONTH

(Metric tons)

Month	1989	1990
January	33,553	41,556
February	31,323	38,255
March	34,840	39,050
April	33,996	36,619
May	34,885	39,984
June	36,401	38,024
July	33,509	41,432
August	38,992	46,271
September	34,601	37,144
October	35,379	42,116
November	33,116	37,726
December	30,320	35,815
Total	410,915	473,992

TABLE 5

TWENTY-FIVE LEADING LEAD-PRODUCING MINES IN THE UNITED STATES IN 1990, IN ORDER OF OUTPUT

Rank	Mine	County and State	Operator	Source of lead
1	Fletcher	Reynolds, MO	The Doe Run Co.	Lead-zinc ore.
2	Buick	Iron, MO	do.	Do.
3	Magmont	do.	Cominco American Inc.	Do.
4	West Fork	Reynolds, MO	ASARCO Incorporated	Do.
5	Red Dog	Northwest Arctic, AK	Cominco Alaska Inc.	Zinc ore.
6	Casteel[1]	Iron, MO	The Doe Run Co.	Copper-lead ore.
7	Sweetwater	Reynolds, MO	ASARCO Incorporated	Lead-zinc ore.
8	Viburnum No. 29	Washington, MO	The Doe Run Co.	Do.
9	Viburnum No. 28	Iron, MO	do.	Copper-lead ore.
10	Lucky Friday	Shoshone, ID	Hecla Mining Co.	Lead-zinc ore.
11	Greens Creek	Admiralty Island, AK	Greens Creek Mining Co.	Zinc ore.
12	Montana Tunnels	Jefferson, MT	Montana Tunnels Mining Inc.	Do.
13	Bunker Hill	Shoshone, ID	Bunker Hill Mining Co. (U.S.) Inc.	Do.
14	Sunnyside	San Juan, CO	San Juan County Mining Venture	Do.
15	Leadville Unit	Lake, CO	ASARCO Incorporated	Lead-zinc ore.
16	Butte Hill	Silver Bow, MT	New Butte Mining Co. Inc.	Do.
17	Balmat	St. Lawrence, NY	Zinc Corporation of America	Zinc ore.
18	Ward/Taylor	White Pine, NV	Alta Gold Co.	Lead-zinc ore.
19	Galena	Shoshone, ID	ASARCO Incorporated	Silver ore.
20	Pierrepont	St. Lawrence, NY	Zinc Corporation of America	Zinc ore.
21	Rosiclare	Hardin and Pope, IL	Ozark-Mahoning Co.	Fluorspar.
22	Franklin	Clear Creek, CO	Franklin Consolidated Mines Inc.	Gold-silver ore.
23	Gies Mine	Fergus, MT	Blue Range Mining Co.	Gold ore.
24	Young	Jefferson, TN	ASARCO Incorporated	Zinc ore.
25	Center	Grant, NM	Mount Royal Mining Co.	Gold ore.

[1]Includes Brushy Creek Mill.

TABLE 6

REFINED LEAD PRODUCED AT PRIMARY REFINERIES IN THE UNITED STATES, BY SOURCE MATERIAL[1]

(Metric tons unless otherwise specified)

Source material		1986	1987	1988	1989	1990
Refined lead:						
Domestic ores and base bullion		348,217	336,471	371,348	379,034	385,637
Foreign ores and base bullion		22,071	37,139	20,739	17,421	18,020
Total		370,288	373,610	392,087	396,455	403,657
Calculated value of primary refined lead[2]	thousands	$180,004	$296,026	$321,039	$343,932	$409,537

[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.

21 small companies with 22 plants of less than 1,000 tons per year of capacity each were producing mainly specialty alloys for such uses as solders, brass or bronze ingots, and bearing metals, etc. Production from the latter two secondary sectors in 1990 combined, excluding Doe Run, was 37,900 tons. Although Doe Run was technically a secondary producer during 1990, its battery scrap was tolled by others, but its "high-grade" scraps and drosses, etc., were processed in the Buick primary plant's blast furnace and kettles at Boss, MO. Therefore, although its production is included in the first category, the "interim" capacity is not. However, work proceeded on a new secondary plant and breaker at Buick during the year after the Homestake buyout, and an additional 54,000 tons of secondary capacity was expected to come on-stream in late summer 1991. In Texas, Tejas Resources Inc. started construction at Terrell of a new, conventional 27,000-ton-per-year capaci-

ty smelter to process 10,000 batteries per day on a "just-in-time" basis from offsite breakers. The rotary furnace with wet scrubbers was expected to come on-stream in mid-1991, producing a nonleachable sodic slag reportedly safe for conventional landfilling, which is considerably cheaper than disposing of toxic slags.

Consumption

Reported consumption of lead (tables 10 through 13) was about the same as for 1989, with battery manufacturers again using more than 1 million tons or 79% of the total consumer offtake. Although automotive starting-lighting-ignition (SLI) battery shipments, domestic and export, exceeded 80 million units for the third consecutive year, they were about 300,000 lower than in 1989 (3,000 tons of lead), according to Battery Council International statistics. However, inventories rose by 1.52 million units, accounting for 15,000 tons of increased lead use. Lead use by the industrial-traction battery sector declined slightly, from an estimated 174,000 tons in 1989 to 172,000 tons in 1990; use in all other specialty batteries declined from 43,000 tons (revised) in 1989 to 40,000 tons in 1990. When this 5,000-ton decrease is added to the SLI battery shipments decrease and subtracted from the inventory buildup, the result is the 7,000-ton net increase in total battery lead consumed shown on table 10. It was estimated that small, sealed "consumer battery" cells accounted for 5,000 to 10,000 tons of the specialty battery offtake, which includes nonstandard military and civilian research applications not covered by the SLI (includes aircraft), stationary, or motive power categories. The industrial and traction battery sector includes uninterruptible power supply (UPS) designed to ensure constant voltage for large computer systems at hospitals, banks, communication networks, etc., and standby power supply (SBS) for emergency lighting and some telephone systems. About one-third of the lead total in this category applies to electric vehicles and submarines, including some surface boats, and some in-plant and mine equipment. The whole industrial-traction sector exhibits great potential for continued future growth as networking of computers of all capacities continues to grow and general purpose electric vehicles and customer load-leveling loom ever closer to universal application.

Lead oxides used for glass, paint, ceramics, and other chemicals, which had been the second largest use for lead, declined for the sixth consecutive year. All other uses exhibited marginal increases or decreases, except cable lead, which declined significantly, ostensibly a rationalization of 1989's 40% increase over that of 1988.

TABLE 7

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	
1989[r]						
Smelters, refiners, others:						
Soft lead[2]	1,682	31,260	—	31,914	31,914	1,028
Hard lead	191	8,616	—	8,616	8,616	191
Cable lead	885	11,372	—	11,237	11,237	1,021
Battery-lead	21,457	997,269	—	994,301	994,301	24,425
Mixed common babbitt	115	2,071	—	1,990	1,990	196
Solder and tinny lead	2,212	19,680	—	20,057	20,057	1,835
Type metals	103	1,803	—	1,800	1,800	106
Drosses and residues	4,045	64,983	66,847	490	67,337	1,692
Total[1]	30,690	1,137,057	66,847	1,070,406	1,137,253	30,494
1990						
Smelters, refiners, others:						
Soft lead[2]	1,028	29,622	—	29,259	29,259	1,392
Hard lead	191	7,115	—	6,526	6,526	780
Cable lead	1,021	15,890	—	15,750	15,750	1,161
Battery-lead	24,425	1,030,768	—	1,032,199	1,032,199	22,994
Mixed common babbitt	196	748	—	752	752	192
Solder and tinny lead	1,835	31,087	—	31,110	31,110	1,812
Type metals	106	4,601	—	4,618	4,618	90
Drosses and residues	1,692	62,824	61,902	958	62,860	1,655
Total[1]	30,494	1,182,655	61,902	1,121,171	1,183,073	30,077

[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 8

SECONDARY METAL RECOVERED[1] FROM LEAD AND TIN SCRAP IN THE UNITED STATES

(Metric tons)

	Lead	Tin	Antimony	Other	Total[2]
1989[r]					
Refined pig lead[3]	438,013	—	—	—	438,013
Refined pig tin[4]	—	563	—	—	563
Lead and tin alloys:					
Antimonial lead	418,584	967	14,714	740	435,005
Lead-base babbitt	1,523	116	178	(5)	1,817
Solder	16,732	3,225	128	(5)	20,085
Type metal	936	46	137	(5)	1,119
Other alloys, including cable lead	2,141	30	9	—	2,180
Total[2]	439,918	4,384	15,166	740	460,208
Tin content of chemical products	—	W	—	—	W
Grand total[2]	877,931	4,947	15,166	740	898,784
1990					
Refined pig lead[3]	461,868	—	—	—	461,868
Refined pig tin[4]	—	186	—	—	186
Lead and tin alloys:					
Antimonial lead	425,979	742	15,032	737	442,489
Lead-base babbitt	530	28	57	(5)	615
Solder	(6)	2,876	126	(5)	3,002
Type metal	868	46	122	4	1,040
Other alloys, including cable lead	17,778	36	3	—	17,817
Total[2]	445,154	3,729	15,340	740	464,962
Tin content of chemical products	—	33	—	—	33
Grand total[2]	907,022	3,946	15,340	740	927,048

[r]Revised. 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.

World Review

According to the International Lead and Zinc Study Group (ILZSG) statistics, consumption of soft lead and antimonial lead in the market economy countries (MEC) was 4.44 million tons in 1990, down from the record high of 4.52 million tons set in 1989.[1] Estimated world consumption of lead in all forms decreased for the first time since 1982, to 5.9 million tons, after setting a record of almost 6.1 million tons in 1989 (table 16). A considerable part of this decline occurred in the U.S.S.R., a result of the year's political and resulting economic turmoil, and in the former Soviet bloc in general (excluding China and North Korea), where estimated refinery production declined 60,000 tons from that of 1989 (table 19). From 1983, when the world emerged from a previous 3-year recessionary period, through 1989, a continual growth in demand averaging 2.3% per year had occurred. This was attributed to electrical power storage requirements for vehicles and aircraft or ships; emergency standby power for lighting, communication, and computers, including voltage regulation; and load-leveling for light manufacturing.

Estimated world total refinery production in 1990, including that from recycled new and old scrap, decreased slightly from 1989's record high as metal stocks increased for the first time in 3 years. A 70,000-ton decrease in primary metal output was partially offset by a record secondary output of more than 2.7 million tons, paced by that sector in the United States that set a domestic secondary production record for the second straight year. The high overall production rate in the face of dwindling world demand from battery manufacturers, who were already sitting on high stocks, resulted in the considerable drop in the world price of lead in the fourth quarter of the year. That was the first significant price decline since the first quarter rationalization in 1989 that reflected high yearend 1988 metal stocks. At yearend, LME physical stocks of lead at 56,400 tons were only 5,000 tons below the high level at yearend 1988. Four new lead-producing mines came on-stream in 1990, two in China and one each in Australia (Thalanga) and Canada (Estrades). Although there was a net capacity increase for the year, there were six closures owing to depletion of ore. However, as a result of numerous other expansions and/or facility upgrades, the only net capacity decreases were in Greenland, whose only mine closed in midyear; Japan; Spain; and

TABLE 9

LEAD RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1989[r]	1990
KIND OF SCRAP		
New scrap:		
Lead-base	46,715	43,608
Copper-base	2,894	[e]5,000
Tin-base	3	4
Total	49,612	48,612
Old scrap:		
Battery-lead	761,279	783,860
All other lead-base	69,644	79,439
Copper-base	10,806	[e]11,000
Tin-base	—	—
Total	841,729	874,299
Grand total	891,341	922,911
FORM OF RECOVERY		
As soft lead	438,013	461,868
In antimonial lead	418,584	425,979
In other lead alloys	21,040	19,060
In copper-base alloys	13,701	[e]16,000
In tin-base alloys	3	4
Total	891,341	922,911
Value[1] thousands	$773,254	$936,354

[e]Estimated. [r]Revised.
[1]Value based on average quoted price of common lead.

TABLE 10

U.S. CONSUMPTION OF LEAD, BY PRODUCT

(Metric tons)

SIC code	Product	1989	1990
	Metal products:		
3482	Ammunition: Shot and bullets	[r]57,310	58,210
	Bearing metals:		
35	Machinery except electrical	W	W
36	Electrical and electronic equipment	W	199
371	Motor vehicles and equipment	1,683	W
37	Other transportation equipment	W	W
	Total bearing metals	2,586	2,878
3351	Brass and bronze: Billets and ingots	9,610	9,943
36	Cable covering: Power and communication	22,605	18,253
15	Calking lead: Building construction	1,831	1,688
	Casting metals:		
36	Electrical machinery and equipment	524	538
371	Motor vehicles and equipment	W	W
37	Other transportation equipment	3,395	1,996
3443	Nuclear radiation shielding	W	W
	Total casting metals	16,175	14,843

See footnotes at end of table.

Yugoslavia. The largest capacity increase by far was in the United States, which reflected the official opening of Cominco Alaska's Red Dog Mine. The largest expansion was MIM Holdings Ltd.'s (MIM) Hilton Mine (10,000 tons), which in 1989 was integrated into the Mount Isa complex in Queensland, Australia. Although Nuova Samim brought its large primary plant at Porto Vesme, Sardinia, back onstream in midyear with a capacity increase after being shut down for 11 months, permanent closures in Greece, the Republic of Korea, and Yugoslavia resulted in an insignificant net loss of smelter capacity worldwide (table 17).

Australia.—The Pancontinental-Outokumpu-Agip partnership started the Thalanga open pit in Queensland and continued development of the underground mine, expected to be in production in 1991 and eventually to replace the surface operation. Also in Queensland, MIM continued construction of its new, patented, 60,000-metric-ton-per-year Isasmelt plant scheduled to open in 1991. In New South Wales (NSW), Denehurst Ltd. continued development of the Currawong deposit, a satellite ore body to its Woodlawn open pit mine, expected to be operational in 1991 at a rate of 3,000 tons of lead per year. Reserves were estimated at 500,000 tons of complex base and precious-metal ore grading more than 13% lead. At Broken Hill, NSW, Pasminco Ltd. announced a modernization program to reduce mining and milling costs by 25% to 30% at its ZC Mine by increasing throughput from an additional 7-million-ton ore body to 2.5 million tons per year grading 8% lead and 10% zinc by 1992-93. At the Silver King project, near Mount Isa, Diversified Resources announced a preliminary reserve estimate of 712,000 tons grading 0.48% lead and 4.94% zinc. Enterprise Metals, a wholly owned subsidiary of CRA Ltd., announced a decision to develop the Peak Gold project in NSW near its Cobar Mine. The deposit reserves were estimated to be 3.9 million tons grading 1.3% and 1.5%, respectively, for lead and zinc. CRA also announced the discovery of a potentially significant ore body, amenable to open pit mining, estimated to be about 70 million tons grading 1% lead and 7% zinc approximately 250 kilometers northwest of Mount Isa. MIM acquired a 50% share of Metallgesellschaft's ISF plant at Duisburg in the Federal Republic of Germany, to which they

TABLE 10—Continued

U.S. CONSUMPTION OF LEAD, BY PRODUCT

(Metric tons)

SIC code	Product	1989	1990
	Metal products—Continued		
	Pipes, traps, other extruded products:		
15	Building construction	8,856	9,281
3443	Storage tanks, process vessels, etc.	962	(1)
	Total pipes, traps, other extruded products	9,818	9,281
	Sheet lead:		
15	Building construction	15,900	17,534
3443	Storage tanks, process vessels, etc.	(1)	(1)
3693	Medical radiation shielding	5,087	3,479
	Total sheet lead	20,987	21,013
	Solder:		
15	Building construction	3,909	4,472
341	Metal cans and shipping containers	762	552
367	Electronic components and accessories	4,092	4,040
36	Other electrical machinery and equipment	2,029	1,737
371	Motor vehicles and equipment	6,217	5,688
	Total solder	17,009	2,16,490
	Storage batteries:		
3691	Storage battery grids, post, etc.	552,308	571,187
3691	Storage battery oxides	459,847	448,450
	Total storage batteries	1,012,155	1,019,637
371	Terne metal: Motor vehicles and equipment	2,286	2,341
27	Type metal: Printing and allied industries	(3)	(3)
34	Other metal products[4]	4,564	3,812
	Total metal products	2,1,176,937	2,1,178,388
	Other oxides:		
285	Paint	W	W
32	Glass and ceramics products	W	W
28	Other pigments and chemicals	10,074	13,500
	Total other oxides	57,984	56,484
2911	Gasoline additives	(5)	(5)
	Miscellaneous uses	42,684	40,361
	Grand total	2,1,277,604	2,1,275,233

rRevised. W Withheld to avoid disclosing company proprietary data; included in appropriate totals.
[1]Included with "Building construction" to avoid disclosing company proprietary data.
[2]Data do not add to total shown because of independent rounding.
[3]Included with "Other metal products" to avoid disclosing company proprietary data.
[4]Includes lead consumed in foil, collapsible tubes, annealing, galvanizing, plating, and fishing weights.
[5]Included with "Miscellaneous uses" to avoid disclosing company proprietary data.

TABLE 11

U.S. CONSUMPTION OF LEAD, BY MONTH[1]

(Metric tons)

Month	1989r	1990
January	111,003	107,331
February	103,556	108,221
March	106,492	114,093
April	104,443	102,628
May	107,677	107,788
June	106,883	104,627
July	98,419	98,715
August	110,839	114,138
September	107,063	106,059
October	114,441	113,796
November	107,865	105,228
December	98,923	92,609
Total[2]	1,277,604	1,275,233

rRevised.
[1]Monthly totals include monthly reported consumption plus the prorated monthly distribution for companies that report on an annual basis only.
[2]Includes lead that went directly from scrap to fabricated products.

already ship some of the bulk concentrates produced at Mount Isa. Denehurst Ltd. revised reserve estimates for its base-and-precious-metals open pit mine in NSW to 3.58 million tons grading 2.4% lead, in effect extending its life for an additional 10 years.

Austria.—BBU-Metalle completed expansion and modernization of its 1963 round hearth, secondary smelter at Arnoldstein and installed a state-of-the-art Tonolli CX battery breaking system. Capacity was increased from 8,000 tons per year to 32,000 tons per year.

Canada.—Breakwater Resources Ltd. opened the country's only new lead producer in 1990, the underground Estrades Mine, primarily a zinc and copper mine, near Joutel, Quebec; the ore was milled at Noranda's Mattagami facility. Estrades' reserves were estimated to be 941,400 tons grading 10.7% zinc, 0.94% copper, and 0.92% lead. During the year, Breakwater also acquired all of the shares of Bathhurst Metals and its Caribou Mine in New Brunswick, but shut Caribou down in October rather than revamp the mill and further develop the mine to increase output, preferring to concentrate on its Estrades Mine and El Mochito Mine (Honduras) instead. Westminer Canada, a wholly owned affiliate of Western Mining of Australia, brought the Gays River underground mine in Nova Scotia, closed since 1981, back on-stream with an expected capacity of about 10,000 tons per year from ore grading about 4.5% lead. Curragh Resources completed a development plan for its Mount Hundere project in the Yukon Territory, estimating reserves of 3.94 million tons grading 4.1% lead and 12.8% zinc. The production plan was for 50,000 tons per year of 73% lead concentrate. Construction work on the mill and tailings dam began after the issuance of a C$130 million bond issue and negotiation of a C$55 million financing package for mine development. The mine was expected to come on-stream in late 1991 or early 1992. In northern British Columbia, Curragh continued to develop the huge Cirque deposit, planned for 1992 startup. Reserves were estimated to be 13 million tons of 14% combined lead and

TABLE 12

U.S. CONSUMPTION OF LEAD IN 1990, BY STATE[1]

(Metric tons)

State	Refined soft lead	Lead in antimonial lead	Lead in alloys	Lead in copper-base scrap	Total[2]
Arizona and California	42,840	32,057	6,506	—	81,402
Florida	3,871	5,818	—	—	9,689
Georgia	33,600	6,380	1,784	—	41,763
Illinois	29,474	41,055	1,124	915	72,568
Michigan	16,152	10,903	510	—	27,563
Missouri	11,102	16,487	—	—	27,588
Ohio	23,437	11,827	2,542	267	38,073
Pennsylvania	87,460	33,229	34,642	574	155,903
Texas	93,624	18,800	8,515	—	120,940
Alabama, Louisiana, Mississippi, Arkansas, Oklahoma	26,073	19,929	10,353	2,566	58,921
Delaware and New Jersey	45,204	6,903	2,669	280	55,057
Indiana, Kansas, Kentucky, Tennessee	258,579	65,184	35,270	599	359,632
North Carolina and South Carolina	44,823	30,406	10,820	—	86,048
Connecticut, Massachusetts, Rhode Island	4,475	17	—	—	4,492
District of Columbia, Maryland, Virginia, West Virginia	149	—	7	—	156
Idaho, Oregon, Washington	13,681	7,511	2,177	1,330	24,698
Maine, New Hampshire, New York, Vermont	23,462	10,862	8,420	19	42,761
Iowa, Minnesota, Nebraska, Wisconsin	25,144	27,932	14,237	666	67,978
Total[2]	783,147	345,297	139,573	7,216	1,275,233

[1]Includes lead that went directly from scrap to fabricated products.
[2]Data may not add to totals shown because of independent rounding.

TABLE 13

U.S. CONSUMPTION OF LEAD IN 1990, 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	66,523	64,617	20,395	7,216	158,751
Storage batteries	624,241	279,571	115,825	—	1,019,637
Other oxides	56,484	—	—	—	56,484
Miscellaneous[2]	35,899	1,109	3,353	—	40,361
Total	783,147	345,297	139,573	7,216	[3]1,275,233

[1]Includes lead that went directly from scrap to fabricated products.
[2]Includes gasoline additives to avoid disclosing company proprietary data.
[3]Data do not add to total shown because of independent rounding.

TABLE 14

STOCKS OF LEAD AT CONSUMERS AND SECONDARY SMELTERS IN THE UNITED STATES, DECEMBER 31

(Metric tons, lead content)

Year	Refined soft lead	Lead in antimonial lead	Lead in alloys	Lead in copper-base scrap	Total
1986	47,589	30,442	5,524	269	83,824
1987	55,278	27,959	5,185	164	88,586
1988	50,850	34,108	4,756	151	89,865
1989[r]	48,592	28,960	4,564	239	82,355
1990	46,096	35,079	5,109	219	86,503

[r]Revised.

zinc with a lower grade reserve base of an additional 20 million tons. Development continued at Curragh's Vangorda and Grum deposits in the Yukon, planned open pits intended to maintain the nearby Faro Mine and mill production levels of 120,000 tons per year of lead and 200,000 tons per year of zinc when that operation begins to tail off in 1991.

Canadian metal production suffered during the year when the labor force struck the Bathurst Mining and Smelting Co.'s smelter-refinery from July 22 through yearend; management continued to operate the facility at only 25% of capacity. There was no settlement by yearend when the company retracted its "final" offer. Also affecting production was Cominco Ltd.'s decision to shut down and reevaluate its new, in 1989, 160,000-ton-per-year QSL smelter at Trail, British Columbia, in March owing to feed process and mechanical problems. Lead production continued at about 80% of the old smelter capacity of 125,000 tons per year through yearend. The company had closed its Trail "feeder" in British Columbia, the Sullivan Mine at Kimberley, in January, but reopened it in November after the completion of a C$11 million development program. The new smelter, however, was not expected to reopen until well into 1991, or later if major design modifications became necessary.

France.—Berzelius (Federal Republic of Germany) and Société de Traitements Chimiques des Metaux (STCM) signed a cooperative agreement on developing environmental technology for secondary lead plants, with the former to acquire a minority interest in the latter. Berzelius' secondary plant at Braubach, Federal Republic of Germany, has a capacity of 45,000 tons per year, while STCM's two plants in France total 50,000 tons per year capacity. Ste. GAST started construction of a new secondary plant, 20,000-ton-per-year capacity, to open in 1991 at Brenoville, Pont Ste. Maxence.

TABLE 15

AVERAGE MONTHLY AND ANNUAL QUOTED PRICES OF LEAD[1]

(Cents per pound)

Month	1989		1990	
	North American producer price	London Metal Exchange	North American producer price	London Metal Exchange
January	40.17	30.62	39.81	32.08
February	37.01	28.17	41.84	35.31
March	35.07	26.69	54.11	48.05
April	35.02	27.55	48.73	37.86
May	36.34	29.15	45.21	37.41
June	39.15	30.16	45.16	37.98
July	40.29	31.32	50.13	39.67
August	41.75	31.81	50.36	39.70
September	43.63	33.00	49.47	38.00
October	43.63	34.07	46.15	34.47
November	41.26	31.39	42.75	31.77
December	38.89	32.22	38.52	28.30
Average	39.35	30.63	46.02	37.05

[1]Metals Week. Quotations for the United States on a nationwide, delivered basis. LME cash average.

TABLE 16

WORLD SUPPLY AND DEMAND

(Thousand metric tons)

Year	Mine production	Primary demand[1]	Apparent consumption	Stock changes (ILZSG)	Refinery production	Production surplus/deficit
1978	3,395		5,595	-71	5,524	
1979	3,472		5,650	+62	5,712	
1980	3,470	60%	5,364	+66	5,430	+91
1981	3,366		5,337	-7	5,330	
1982	3,448		5,174	+41	5,215	
1983	3,357		5,303	-19	5,284	
1984	3,269		5,582	-113	5,469	
1985	3,431	57.6%	5,587	+54	5,641	
1986	3,345		5,603	-52	5,551	
1987	3,425		5,681	+37	5,718	-174
1988	3,430	55.5%	5,856	-6	5,850	
1989[p]	3,368	53.5%	6,062	-75	5,987	
1990[e]	3,367		5,896	+46	5,942	+46
Total	44,143	58%	72,690	-37	72,653	[2]-37

2.3% per year average growth

[e]Estimated. [p]Preliminary.
[1]Recoverable content (95%) of mine production (lead in concentrate) divided by apparent consumption.
[2]Yearend stocks 1977=468; yearend stocks 1990=431 (estimated; producer, consumer, merchant, LME).

TABLE 17

WORLD PRIMARY PRODUCTION CAPACITY, ANNUAL

(Thousand metric tons)

	1989			1990		
	Mine	Smelter	Refinery	Mine	Smelter	Refinery
North America:						
Canada	370	230	230	381	230	230
Mexico	210	300	320	210	300	320
United States	680	r525	r605	759	525	605
Other	10	—	—	10	—	—
Total	1,270	r1,055	r1,155	1,360	1,055	1,155
South America:						
Peru	210	115	110	212	115	110
Other	85	140	140	88	140	140
Total	295	255	250	300	255	250
Europe:						
Belgium	—	90	125	—	90	125
Bulgaria[e]	100	130	120	100	130	120
France	2	190	150	1	190	150
Germany, Federal Republic of	7	190	250	7	210	270
Italy	18	115	100	18	130	100
Poland	50	90	90	50	90	90
Spain	92	85	85	72	85	85
U.S.S.R.[e]	550	635	675	550	635	675
United Kingdom	—	50	160	—	50	160
Yugoslavia	116	155	155	112	130	155
Other	220	150	110	202	130	90
Total	1,155	1,880	2,020	1,112	1,870	2,020
Africa:						
Morocco	74	65	65	74	65	65
Namibia	40	75	75	40	75	75
South Africa, Republic of	102	—	—	102	—	—
Other	24	30	15	24	30	15
Total	240	170	155	240	170	155
Asia:						
China[e]	350	r250	r250	370	250	250
Japan	30	270	285	28	275	290
North Korea[e]	85	90	70	85	90	70
Other	100	95	150	100	80	135
Total	565	r705	r755	583	695	745
Oceania: Australia	575	445	235	590	445	235
World total	4,100	r4,510	r4,570	4,185	4,490	4,560

[e]Estimated. rRevised.

Sources: International Lead Zinc Study Group, U.S. Bureau of Mines estimates, and other published sources.

TABLE 18

LEAD: WORLD MINE PRODUCTION OF LEAD IN CONCENTRATES, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Algeria[e]	3.6	3.6	r3.5	r3.2	3.2
Argentina	26.9	26.1	28.5	26.7	27.0
Australia	447.7	489.1	465.5	495.0	[3]563.0

See footnotes at end of table.

TABLE 18—Continued

LEAD: WORLD MINE PRODUCTION OF LEAD IN CONCENTRATES, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Austria	4.7	5.2	2.3	1.6	1.5
Bolivia	3.1	9.0	12.5	15.7	18.6
Brazil	13.6	11.6	14.3	16.1	16.0
Bulgaria[e]	r65.0	r60.0	r60.0	[3]57.0	55.0
Burma	r6.6	r4.6	6.0	5.2	4.4
Canada	349.3	413.7	368.4	275.0	[3]236.2
Chile	1.5	.8	1.4	1.2	[3]1.1
China	227.0	r267.0	312.0	341.0	[3]315.0
Colombia	.2	.2	([4])	.4	.3
Congo (Brazzaville)	e1.4	e1.4	1.8	1.0	1.0
Czechoslovakia	2.9	2.8	e2.8	2.7	2.6
Ecuador[e]	.2	.2	.2	.2	.2
Finland	2.0	e2.9	1.9	2.6	2.5
France	2.5	2.2	2.0	1.1	1.2
Federal Republic of Germany: Western states	16.7	18.8	14.3	r e7.3	7.0
Greece	20.9	20.6	23.1	22.7	22.5
Greenland	16.2	20.5	23.1	24.1	18.0
Honduras	12.6	5.0	16.9	e10.0	10.0
India	37.6	36.7	30.5	26.5	28.0
Iran	22.0	20.0	17.0	10.5	12.0
Ireland	36.4	33.8	32.5	e32.1	35.3
Italy	11.1	12.0	16.5	17.0	15.0
Japan	40.3	27.9	22.9	18.6	[3]18.7
Kenya[e 5]	.6	.5	.6	.6	.6
Korea, North[e]	110.0	110.0	110.0	r120.0	120.0
Korea, Republic of	11.9	14.0	14.5	16.5	15.5
Mexico	182.7	177.2	171.3	163.0	[3]179.9
Morocco	76.2	75.7	72.2	67.3	67.0
Namibia	37.5	33.0	37.2	23.7	23.0
Nigeria	e.1	.1	e.1	([6])	—
Norway	3.4	3.1	2.8	3.2	3.0
Peru	194.4	204.0	149.0	192.2	[3]189.0
Poland[e]	r31.2	r37.5	r40.6	r42.0	33.0
Romania[e]	34.3	36.3	30.2	[3]37.7	35.0
South Africa, Republic of	97.8	93.6	90.2	78.2	[3]69.4
Spain	79.6	r83.3	74.7	62.6	60.3
Sweden	88.9	90.4	91.6	89.0	90.0
Thailand	26.3	23.5	29.5	25.1	[3]22.2
Tunisia	1.9	3.5	3.7	2.7	2.7
Turkey	r7.5	r7.3	9.4	r e10.5	10.5
U.S.S.R.[e 7]	r520.0	r510.0	r520.0	r500.0	450.0
United Kingdom	.6	.7	1.2	e.8	.6
United States	353.1	318.7	394.0	420.2	[3]495.2
Yugoslavia	r103.0	r94.0	95.0	86.0	[3]73.0
Zambia[8]	r12.2	r12.5	12.1	r e12.0	12.0
Total	r3,345.2	r3,424.6	3,429.8	3,367.8	3,367.2

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through June 14, 1991.

[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]Less than 1/2 unit.

[5]Reported for 1987 and 1988 as galena (not further specified), assumed 78% Pb.

[6]Revised to zero.

[7]Estimated by International Lead Zinc Study Group Secretariat.

[8]Pb content of ore.

TABLE 19

LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Argentina:					
Primary	15.7	16.2	14.0	13.0	14.0
Secondary	15.0	16.0	15.0	13.0	13.0
Total	30.7	32.2	29.0	26.0	27.0
Australia:					
Primary	156.2	201.7	168.0	193.0	[2]212.0
Secondary[e]	14.8	15.0	15.0	15.0	15.0
Total[e]	171.0	216.7	183.0	[r]208.0	227.0
Austria:					
Primary	6.0	6.8	9.0	8.8	8.8
Secondary	19.0	16.0	16.0	15.2	15.2
Total	25.0	22.8	25.0	24.0	24.0
Belgium:					
Primary	64.5	71.1	83.2	72.7	75.0
Secondary	33.8	36.9	43.4	36.8	45.0
Total[3]	98.3	108.0	126.6	109.4	120.0
Bolivia: Primary	.2	.2	(4)	(4)	(4)
Brazil:					
Primary	32.7	29.8	29.5	33.5	33.0
Secondary	52.0	58.4	68.7	53.3	55.0
Total	84.7	88.2	98.2	86.8	88.0
Bulgaria:[e]					
Primary	[r]95.0	[r]88.0	[r]88.0	[r]89.0	89.0
Secondary	17.0	17.0	17.0	10.0	10.0
Total	[r]112.0	[r]105.0	[r]105.0	[r]99.0	99.0
Burma: Primary	5.4	4.0	4.4	3.4	2.8
Canada:					
Primary	169.9	139.5	178.6	157.3	125.8
Secondary	87.7	91.2	89.4	87.2	98.3
Total[3]	[r]257.7	230.7	268.1	244.5	224.0
China:[e]					
Primary	200.0	200.0	200.0	[r]245.0	235.0
Secondary	40.0	[r]45.0	45.0	[r]55.0	55.0
Total	240.0	[r]245.0	245.0	[r]300.0	290.0
Colombia: Secondary[e]	4.0	4.0	4.0	3.5	3.5
Czechoslovakia: Secondary	23.6	26.0	26.0	26.0	25.5
Denmark: Secondary	.6	—	—	—	—
Finland: Secondary[e]	[2]1.2	1.2	2.0	2.0	2.0
France:					
Primary	132.0	138.8	146.5	149.3	150.0
Secondary	98.4	107.1	109.2	118.1	110.0
Total	230.4	245.9	255.7	267.4	260.0
Germany, Federal Republic of:					
Eastern states:[e]					
Primary	15.5	17.1	19.2	18.2	18.0
Secondary	29.0	32.0	35.8	33.8	30.0
Total	44.5	49.1	55.0	52.0	48.0
Western states:					
Primary	182.1	167.6	176.6	181.8	180.5
Secondary	184.5	172.8	168.5	168.0	168.0
Total	366.6	340.4	345.1	349.8	348.5
Greece: Primary	19.3	2.7	15.1	7.0	7.2
Guatemala: Secondary	.1	.1	.1	.2	.2

See footnotes at end of table.

TABLE 19—Continued

LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Hungary: Secondary[e]	0.1	0.1	0.1	0.1	0.1
India:					
Primary	19.9	20.7	18.8	21.3	22.0
Secondary	11.3	12.1	9.9	13.5	13.5
Total[3]	31.2	32.8	28.7	34.7	35.5
Iran: Secondary[e]	8.0	10.0	10.0	10.0	10.0
Ireland: Secondary	10.2	9.6	11.7	r e12.0	12.0
Italy:					
Primary	29.3	62.3	72.2	74.2	72.0
Secondary	101.7	111.4	111.6	112.0	100.0
Total	131.0	173.7	183.8	186.2	172.0
Jamaica: Secondary[e]	1.0	1.0	1.0	1.0	1.0
Japan:					
Primary	232.7	218.8	217.7	207.7	2204.9
Secondary	128.7	119.5	122.2	125.6	2124.1
Total[3]	r361.5	338.3	340.0	333.4	2329.0
Kenya: Secondary[e]	2.0	2.0	2.0	1.0	1.0
Korea, North: Primary[e]	95.0	95.0	95.0	95.0	95.0
Korea, Republic of:[e]					
Primary	32.1	52.5	46.0	36.8	38.0
Secondary	27.5	30.0	44.0	44.1	45.0
Total	59.6	82.5	90.0	80.9	83.0
Malaysia: Secondary	r12.0	r9.0	15.0	16.0	15.2
Mexico:					
Primary	182.0	177.0	171.1	162.5	179.0
Secondary[e]	33.0	235.0	35.0	35.0	35.0
Total	215.0	212.0	206.1	197.5	214.0
Morocco:					
Primary	60.0	62.5	68.4	63.7	64.0
Secondary[e]	2.0	2.0	2.0	2.0	2.0
Total[e]	62.0	64.5	r70.4	r65.7	66.0
Namibia: Primary	40.0	40.6	44.4	44.2	44.0
Netherlands: Secondary[e]	r36.0	r40.0	r39.0	r43.0	35.0
New Zealand: Secondary[e]	4.0	23.6	3.0	5.0	5.0
Nigeria: Secondary	1.0	.3	e.5	e.5	.3
Pakistan: Secondary[e]	1.0	2.0	2.0	2.0	2.5
Peru:					
Primary	66.4	71.3	56.5	73.4	69.3
Secondary[e]	5.0	5.0	5.0	5.0	5.0
Total[e]	71.4	76.3	r61.5	r78.4	74.3
Philippines: Secondary[e]	7.0	7.0	7.0	7.0	7.0
Poland:					
Primary[e]	63.3	64.5	61.0	61.0	57.0
Secondary[e]	25.0	25.0	r30.0	20.0	22.0
Total	88.3	89.5	91.0	81.0	79.0
Portugal: Secondary[e]	6.0	6.5	6.5	6.5	7.0
Romania:[e]					
Primary	36.0	233.2	38.0	45.0	40.0
Secondary	15.5	10.0	10.0	15.0	10.0
Total	51.5	43.2	48.0	60.0	50.0
South Africa, Republic of: Secondary	40.5	38.3	37.4	36.9	34.6

See footnotes at end of table.

TABLE 19—Continued

LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Spain:					
Primary	88.0	71.4	[e]68.8	68.3	70.0
Secondary	42.0	51.3	[e]52.0	45.0	50.0
Total	130.0	122.7	[e]120.8	113.3	120.0
Sweden:					
Primary	49.2	61.2	57.8	48.7	47.5
Secondary	27.8	30.2	26.9	22.7	22.1
Total[3]	[r]76.9	91.4	84.7	71.4	69.6
Switzerland: Secondary	2.5	2.5	1.5	[e]1.4	1.4
Taiwan: Secondary[e]	53.5	66.4	67.3	[r]58.2	57.6
Thailand: Secondary	9.1	11.4	15.6	18.7	[2]15.9
Trinidad and Tobago: Secondary[e]	2.0	1.8	1.8	1.8	1.8
Tunisia:[e]					
Primary	[2]2.2	2.2	2.2	2.2	2.2
Secondary	.5	.5	.5	.5	.5
Total	2.7	2.7	2.7	2.7	2.7
Turkey:[e]					
Primary	7.0	7.0	7.3	[r]6.3	8.4
Secondary	2.6	3.0	3.7	[r]2.7	3.6
Total	9.6	10.0	11.0	[r]9.0	12.0
U.S.S.R.:[e]					
Primary	485.0	475.0	447.0	[r]465.0	420.0
Secondary	270.0	275.0	280.0	280.0	280.0
Total	755.0	750.0	727.0	[r]745.0	700.0
United Kingdom:					
Primary	156.1	137.5	172.2	156.5	160.0
Secondary	172.5	200.7	201.6	193.5	200.0
Total	328.6	338.2	373.8	350.0	360.0
United States:					
Primary	370.3	373.6	392.1	396.5	[2]403.7
Secondary	624.8	710.2	736.4	891.3	[2]922.9
Total	995.1	1,083.8	1,128.5	1,287.8	[2]1,326.6
Venezuela: Secondary[e]	16.0	17.0	[r]18.0	17.0	17.0
Yugoslavia:					
Primary	75.0	76.4	70.9	[r e]78.2	60.0
Secondary	38.0	36.0	[e]39.0	[r e]19.0	22.0
Total	113.0	112.4	109.9	[r e]97.2	[2]82.0
Zambia: Primary[5]	[r]6.8	[r]7.6	6.3	[r e]6.0	6.0
Grand total[3] of which:	[r]5,551.4	[r]5,717.7	5,850.4	5,986.6	5,941.7
Primary	[r]3,190.9	[r]3,193.7	3,246.0	3,284.5	3,214.0
Secondary	[r]2,360.5	[r]2,524.1	2,604.4	2,702.1	2,727.7

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through June 14, 1991. 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]Data may not add to totals shown because of independent rounding.

[4]Less than 1/2 unit.

[5]Data are for fiscal year beginning Apr. 1 of that stated.

Germany, Federal Republic of.—Berzelius Metallhütten GmbH, the operating arm of Metallgesellschaft, opened the new QSL plant at Stolberg (Binsfeldhammer) late in the year. Rated at a capacity of 100,000 tons per year, it replaced an existing smelter rated at 80,000 tons per year. Earlier in the year Metallgesellschaft had signed an agreement with the State-owned Eastern State company BHKF for replacement of its Freiberg smelter with a QSL plant. Berzelius also completed plans

to modify and expand its ISF plant at Duisburg, which can process both primary and secondary material, by mid-1991. MIM was buying a 50% stake in that plant in order to increase its involvement worldwide in metal production; it already ships some of the bulk concentrates from its Mount Isa Mine in Queensland to Duisburg.

Honduras.—American Pacific Mining, a wholly owned U.S. subsidiary of Breakwater Resources Ltd. (Canada), continued upgrading the access and haulage systems at the El Mochito Mine in order to be more selective and yield higher average-grade ores. They also completed a new tailings facility to extend the mine's life at least 10 years. Breakwater assumed full control in April and planned to continue exploration to extend the ore bodies and raise mill throughput to 2,000 tons per day in 1991. Ore reserves were estimated to be 5.5 million tons grading 1.6% lead and 6.85% zinc.

India.—Hindustan Zinc Co. Ltd. continued development of its open pit at Rampura-Agucha, Rajasthan, expected to open in 1991 and to be producing 8,000 tons per year of lead by 1992. The company continued on schedule with construction of its new ISF servicing smelter at Chanderiya, Rajasthan, expected to start up in mid-1991 and reach capacity of 35,000 tons per year in 1993. About 40% of the feed was expected to come from Rampura-Agucha and Hindustan's underground Ambamata Mine at Gujrat, also under development, and more than one-half to be imported, with zinc capacity estimated at 70,000 tons per year. A new secondary plant, expected to open in 1991 at 6,000-ton-per-year capacity, was under construction on the west coast by the Rohit Pulp and Paper Mills Co.

Iran.—Four active mines were undergoing expansion projects to yield an additional total capacity of 18,000 tons per year between 1991 and 1994. These mines, Angouran open pit in the north at Zandjan, Emarat open pit at Khomain in the central province of Esphahan, Ahangzan open pit at Hamadaz in the west, and Nakhlak underground at Yazd in central Iran, were expected to reach full production in that phasing order.

Ireland.—Conroy Petroleum Ltd. completed the feasibility study for its proposed Galmoy Mine and reportedly estimated reserves at 6.2 million tons grading 11.31% zinc and 1.12% lead. The company applied for permits to develop the underground ore body through a 13% surface decline ramp and planned to produce 2,000 to 5,000 tons per year of lead starting in 1992 or 1993. Tara Mines Ltd. was in the process of completely upgrading the equipment for its underground mine at Navan, County Meath, in order to reach the original planned production of 38,000 tons of lead per year by 1991 or 1992.

Korea, Republic of.—Korea Zinc Co. Ltd. neared completion of its new 80,000-ton-per-year QSL smelter and refinery at Onsan, on schedule to open in 1991. Korea Mining and Smelting Co. Ltd. closed its 15,000-ton-per-year primary smelter and refinery at Changhang, a result of insurmountable environmental problems.

Malaysia.—Metals Reclamation Industrial Snd. Bhd. started a plant relocation and capacity upgrade from 16,000 to 24,000 tons per year at its secondary plant at Selayang, to be fully operational by 1992.

Pakistan.—Additional lead-zinc deposits were discovered and evaluated in the Baluchistan region, where previous explorations had identified a 10-million-ton ore body near Khudzar. One at Duddar was estimated to contain 0.66 million tons grading about 3% lead and 15.5% zinc. Another at Surmain was estimated to contain 2.93 million tons grading 6.5% combined lead-zinc.

United Kingdom.—Britannia Refined Metals, a wholly owned subsidiary of MIM, neared completion of its new 40,000-ton-per-year secondary Isasmelt furnace and refinery, scheduled to replace the 10,000-ton-per-year conventional plant by mid-1991. The new complex at Northfleet, Kent, will also have a state-of-the-art Tonolli CX battery breaking system, which was being installed by Engitec Impianti of Italy. Anglesey Mining Ltd., a subsidiary of Imperial Metals Corp., initiated shaft sinking at its planned Parys Mountain underground mine in North Wales. Bulk sampling was initiated to further evaluate the deposit, for which the preliminary estimate was that it could be producing 300,000 tons per year of ore, primarily zinc and copper ore but containing about 5,000 tons of lead, by 1992 or 1993.

Yugoslavia.—At yearend, Ro Rudniki Svinca in Topilnica closed its 26,000-ton-per-year primary smelter at Mezica, Slovenia, which had been producing refined lead since 1906. The company also started closure of the plant's captive mine at the same location, to be completed in stages by 1995. SOUR Hemijska Industrija completed closure of its Brskovo Mine at Mojkovac, Montenegro, a process started in 1987. The closures are to be more than offset by Zletovo-Sasa's 10,000-ton-per-year expansion project underway at its Toranica Mine and Zorka-Sabac's 2,000-ton-per-year expansion project underway at its mine at Sastavci-Kizevac. Both underground mines were expected to be at full capacity by 1992.

Current Research

In recent years, research in lead use worldwide has focused strongly on improvements to the lead-acid battery, through all its applications, in terms of safety, capacity, longevity, durability, dependability, and manufacturing-marketing economics, including plant robotics. In 1990, two researchers at the California Institute of Technology, under contract to the National Aeronautics and Space Administration, discovered one potential solution to overcoming the most common failure mode in deep drawdown cycle applications, paste softening and, therefore, accelerated disintegration of the positive plate. As the active material paste slakes, the whole cell can become inactive, or the paste can fall to the bottom and short against the negative plate. Exposure of the grid can then lead to abnormal corrosion, producing an insulating layer and higher resistance. The softening can also be manifested by grid "growth" (bulking) causing separation of the positive active paste, causing loss of capacity and leading to premature, but not immediate, failure. Together with overall lowered conductivity, plate utilization during discharge is also reduced. The solution discovered was to mix randomly oriented, very thin and short, lead-coated glass fibers into the paste prior to grid application, which also improved the structural integrity of the plate upon curing. The compatible conductive fibers increase charge uniformity of the plate, preventing electrical isolation and improving paste utilization during discharge. Fibers 0.004 inch thick coated to 0.010 inch thick and cut to 0.100 inch in length displace about 2% of the

lead monoxide paste volume. The approximate 5% weight gain is then offset by increasing grid spacing. Because the lead on the fiber is also charged during formation of the battery, a more thorough electrical and mechanical interface with the active material is established without any loss of structural integrity.[2]

One of the most novel, recently developed uses of lead with continuing developmental applications is for building foundations isolated against severe horizontal earthquake acceleration "shocks." Because of lead's unique softness and density properties, it is ideal for use in dampers under midrise buildings of about four to six stories in commonly severe earthquake-prone areas where the common shock frequency of horizontal accelerations is between 1 and 2 seconds, which is about the resonant frequency of such structures. Harmonic attenuation causes these buildings to shake themselves apart under such conditions. Base-isolation systems commonly consist of large steel springs to support the building weight, dampened by steel-rubber "sandwiches." However, laboratory testing of several cast-lead shapes on computer-driven shaking tables has proven conclusively that lead dampers absorb significantly greater amounts of energy per cycle. Each U-shaped damper, determined to be the optimal form in this application, weighs 132 pounds and can dampen 121 square feet of ground floor in a typical midrise structure. This method for earthquake protection has been accepted by the Japan Institute of Architects, and a 500-page design and construction manual has been written. Two prototype buildings in Japan, which are currently being monitored, were recently completed. At yearend, several other buildings were being planned in Japan, including two office buildings, one of which called for a critical computer facility on the top floor that cannot tolerate disruptions.[3]

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, including batteries, were published in quarterly issues of Leadscan, published by the Lead Development Association, London, United Kingdom.

OUTLOOK

Although domestic demand for lead grew on average about 4% per year from 1985 to 1989 (table 2), this rate cannot be sustained in the future because some end uses of lead will certainly be curtailed or eliminated entirely by legislation or regulation. One of the current pollution prevention strategies, known as source reduction, will probably reduce the use of lead in nongrowth markets such as solders, paints, and coatings (already eliminated in interior house paints), ceramics, gasoline additives, containers or other packaging (including inks or dyes, especially where food is concerned), and cosmetics. Some reduction of lead per battery unit can also be anticipated as the technology continues to advance. As a result, U.S. annual growth in lead demand will probably fall within a range of 0.5% to 1.5% per year in the decade of the 90's, averaging about 1%, as the storage battery sector becomes even more dominant. The lower growth rate can certainly be expected if source reduction is applied to the ammunition sector, currently the second largest end use. The higher growth rate could be attained if the use of lead-acid batteries for peak-power, load-leveling applications becomes widely accepted for households and commercial facilities, and/or there is a moderate demand for private general purpose electric cars. The latter two conditions will probably not prevail until the end of the century.

World demand for lead grew at an average rate of more than 2% through 1989 from the low recession year of 1982 (table 16). Lower growth U.S. demand, which is currently 22% of the total, will undoubtedly lower the overall world growth rate somewhat in the future. However, storage battery use in all applications will undoubtedly grow faster in the rest of the world than in the United States as some poorer nations increase their living standards while they grow with the world economy. It is estimated that currently about 60% of world demand is for batteries, compared with about 80% in the United States, and is forecast to reach about 70% by the end of the decade as the rest of the world's supply-demand pattern is rationalized by environmental concerns. Therefore, the most probable world growth until the end of the century is forecast to average about 1.5% per year.

The attendant worldwide production outlook is interrelated with anticipated structural changes. Because of large capital demand and high costs associated with environmental concerns, large production surpluses in the near term are not likely. High realized producer prices are critical to profitably amortizing the large improvement expenditures anticipated over the next 10 years. However, this will continue to be partially subjected to developing situations in zinc and silver markets because of the geologic relationships of the three metals in the primary production sector. The trend of increasing secondary share of production and consumption exhibited in tables 19 and 16, respectively, is expected to continue until optimum recycling is achieved. Complex multinational, multifaceted realignments and restructuring, including divestitures, among world lead producers and product manufacturers are expected to continue through the rest of the century. Most noticeable will be investments of primary producers, in many cases through acquisitions and mergers, in secondary lead production to protect existing market share.[4]

[1]International Lead and Zinc Study Group (London). Lead and Zinc Statistics. Monthly Bull., v. 32, No. 3, Mar. 1992.
[2]National Aeronautics and Space Administration Contract No. NAS 7-918. NASA Tech Briefs, v. 15, No. 1, Jan. 1991, p. 20.
[3]Goodwin, F. E., Vice Pres., International Lead-Zinc Research Organization, Inc. (ILZRO), Research Triangle Park, NC. New Opportunities for Lead. Presentation at 63d Annual Lead Industry Association Meeting., Apr. 25, 1991, Washington, DC.

Takayama, M., A. Wada, H. Akiyama, and H. Tada. Feasibility Study on Base-Isolated Buildings. Paper in Proceedings of Ninth World Conference on Earthquake Engineering. Tokyo-Kyoto, Japan, v. 5, 1988, p. 669.
[4]Woodbury, W. Lead. Ch. in BuMines Minerals Yearbook, 1989.

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TABLE 20

PRODUCTION AND SHIPMENTS OF LEAD PIGMENTS[1] AND OXIDES IN THE UNITED STATES

(Metric tons unless otherwise specified)

Product	1989				1990			
	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	78,733	73,000	81,684	$82,655,677	85,855	79,717	78,958	$65,010,852
Leady oxide	472,112	448,507	NA	NA	453,076	430,422	NA	NA
Total[3]	550,845	521,507	NA	NA	538,933	510,140	NA	NA

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 21

U.S. IMPORTS FOR CONSUMPTION OF LEAD PIGMENTS AND COMPOUNDS, BY KIND

Kind	Quantity (metric tons)	Value (thousands)
1989		
White lead carbonate	191	$240
Red and orange lead	533	480
Chrome yellow and molybdenum orange pigments and lead-zinc chromates	4,295	8,578
Litharge	9,531	7,744
Leady litharge	1	1
Glass frits (undifferentiated)	6,219	9,987
Total	20,770	27,030
1990		
White lead carbonate	72	120
Red and orange lead	212	298
Chrome yellow and molybdenum orange pigments and lead-zinc chromates	15,146	18,573
Litharge	—	—
Leady litharge	183	182
Glass frits (undifferentiated)	6,552	11,358
Total	22,165	[1]30,530

[1]Data do not add to total shown because of independent rounding.
Source: Bureau of the Census.

TABLE 22

U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ore and concentrates (lead content):				
Belgium	1,114	$345	17,346	$9,492
Brazil	—	—	4,718	3,061
Canada	38,706	12,773	19,484	12,421
India	3,959	1,764	9,511	4,931
Italy	—	—	1,867	1,685
Japan	1,646	759	2,898	1,015
Korea, Republic of	733	308	—	—
Mexico	944	303	101	31
Netherlands	109	58	—	—

See footnotes at end of table.

TABLE 22—Continued

U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ore and concentrates (lead content)—Continued				
Spain	7,788	$6,383	—	—
Taiwan	748	243	—	—
U.S.S.R.	485	303	—	—
United Kingdom	441	125	632	$713
Other	365	152	43	20
Total	57,038	23,516	56,600	33,369
Ash and residues (lead content):				
Belgium	9,560	5,221	11,656	6,895
Brazil	—	—	889	241
Canada	18	19	2	4
France	—	—	69	188
Germany, Federal Republic of	179	200	37	617
India	68	18	86	81
United Kingdom	125	140	14	57
Other	10	14	11	14
Total[1]	9,960	5,612	12,765	8,096
Unwrought lead and lead alloys (lead content):				
Australia	87	133	—	—
Belgium	25	61	28	69
Brazil	—	—	96	206
Canada	4,017	3,500	7,286	6,647
Chile	250	280	283	258
China	978	776	19	32
Dominican Republic	7	6	19	18
Germany, Federal Republic of	19	30	39	52
Haiti	65	233	69	109
Hong Kong	108	100	320	374
Indonesia	18	18	17	21
Israel	3,377	2,579	1,934	1,820
Italy	29	49	3,004	3,354
Japan	1,619	1,873	4,049	5,648
Korea, Republic of	4,384	4,777	14,488	15,321
Malaysia	3,005	2,114	3,720	4,801
Malta	3	13	28	38
Mexico	689	660	145	191
Netherlands	1,597	1,774	2,826	2,366
Peru	80	149	23	47
Philippines	60	79	21	19
Singapore	4,010	3,409	5,623	5,021
South Africa, Republic of	9	54	—	—
Sudan	170	169	313	263
Taiwan	3,518	6,312	11,553	11,229
Trinidad and Tobago[2]	159	100	17	18
United Kingdom	127	575	1,133	910
Other	102	268	172	250
Total[1]	28,512	30,091	57,226	59,080
Wrought lead and lead alloys (lead content):				
Antigua	18	$25	—	—

See footnotes at end of table.

TABLE 22—Continued

U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Wrought lead and lead alloys (lead content)—Continued				
Argentina	6	$24	15	$20
Australia	7	73	14	107
Bahamas	—	—	50	79
Barbados	10	51	1	9
Belgium	11	33	108	287
Bermuda	5	7	—	—
Brazil	—	—	57	148
British Virgin Islands	10	8	4	3
Canada	1,994	2,748	1,362	3,136
Chile	2	18	8	37
Colombia	29	111	30	75
Dominican Republic	4	25	24	45
Ecuador	27	63	4	8
Egypt	5	2	51	222
Finland	18	100	1	7
France	62	430	31	138
Germany, Federal Republic of	516	808	214	586
Guatemala	10	35	5	15
Haiti	21	72	24	89
Hong Kong	115	410	162	407
India	121	231	255	181
Israel	37	164	67	177
Italy	19	119	1,126	2,088
Jamaica	10	24	—	—
Japan	312	1,255	336	2,821
Korea, Republic of	61	329	319	781
Malta	12	83	(3)	21
Mexico	1,110	2,999	1,527	5,301
Netherlands	193	428	112	352
Philippines	34	223	30	142
Saudia Arabia	49	145	48	216
Singapore	59	829	38	268
Spain	167	747	128	219
Sweden	14	94	—	—
Taiwan	58	240	214	679
Thailand	21	267	38	306
United Arab Emirates	5	7	—	—
United Kingdom	148	402	134	333
Venezuela	23	102	88	57
Other	42	382	131	563
Total[1]	5,365	14,113	6,759	19,923
Grand total[1]	100,875	73,332	133,349	120,468
Scrap (gross weight):				
Bahamas	380	45	127	129
Belgium	1,173	291	87	34
Brazil	4,559	1,550	2,512	1,111
Canada	10,646	4,658	34,497	11,190
Chile	105	10	—	—

See footnotes at end of table.

TABLE 22—Continued

U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Scrap (gross weight)—Continued				
China	3,054	$703	3,507	$1,472
France	549	146	640	221
Germany, Federal Republic of	1,618	363	4,551	1,629
Honduras	50	5	—	—
Hong Kong	—	—	492	440
India	5,768	2,623	1,989	702
Indonesia	—	—	1,394	678
Ireland	—	—	198	131
Italy	—	—	511	61
Japan	1,296	4,060	1,135	1,347
Korea, Republic of	3,655	4,601	2,301	2,324
Mexico	10,755	2,854	9,391	4,427
Netherlands	3,010	728	94	47
Netherlands Antilles	89	46	6	27
Panama	96	26	86	23
Philippines	26	5	44	190
Saudi Arabia	1,573	288	(3)	3
Singapore	272	159	644	541
South Africa, Republic of	877	377	1,536	1,235
Spain	6,155	690	858	1,962
Taiwan	997	654	3,369	1,808
Thailand	—	—	220	119
Trinidad and Tobago[2]	—	—	291	59
United Arab Emirates	91	21	—	—
United Kingdom	2,232	886	4,804	1,717
Venezuela	739	174	81	45
Other	144	202	139	264
Total[1]	59,909	26,165	75,507	33,934

[1]Data may not add to totals shown because of independent rounding.
[2]Data for 1989 was listed for "Trinidad" only; correct country title is as listed.
[3]Less than 1/2 unit.
Source: Bureau of Census.

TABLE 23

U.S. EXPORTS OF LEAD[1]

Year	Blocks, pigs, anodes, etc.				Wrought lead and lead alloys				Scrap (gross weight)		Ash and residues[5]	
	Unwrought[2]		Unwrought alloys		All forms, including foil and wire[3]		Powder and flakes[4]					
	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)
1988	6,413	$6,196	1,133	$1,893	5,848	$7,582	200	$248	81,910	$23,212	15,483	$8,808
1989[6]	23,787	25,909	4,725	4,182	5,053	12,874	312	1,239	59,909	26,165	9,960	5,612
1990	50,194	50,554	7,031	8,526	6,030	18,987	729	936	75,507	33,934	12,765	8,096

[1]Lead content, unless otherwise specified.
[2]Includes bullion.
[3]Before 1989, title was "Sheets, plates, rods, other forms."
[4]Before 1989, title was "Foil, powder, flakes."
[5]Before 1989, title was "Drosses, etc."
[6]Because of the implementation of the Harmonized Tariff System in Jan. 1989, export categories for 1989 and 1990 are not necessarily comparable with those in 1988.
Source: Bureau of the Census.

TABLE 24

U.S. IMPORTS[1] OF LEAD, BY COUNTRY

Country	1988		1989[2]		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ore and concentrates:[3]						
Australia	1,431	$631	r1,127	r$770	1,285	$887
Bolivia	377	191	r21	r7	19	11
Canada	221,785	72,976	r110,938	r36,540	124,353	43,062
Chile	3	1	—	—	—	—
Honduras	—	—	21	11	—	—
Italy	—	—	—	—	138	175
Mexico	—	—	r15	r17	1,154	834
Peru	11,436	6,077	r7,604	r3,123	7,132	4,817
Switzerland	—	—	—	—	73	18
Total	235,032	79,876	r119,726	r40,468	134,154	49,804
Base bullion:						
Belgium	999	737	—	—	—	—
Canada	50	33	37	31	38	30
China	34	15	345	173	91	43
France	249	170	—	—	—	—
Korea, Republic of	76	49	—	—	—	—
Mexico	1,213	779	5,400	4,334	2,584	1,563
Morocco	376	267	—	—	—	—
Peru	501	354	—	—	—	—
Sweden	2,002	1,498	—	—	—	—
United Kingdom	999	660	—	—	—	—
Other	50	33	—	—	—	—
Total	6,549	4,595	5,782	4,538	2,713	1,636
Pigs and bars:						
Australia	6,719	3,981	—	—	6,992	5,751
Belgium	499	310	41	25	—	—
Bolivia	36	22	52	48	—	—
Brazil	(4)	2	1,510	974	—	—
Canada	104,815	77,207	90,479	61,951	70,662	58,099
China	653	403	6	5	—	—
France	299	94	—	—	—	—
Germany, Federal Republic of	1,212	1,446	144	269	66	253
India	—	—	—	—	330	223
Italy	1,800	1,139	1,731	1,238	—	—
Mexico	30,937	21,580	19,178	13,232	24,666	19,988
Netherlands	—	—	—	—	5	5
Peru	—	—	4,316	2,913	1,000	822
Switzerland	58	40	—	—	—	—
United Arab Emirates	8	44	296	510	239	646
United Kingdom	88	161	—	—	269	332
Venezuela	—	—	126	81	13	11
Yugoslavia	—	—	277	319	—	—
Total	147,124	106,429	118,156	81,565	[5]104,241	[5]86,129
Reclaimed scrap, including ash and residues:[6 7]						
Canada	2,854	1,230	487	182	233	119
Costa Rica	52	28	—	—	—	—
Japan	16	90	(4)	4	—	—
Mexico	4,202	1,845	—	—	116	30
Netherlands Antilles	22	3	332	169	—	—

See footnotes at end of table.

TABLE 24—Continued

U.S. IMPORTS[1] OF LEAD, BY COUNTRY

Country	1988		1989[2]		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Reclaimed scrap, including ash and residues[6 7]—Continued						
Panama	92	$53	—	—	—	—
United Arab Emirates	25	78	—	—	—	—
Other	26	12	—	—	—	—
Total	7,289	3,339	819	$355	349	$149
Grand total	395,994	194,239	r244,483	r126,926	241,457	137,718

rRevised.
[1]Data are "general imports;" that is, they include lead imported for immediate consumption plus material entering the country under bond.
[2]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 and 1990 are not necessarily comparable with those in 1988.
[3]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.
[4]Less than 1/2 unit.
[5]Data do not add to total shown because of independent rounding.
[6]Also includes other lead-bearing materials containing greater than 10% by weight of copper, lead, or zinc (any one).
[7]Before 1989, title was "Reclaimed scrap, including drosses."
Source: Bureau of the Census.

TABLE 25

U.S. IMPORTS FOR CONSUMPTION OF LEAD, BY COUNTRY

Country	1988		1989[1]		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ore and concentrates (lead content):[2]						
Australia	6,656	$3,508	—	—	1,033	$378
Canada	8,171	3,995	r1,170	r$442	1,494	321
Honduras	1,396	1,016	21	11	—	—
Italy	—	—	—	—	138	175
Mexico	—	—	r15	r17	1,177	839
Peru	4,383	2,705	r1,733	r653	3,875	1,725
Switzerland	—	—	—	—	73	18
Total	20,606	11,224	r2,939	r1,123	7,790	3,456
Base bullion (lead content):						
Belgium	999	737	—	—	—	—
Canada	50	33	37	31	38	30
China	34	15	345	173	91	43
France	249	170	—	—	—	—
Korea, Republic of	76	49	—	—	—	—
Mexico	1,213	779	5,400	4,334	2,584	1,563
Morocco	376	267	—	—	—	—
United Kingdom	999	660	—	—	—	—
Other	50	33	—	—	—	—
Total	4,046	2,743	5,782	4,538	2,713	1,636
Pigs and bars (lead content):						
Australia	6,719	3,981	—	—	—	—
Belgium	499	310	41	25	—	—
Bolivia	36	22	52	48	—	—
Brazil	(3)	2	1,510	974	—	—
Canada	104,815	77,207	90,479	61,951	70,662	58,099
China	653	403	6	5	—	—
France	299	94	—	—	—	—

See footnotes at end of table.

TABLE 25—Continued

U.S. IMPORTS FOR CONSUMPTION OF LEAD, BY COUNTRY

Country	1988		1989[1]		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Pigs and bars (lead content)—Continued						
Germany, Federal Republic of	2,713	$2,519	144	$269	66	$253
India	—	—	—	—	330	223
Italy	1,800	1,139	1,731	1,238	—	—
Mexico	30,916	21,562	18,703	12,900	18,055	14,005
Peru	—	—	2,316	1,543	1,000	822
Switzerland	58	40	—	—	—	—
United Arab Emirates	8	44	296	510	239	646
United Kingdom	88	161	277	319	269	332
Venezuela	—	—	126	81	13	11
Total[4]	148,604	107,484	115,681	79,863	90,638	74,395
Reclaimed scrap, including ash and residues (lead content):[5 6]						
Canada	2,854	1,230	345	113	165	72
Costa Rica	52	28	—	—	—	—
Japan	16	90	([3])	4	—	—
Mexico	4,202	1,845	—	—	116	30
Netherlands Antilles	22	3	332	169	—	—
Panama	92	53	—	—	—	—
United Arab Emirates	25	78	—	—	—	—
Other	26	12	—	—	—	—
Total	7,289	3,339	677	286	281	102
Grand total[4]	180,545	124,790	[r]125,079	[r]85,810	101,421	79,589
Wrought lead, all forms, including wire and powders (gross weight):[7]						
Belgium	32	65	68	181	1	86
Canada	283	472	770	1,257	1,152	2,068
China	—	—	279	719	278	771
France	—	—	—	—	21	140
Germany, Federal Republic of	199	494	244	837	258	1,167
Italy	39	87	50	160	330	448
Japan	3	76	37	393	37	399
Mexico	2,285	1,280	2,539	1,797	2,769	2,061
Netherlands	—	—	—	—	55	241
Peru	40	28	1,284	927	735	628
Spain	45	101	7	117	4	96
Taiwan	7	18	248	658	178	495
Thailand	—	—	—	—	30	120
United Arab Emirates	—	—	—	—	40	101
United Kingdom	478	586	406	989	88	513
Venezuela	—	—	—	—	709	366
Other	34	73	136	1,041	40	245
Total	3,445	3,280	6,068	9,076	6,723	9,944

[r]Revised.

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 and 1990 are not necessarily comparable with those in 1988.

[2]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.

[3]Less than 1/2 unit.

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

[5]Also includes other lead-bearing materials containing greater than 10% by weight of copper, lead, or zinc (any one).

[6]Before 1989, title was "Reclaimed scrap, etc."

[7]Before 1989, title was "Sheets, pipe, shot, other forms."

Source: Bureau of the Census.

TABLE 26

U.S. IMPORTS FOR CONSUMPTION OF LEAD[1]

Year	Blocks, pigs, anodes, etc.				Wrought lead and lead alloys (gross weight)				Scrap		Drosses, etc.	
	Unwrought[2]		Unwrought alloys		Sheets, plates, rods, other forms		Foil, powder, flakes					
	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)
1988	137,598	$97,565	15,052	$12,662	3,331	$3,101	114	$179	6,938	$3,094	351	$245

	Blocks, pigs, anodes, etc.				Wrought lead and lead alloys (gross weight)						Scrap		Ash and residues	
	Unwrought[2]		Unwrought alloys		Strips, sheets, plates, and foil		Bars, rods, tubes, pipe, wire, fittings		Powders and flakes					
	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)	Quantity (metric tons)	Value (thousands)
1989[3]	102,319	$71,823	19,144	$12,578	718	$1,356	5,337	$7,670	13	$50	—	—	677	$286
1990	81,490	65,059	11,861	10,972	427	1,126	6,197	8,634	98	185	—	—	281	102

[1]Lead content, unless otherwise specified.
[2]Includes bullion.
[3]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import catergories for 1989 and 1990 are not necessarily comparable with those in 1988.
Source: Bureau of Census.

TABLE 27

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS PRODUCTS CONTAINING LEAD[1]

Year	Gross weight (metric tons)	Lead content (metric tons)	Value (thousands)
1987	970	515	$4,185
1988	1,623	992	8,838
1989[2]	1,789	852	11,908
1990	1,238	515	6,782

[1]Babbitt metal, solder, white metal, and other lead-containing combinations.
[2]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 and 1990 are not necessarily comparable with those in previous years.
Source: Bureau of the Census.

LIME

By M. Michael Miller

Mr. Miller, a physical scientist with 13 years of minerals experience with the Department of the Interior, has been the commodity specialist for lime since 1989. Domestic survey data were prepared by Blanche S. Hughes, mineral data assistant; and the world production table was prepared by Harold D. Willis, international data assistant.

Lime is vital to the economic and enviromental well-being of the United States. It is a basic chemical that ranked fifth in total production in the United States in 1990. Its major uses are in steelmaking; pulp and paper manufacturing; construction; and the treatment of water, sewage, and smokestack emissions.

Total lime sold or used by domestic producers, including that from Puerto Rico, increased by about 300,000 short tons to 17.5 million tons in 1990. These products, valued at more than $905 million, included quicklime and hydrated lime for commercial sale or captive consumption. Commercial sales increased for the fourth straight year and were at record-high levels. Captive consumption decreased to the lowest level since the U.S. Bureau of Mines first collected accurate data on captive production in 1958.

TABLE 1

SALIENT LIME STATISTICS

(Thousand short tons unless otherwise specified)

	1986	1987	1988	1989	1990
United States:[1]					
Number of plants	116	116	115	115	113
Sold or used by producers:					
Quicklime	11,850	12,979	r14,066	r14,500	14,762
Hydrated lime	2,199	2,468	2,531	r2,249	2,313
Dead-burned dolomite	424	285	r455	r402	377
Total[2]	14,474	15,733	17,052	17,152	17,452
Value[3] thousands	$757,867	$786,125	$817,893	$852,113	$901,549
Average value per ton	$52.36	$49.96	$47.96	$49.68	$51.66
Lime sold	12,097	13,105	14,736	15,016	15,448
Lime used	2,377	2,628	2,317	2,135	2,004
Exports[4]	16	13	15	32	44
Imports for consumption[4]	201	178	210	218	173
Consumption, apparent[5]	14,658	15,898	17,248	17,337	17,581
World: Production	r136,234	r139,782	r147,872	r152,846	e150,151

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.

DOMESTIC DATA COVERAGE

Domestic production data for lime are developed by the U.S. Bureau of Mines from two separate voluntary surveys of U.S. operations. The survey used to prepare this report is the annual "Lime" survey. Of the 114 operations to which the annual survey request was sent, 112 responded, representing 98% of the total sold or used by producers shown in table 4. Production for the two nonrespondents was estimated using reported prior-year production figures.

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. Refractory dolomite is another name for dead-burned dolomite. 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 inches to 2.25 inches, but the specific product size is more precise. This size has traditionally been a product of rotary kilns, but is now available from vertical kilns as either a primary product or as a result of crushing lump lime.

3. *Ground lime*—the product is generally ground from larger size material. A typical product size passes nearly 100% through a No. 8 sieve and 40% to 60% through a No. 100 sieve.

4. *Pulverized lime*—the product is the result of further grinding. A typical product size passes nearly 100% through a No. 20 sieve and 85% to 95% through a No. 100 sieve. This is usually a secondary product and is produced by intense grinding and classification.

5. *Pelletized lime*—almond-shaped pellets or briquets 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. A typical analysis is shown in table 2.

TABLE 2

TYPICAL ANALYSES OF COMMERCIAL QUICKLIMES

Component	High-calcium quicklimes, range,[1] percent	Dolomitic quicklimes, range,[1] percent
CaO	93.25–98.00	55.50–57.50
MgO	.30– 2.50	37.60–40.80
SiO_2	.20– 1.50	.10– 1.50
Fe_2O_3	.10– .40	.05– .40
AI_2O_3	.10– .50	.05– .50
H_2O	.10– .90	.10– .90
Co_2	.40– 1.50	.40– 1.50

[1]The values given in this range do not necessarily represent minima and maxama percentages.

Source: "Chemical Lime Facts," National Lime Association.

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 wide variety of systems in use. The two basic kiln designs are rotary and vertical (or shaft). There are a few other miscellaneous designs, but the majority of commercial kilns are of rotary or vertical design.

A rotary kiln is a long cylindrical kiln with a refractory lining, inclined at a slight angle, rotated at a slow speed, and fired by fuel at the lower end. The calcareous raw material (kiln feed) is fed into the upper end and calcined at about 2,000° F during its travel through the kiln to form quicklime, which is discharged at the lower end. The calcination temperature depends on size and composition of kiln feed and the type of desired product. The carbon dioxide is driven off as a gas and normally exits the system with the stack gas.

Vertical kilns are short, wide, vertical cylinders lined with refractory materials. They are usually circular in cross section, typically with a diameter of 9 to 14 feet and a height of 50 to 70 feet. They are the most widely employed type in the world, especially in Europe. A vertical kiln is divided into four distinct zones where specific parts of the manufacturing process take place. They are, from top to bottom, (1) stone storage zone, (2) preheating zone, (3) calcining zone, and (4) cooling and discharge zone.

Examples of other kiln designs are the rotary hearth kiln and the fluosolids kiln. The rotary hearth design consists of a preheater, circular hearth, and cooler, all refractory lined. Stone is placed on the hearth and rotated through a heating chamber. In the fluosolids kiln, fine-sized stone is densely suspended by air and hot gases in the preheating and calcining zone of a vertical heated chamber. It can be operated at lower temperatures because of the fine stone size. The quicklime product is the most highly reactive of any commercial lime.

Byproducts and Coproducts

Most lime companies mine their own limestone or dolomite for kiln feed. Some companies also coproduce crushed and pulverized stone. If practical and markets exist, byproduct fines from the kiln feed preparation process and kiln dust from the calcination process are also marketed. Precipitated calcium carbonate is produced as a coproduct at three commercial lime plants by combining quicklime with byproduct carbon dioxide recovered from the kiln. Byproduct carbon dioxide is also recovered for use in the carbonation step of sugar refining.

Substitutes

Limestone is a low-cost substitute for lime for many uses such as agriculture, fluxing, and flue gas desulfurization (FGD). Limestone contains less reactive material, is slower to react, and may have other disadvantages compared to lime, depending on the use. Calcined gypsum is an alternative material in industrial plasters and mortars. Cement, lime kiln dust, and fly ash are potential resources as substitutes for some construction uses of lime.

Economic Factors

Prices.—Traditionally, lime has been a low-priced commodity. Its average value, as reported to the U.S. Bureau of Mines on an f.o.b. plant basis, ranged from $4 to $15 per ton from 1910 to 1970. It was only in the 1970's, when energy prices escalated, that lime prices showed a progressive and dramatic increase. This steady increase continued into the 1980's, although at a slower pace. In 1987, lime decreased in value for the first time since 1968. When comparing prices over the past 20 years, based on constant 1990 dollars, two trends become evident. From 1971 to 1980, prices increased steadily, finishing the period up 46%. From 1981 to 1990, prices decreased steadily, finishing the period down 21%.

Costs.—Production costs in lime manufacture can be divided, in descending

TABLE 3

TIME-PRICE RELATIONSHIPS FOR LIME[1]

Year	Average annual price, dollars per ton	
	Actual price[2]	Based on constant 1990 dollars
1971	15.78	46.74
1972	16.78	47.53
1973	17.42	46.28
1941	22.02	53.62
1975	27.46	60.89
1976	30.19	62.92
1977	33.50	65.46
1978	36.76	66.95
1979	41.26	69.03
1980	44.50	68.28
1981	47.01	65.76
1982	49.47	65.05
1983	51.10	64.67
1984	51.12	62.42
1985	51.69	61.29
1986	52.50	60.67
1987	50.11	56.13
1988	48.12	52.17
1989	49.83	51.88
1990	51.77	51.77

[1]Includes Puerto Rico.
[2]The average value of lime sold or used by producers f.o.b. plant excluding cost of containers.

order, into the following categories: energy (mainly fuel costs), kiln feed, dust collection, depreciation, direct labor, and miscellaneous. The ranking may differ from plant to plant, and most of the categories display a great range in costs from one plant to another. The difference in ranking and the range in costs are accounted for by such variables as distance from fuel sources; thermal efficiency of individual kilns; whether kiln feed is quarried, mined underground, or purchased; electrical energy rates; and age of the plant.[3]

Tariffs.—In the Harmonized Tariff Schedule of the United States, quicklime, slaked lime (hydrate), and hydraulic lime are listed under 2522.10, 2522.20, and 2522.30, respectively. Imports are free from countries with most-favored-nation (MFN) status and Canada. Non-MFN countries have tariffs of 0.2¢ per kilogram (about $2.20 per short ton) for quicklime, 0.3¢ per kilogram (about $3.31 per short ton) for slaked lime, and 0.2¢ per kilogram (about $2.20 per short ton) for hydraulic lime. Mexican imports of lime are assessed a countervailing duty of 1.21%. This applies 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

On November 15, 1990, the Clean Air Act Amendments of 1990 were enacted into law. "Title IV—Acid Deposition Control" was amended to include a market-based system of sulfur dioxide (SO_2) and nitrogen oxide emission reduction. The system is based on the allocation of emission allowances, which are calculated from emissions limits and baseline fuel consumption levels. An allowance allows the holder to emit 1 ton of SO_2 during or after the year in which the allowance was issued. Title IV of the law is directed at new and existing fossil fuel-fired electric generating stations containing one or more units that serve commercial generators of electricity. The domestic electric utility industry currently accounts for approximately 75% of annual SO_2 emissions. The goal is to reduce SO_2 emissions by 10 million tons from 1980 levels. To achieve this goal, emissions will be capped at 8.9 million tons by the year 2000.

In phase I, effective January 1, 1995, 110 existing electric utility plants with generating capacity in excess of 25 megawatts will be allocated SO_2 emission allowances. The allowances can be reassigned to other units within a utility's system, and they can be bought and sold between other allowance holders. Sulfur dioxide emissions cannot exceed the total of allocated and acquired allowances. Two-year extensions can be had for compliance with the allowance limitations if using a qualifying phase I technology achieving 90% SO_2 removal. Bonus allowances will be awarded for the installation of phase I technology; for achieving reductions before 1995; for achieving reductions through conservation and use of renewable energy; and to utilities in Illinois, Indiana, and Ohio.

In phase II, effective January 1, 2000, utility plants will receive emission allowances that are equal to 48% of the phase I allowance level. Four-year extensions can be had for utilizing clean coal technology. Bonus allowances will be awarded for achieving reductions through conservation or use of renewable energy, for operating in a State with a very low average emissions rate (as measured in 1985), for operating in 10 Midwestern States, and for additional special situations.[4]

The compliance options currently available to utility plants consist primarily of flue gas desulfurization (FGD) systems and fuel switching. FGD systems using either lime or limestone are used on more than 60 gigawatts of utility capacity. These systems have SO_2 removal efficiencies ranging from 50% to 95%. The high removal rates possible make FGD systems a cost-effective compliance option. This is despite their large size, relatively high capital costs, and byproduct waste disposal concerns.

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 ($CaO \cdot MgO$); two types of dolomitic hydrate, (4) type N [$Ca(OH)_2 \cdot MgO$] and (5) type S [$Ca(OH)_2 \cdot Mg(OH)_2$]; and (6) dead-burned dolomite. Nondolomitic quicklime and hydrated lime are also called high-calcium lime. Lime can also be produced from a variety of calcareous materials such as aragonite, chalk, coral, marble, and shell. Lime is also regenerated; that is, produced as a byproduct, by paper mills, carbide plants, and water treatment plants; however, regenerated lime is beyond the scope of this report.

Total U.S. lime production from limestone, including that of Puerto Rico, was essentially unchanged. Commercial lime sold by producers increased by 434,000 tons from the previous year. Captive lime used by producers decreased by 131,000 tons or about 6% compared with the previous year.

In 1990, 70 companies produced lime. Leading producing companies, in descending order, were Dravo Lime Co. with two plants in Kentucky and one

TABLE 4

LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

State	1989					1990				
	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	5	162	1,319	1,481	$70,361	4	154	1,372	1,526	$70,816
Arizona	3	W	W	W	W	3	W	W	W	W
Arkansas, Louisiana, Oklahoma	3	71	214	286	15,548	3	48	205	254	15,143
California	11	W	W	395	24,503	10	51	295	345	19,425
Colorado, Nevada, Wyoming	9	W	W	357	24,136	9	W	W	464	29,968
Oregon and Washington	4	W	W	393	26,348	4	W	W	406	23,046
Idaho	3	W	W	W	W	3	—	W	W	W
Illinois, Indiana, Missouri	8	458	3,196	3,654	168,979	8	530	3,174	3,704	173,559
Iowa, Nebraska, South Dakota	4	W	W	W	W	5	W	W	264	14,014
Kentucky, Tennessee, West Virginia	5	117	1,529	1,624	89,859	5	129	1,867	1,996	109,685
Massachusetts	2	W	W	W	W	2	W	W	W	W
Michigan	8	W	W	621	32,479	8	W	W	622	30,898
Minnesota and Montana	7	W	W	W	W	7	—	W	W	W
North Dakota	3	85	22	107	5,439	3	—	82	82	4,623
Ohio	9	W	W	1,888	94,157	9	W	W	1,884	92,817
Pennsylvania	10	300	1,360	1,660	92,139	10	345	1,280	1,626	92,557
Puerto Rico	1	26	—	26	3,800	1	29	—	29	3,483
Texas	8	367	937	1,304	60,829	8	314	1,024	1,337	76,181
Utah	4	W	W	373	17,974	3	W	W	354	18,878
Virginia	5	170	650	821	38,353	5	174	672	846	39,784
Wisconsin	4	120	317	437	18,129	4	119	342	461	24,608
Other[3]	([4])	611	5,146	1,750	72,880	([4])	448	4,825	1,279	65,547
Total[2]	116	2,487	14,690	17,178	855,913	114	2,341	15,140	17,481	905,032

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Excludes regenerated lime. Includes Puerto Rico.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes data indicated by the symbol W.
[4]Included with data for each individual State.

TABLE 5

LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES,[1] BY SIZE OF PLANT

Size of plant	1989			1990		
	Plants	Quantity (thousand short tons	Percent of total	Plants	Quantity (thousand short tons)	Percent of total
Less than 10,000 tons	12	74	([2])	15	96	([2])
10,000 to 25,000 tons	19	318	2	18	317	2
25,000 to 50,000 tons	15	585	3	13	472	3
50,000 to 100,000 tons	21	1,496	9	16	1,168	7
100,000 to 200,000 tons	20	2,883	17	21	2,990	17
200,000 to 400,000 tons	21	5,844	34	23	6,298	36
More than 400,000 tons	8	5,979	35	8	6,140	35
Total[3]	116	17,178	100	114	17,481	100

[1]Excludes regenerated lime. Includes Puerto Rico.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.

plant in Alabama; Mississippi Lime Co. in Missouri; Marblehead Lime Co. with two plants in Illinois and one each in Indiana and Michigan; Chemstar Inc. with two plants each in Arizona, California, and Nevada and one in Utah; Martin Marietta Corp. in Ohio; Allied Lime Co. with two plants in Alabama; Continental Lime Inc. with one plant each in Montana, Nevada, Utah, and Washington; APG Lime Co. with one plant each in Texas and Virginia; Chemical Lime Southwest with two plants in Texas; and LTV Steel Co. in Ohio. These 10 companies operated 26 plants and accounted for 57% of total lime production.

Domestic lime plant capacity is based on 365 days minus the average number of days for maintenance times the average 24-hour capacity of quicklime production, including quicklime converted to hydrated lime, and reported in short tons per year. Specific plant capacity data were available for 72% of commercial lime plants. Based on the data available, the commercial lime industry operated at 79% of capacity in 1990.

The industry announced a number of plant expansions and plans for new plant construction. Dravo Lime Co. began installation of a 800-ton-per-day preheater rotary kiln of Kennedy Van Saun design at its plant in Saginaw, AL. It was scheduled to go on-line in late March 1991. It will replace a 200-ton-per-day rotary, which will be placed in inactive status. Cheney Lime and Cement Co. began installation of a preheater rotary kiln of Kennedy Van Saun design at its plant in Shelby County, AL. It was scheduled to go on-line in the first quarter of 1991. Continental Lime Inc. began installation of a second kiln at its plant at Townsend, MT. The kiln was a used Allis Chalmers with a preheater of Continental design. Chemstar Inc. worked on zoning and permitting approvals for two new plants planned for Soda Springs, ID, and Cosgrave, NV. The plans for Soda Springs called for installation of a 600-ton-per-day Mertz vertical shaft kiln to go on-line the second quarter of 1992. Owing to zoning problems, Chemstar had to relocate its planned Winnemucca operation to Cosgrave, NV, about 6 miles northeast of the original site. The plant is expected to go on-line in the third quarter of 1992. Pfizer Inc.'s Specialty Minerals Group began a $13 million expansion at its facility in Adams, MA. The facility contains a crushed stone operation, lime plant, and precipitated calcium carbonate plant. The plans called for construction of a new office and laboratory building, renovation of an existing building, replacement of a 30,000-gallon lime slurry tank, and removal of several existing structures deemed inadequate for current needs. Additional annual expenditures are planned as part of a 10-year program to continue upgrading the facility, address environmental concerns, meet market projections, and maintain profitability.

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

TABLE 6

DESTINATION OF SHIPMENTS OF LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

(Thousand short tons)

State	1989			1990		
	Quicklime	Hydrated lime	Total[2]	Quicklime	Hydrated lim	Total[2]
Alabama	483	47	529	589	38	627
Alaska	3	1	3	3	—	3
Arizona	257	70	326	254	59	312
Arkansas	183	31	214	170	27	197
California	479	127	606	521	120	640
Colorado	61	11	72	80	15	95
Connecticut	18	10	27	15	6	21
Delaware	12	4	16	14	2	17
District of Columbia	15	26	41	17	38	55
Florida	392	18	410	369	19	388
Georgia	314	81	395	238	70	308
Idaho	137	2	139	124	2	126
Illinois	575	144	719	639	183	822
Indiana	1,527	30	1,557	1,514	31	1,545
Iowa	70	22	92	79	29	107
Kansas	72	24	96	73	18	92
Kentucky	482	27	510	502	45	547

See footnotes at end of table.

TABLE 6—Continued

DESTINATION OF SHIPMENTS OF LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

(Thousand short tons)

State	1989			1990		
	Quicklime	Hydrated lime	Total[2]	Quicklime	Hydrated lim	Total[2]
Louisiana	272	98	370	325	105	431
Maine	([3])	1	1	—	—	—
Maryland	328	19	347	135	19	154
Massachusetts	148	12	160	145	9	154
Michigan	1,138	40	1,178	1,043	41	1,085
Minnesota	157	145	301	246	16	262
Mississippi	175	6	182	199	6	205
Missouri	183	55	237	196	67	263
Montana	132	13	145	206	13	218
Nebraska	66	76	142	61	13	74
Nevada	212	37	249	269	57	327
New Hampshire	—	1	1	—	—	—
New Jersey	101	22	123	106	24	130
New Mexico	187	33	220	166	21	187
New York	71	41	112	73	42	115
North Carolina	191	36	228	201	43	244
North Dakota	123	88	211	187	4	192
Ohio	1,369	139	1,508	1,453	147	1,600
Oklahoma	104	6	111	121	14	134
Oregon	115	25	141	104	33	136
Pennsylvania	1,826	233	2,059	1,900	265	2,165
Rhode Island	2	2	4	7	1	8
South Carolina	218	23	241	191	25	216
South Dakota	24	2	26	45	2	47
Tennessee	183	55	238	214	61	275
Texas	947	369	1,316	1,010	311	1,321
Utah	224	18	242	147	9	157
Vermont	—	1	1	—	—	—
Virginia	151	40	191	150	89	239
Washington	250	21	271	304	22	327
West Virginia	471	51	522	454	61	515
Wisconsin	112	47	159	128	47	175
Wyoming	68	19	87	95	22	116
Total[2]	14,628	2,449	17,076	15,082	2,290	17,376
Exports:						
Canada	35	13	48	39	17	56
Other countries[4]	28	26	54	17	29	46
Total	63	39	102	56	46	102
Grand total[2]	14,690	2,487	17,178	15,140	2,341	17,481

[1]Excludes regenerated lime.
[2]Data may not add to totals shown because of independent rounding.
[3]Less than 1/2 unit.
[4]Includes U.S. possessions.

was often substituted for a fraction of the high-calcium lime to extend refractory life. Dead-burned dolomite, also called refractory lime, was used to line the bottom of open-hearth steel furnaces to extend the life of the brick lining. Dead-burned dolomite was a component in tar-bonded refractory brick used in basic oxygen furnaces. Lime consumption for raw steel production remained essentially unchanged at 5.1 million tons and accounted for 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 maintain the proper pH in the flotation process. It was used to process alumina and magnesia, to extract uranium from gold slimes, to control pH and reduce cyanide loss in gold and silver leaching operations, and in the recovery of nickel by precipitation.

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 causticizing agent and for bleaching paper pulp to the desired degree of whiteness. Lime was also used in the clarification and color removal of paper mill wastes and to make precipitated calcium carbonate, a specialty pigment used in premium-quality coated and uncoated papers.

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.

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 to $51.77 per short ton. Average values were $50.53 per ton for chemical and industrial lime, $58.70 for construction lime, $59.44 for lime used in agriculture, and $71.61 for refractory dolomite.

The average value of quicklime sold increased to $49.55 per ton. Average values per ton were $49.13 for chemical lime, $45.17 for construction lime, $57.10 for lime used in agriculture, and $67.60 for refractory dead-burned dolomite.

The average value of hydrated lime sold decreased to $60.88 per ton. Average values were $58.21 for chemical lime, $67.54 for lime used in construction, and $60.37 for lime used in agriculture.

Foreign Trade

Exports of lime increased by 37% to 44,287 tons. Imports of lime decreased by about 20% to 173,197 tons. Most U.S. trade was with Canada and Mexico, which together accounted for 99% of the U.S. imports and exports of lime. Canada was the major trading partner, receiving 80% of U.S. exports and shipping 87% of U.S. imports.

World Review

Denmark.—The largest lime producer in Denmark is Faxe Kalk, a 51% subsidiary of Aalborg Portland Holding A/S. Faxe Kalk and its subsidiaries produced an assortment of calcium carbonate derived products. Limestone was quarried near the town of Fakse and transported a short distance to the lime plant operation at Stubberup. Quicklime was produced from two rotary kilns, with some further processing into pulverized lime and hydrate. Hydrated lime was also produced at Vejle. Annual lime production by Faxe Kalk averages between 125,000 to 145,000 tons.[5]

Germany, Federal Republic of.—With the reunification of the two Germanies, the German Democratic Republic ceased to exist and became simply the Eastern states of the Federal Republic of Germany. Reunification and the resulting economic turmoil in the Eastern states had a large negative impact on lime production and lime markets in the Eastern states. Harzer Kalk-Werke GmbH was the largest lime producer in the Eastern states. It operated the following six limestone and lime facilities: Werk Rbeland, Werk Kaltes Tal, Werk Hornberg, Werk Bad Ksen, Werk Oberrohn, and Werk Schraplau. These operations supplied quicklime and hydrate for use by industries such as chemicals, steel, pulp, sugar refining, metallurgy, and agriculture. Production was down in 1990, primarily owing to the uncertainties facing the chemical industry of the former German Democratic Republic.[6]

Mexico.—There are about 130 lime plants in Mexico. The Fideocomiso de Minerales No-Metálicos Méxicanos, the Government agency that oversees the nonmetallic mining sector, classifies only 15 of Mexico's lime plants as "modern." These 15 plants produce about 50% of Mexico's annual production. Most lime producers are small and face three major problems: lack of quality control, low-level technology and antiquated equipment, and lack of adequate financing. Mexico's annual lime production ranges between 5 to 7 million tons. The two largest markets are the construction industry and the steel industry, which consume about 80% and 8%, respectively.

New Zealand.—Lime was produced on both the North and South Islands. There are only a relatively small number of "calcined lime" producers in New Zealand, where pulverized agricultural lime is also termed lime. Quicklime and hydrate were produced by McDonalds Lime Ltd. at

FIGURE 1

TRENDS IN MAJOR USES OF LIME

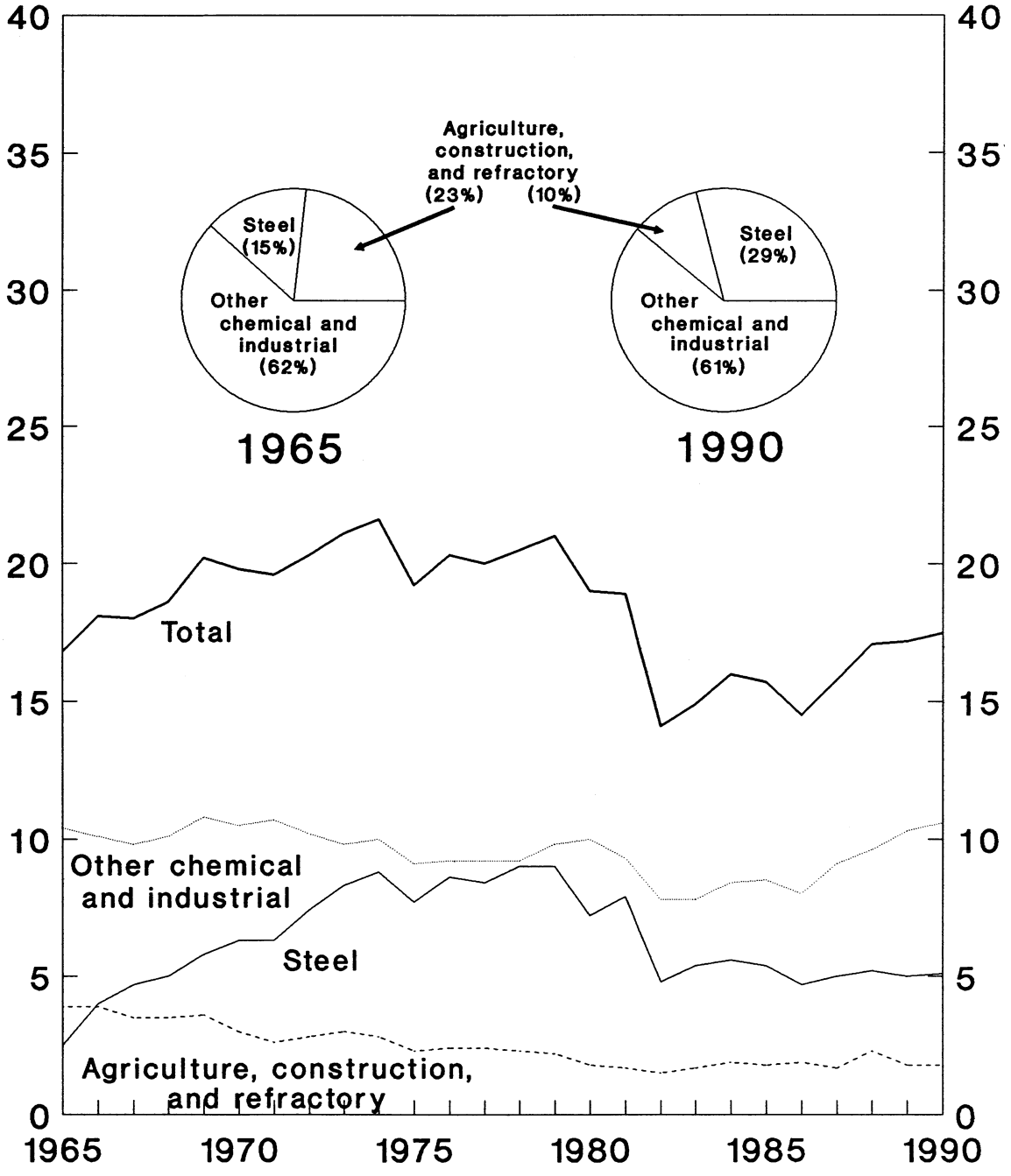

TABLE 7

LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE[1]

(Thousand short tons and thousand dollars)

Use	1989[r]				1990			
	Sold	Used	Total[2]	Value	Sold	Used	Total[2]	Value
Agriculture	56	—	56	3,077	49	—	49	2,898
Chemical and industrial:								
Alkalies	W	W	164	8,452	W	W	106	5,170
Aluminum and bauxite	169	—	169	8,383	155	—	155	8,122
Copper ore concentration	W	W	419	18,821	W	W	373	17,540
Food products, animal or human	28	—	28	1,534	21	—	21	1,171
Glass	130	—	130	6,418	99	—	99	5,022
Magnesia from seawater or brine	W	W	646	32,214	W	W	653	31,987
Oil well drilling	W	—	W	474	12	—	12	693
Oil and grease	18	—	18	889	W	W	19	1,283
Ore concentration, other	W	—	W	W	331	—	331	15,940
Paper and pulp	W	W	1,178	56,997	W	W	1,265	64,901
Precipitated calcium carbonate	W	W	W	W	W	W	254	11,718
Steel, BOF	W	W	4,051	187,567	W	W	4,034	193,254
Steel, electric	W	W	1,021	48,654	W	W	974	50,698
Steel, open-hearth	64	—	64	2,877	122	—	122	5,856
Sugar refining	40	642	682	34,214	30	627	657	35,596
Tanning	W	W	55	3,765	26	—	26	1,548
Other[3]	9,567	822	2,855	144,148	8,919	1,178	2,419	131,599
Total[2]	10,016	1,464	11,480	555,407	9,716	1,805	11,521	582,100
Construction:								
Soil stabilization	667	—	668	33,999	672	—	672	36,188
Finishing lime	207	—	207	22,372	160	—	160	14,708
Mason's lime	W	W	111	8,320	W	W	254	17,932
Other[4]	444	—	342	16,667	500	—	295	12,217
Total[2]	W	W	1,327	81,358	W	W	1,381	81,046
Environmental:								
Acid water, mine or plant	251	—	251	11,332	285	—	285	16,120
Sewage treatment	455	—	455	21,365	467	—	467	22,014
Flue gas sulfur removal	1,485	—	1,485	70,792	1,673	—	1,673	89,694
Water purification	1,030	—	1,030	49,134	1,072	—	1,072	50,271
Other[5]	665	26	691	34,549	647	10	657	33,900
Total[2]	3,886	26	3,912	187,172	4,143	10	4,154	211,999
Refractory lime (dead-burned dolomite)	W	W	402	28,899	W	W	377	26,988
Grand total[2]	15,042	2,135	17,178	855,913	15,476	2,004	17,481	905,032

[r]Revised. W Withheld to avoid disclosing company proprietary data.
[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, environmental uses (1989), explosives, ferroalloys, fiberglass, glue, insecticides, ladle desulfurizing, magnesium metal, manganese, metallurgy, pelletizing, pharmaceuticals, petrochemicals, precipitated calcium carbonate (1989), rubber, silica brick, soap, wire drawing, and uses indicated by symbol W in "Chemical and industrial" lime only.
[4]Includes asphalt antistripping.
[5]Includes industrial solid waste treatment, industrial wastewater treatment, scrubber sludge solidification, and other environmental uses.

TABLE 8

U.S. EXPORTS OF LIME

	Quantity (short tons)	Value[1] (thousands)
1987	12,644	$2,971
1988	14,908	3,113
1989	32,241	3,893
1990	44,287	4,755

[1]Customs value.

Source: Bureau of the Census.

Otorohanga and Te Kuiti on the North Island. McDonalds operated two coal-fired rotary kilns at Otorohanga and a gas-fired Mertz vertical kiln at Te Kuiti. Its major market was the steel industry, but it also supplied lime for sugar refining, soil stabilization, pulp manufacture, and water treatment. Taylors Lime Co. Ltd. operated on the South Island. In 1990, Taylors relocated its lime plant from Oamaru to Makareo and installed a new rotary kiln. The main objective in relocating the plant was to supply lime to the Macraes Flat gold-mining operation. Both McDonalds and Taylors are subsidiaries of Milburn New Zealand Ltd.[7]

Current Research

Researchers at the Illinois State Geological Survey Minerals Engineering Laboratory have developed a high-surface-area (HSA) hydrated lime for use in dry-sorbent FGD systems. The HSA hydrate is very reactive because it has a smaller particle diameter and crystallite size and greater surface area and porosity than commercial hydrates. The HSA hydrate was tested at the Environmental Protection Agency's (EPA) furnace sorbent injector reactor at Research Triangle Park, NC; Consolidation Coal's Coolside pilot unit at Library, PA; and Research-Cottrell's boiler economizer furnace at Irvine, CA. The tests determined SO_2 removal rates under conditions similar to burning high-sulfur coal. The tests were very favorable, and under most conditions demonstrated removal rates up to 70% higher than those of commercial hydrates.

Dry-sorbent injection systems are considered more cost effective for retrofitting smaller coal-fired powerplants of 150 megawatts or less. Such systems are smaller, easier to install and operate, and cost less than larger wet scrubber systems. The HSA hydrate could provide an effective sorbent for such systems that could significantly boost their SO_2 removal rates.[8]

In 1987, EPA accidentally discovered that quicklime had apparently destroyed polychlorinated biphenyls (PCB's) when applied to PCB-containing sludges for stabilization purposes. In an effort to explain this phenomenon, EPA's Risk Reduction Engineering Laboratory in Cincinnati, OH, funded a project with RMC Environmental & Analytical Laboratory of West Plains, MO, to conduct controlled experiments on PCB-contaminated soils. The unpublished results verified the field observations and showed that the addition of quicklime apparently destroys PCB's within about 96 hours. The end products of the chemical reaction were calcium chloride, water, and carbon dioxide. The reaction occurs at high temperature and pH levels and apparently requires a metal catalyst. The latter is probably supplied by the small amounts of magnesium, iron, or aluminum oxides normally found in high-calcium quicklimes.[9]

EPA researchers and non-EPA scientists recommended additional studies be conducted to confirm RMC's results and to collect additional data to determine whether PCB destruction or some other phenomena is occurring. The additional studies will be conducted in-house by EPA. If the results confirm PCB destruction with quicklime treatment, additional studies will be needed to determine in-field application methods, economics, reaction optimization, appropriate wastes to be treated, and to evaluate potential reaction byproducts.

OUTLOOK

Lime has dozens of end uses in the chemical, industrial, and construction industries. Steelmaking is still the largest single end use for lime, although the total consumption by tonnage and percentage of total lime production has decreased. During the past 20 years, lime consumed for steelmaking averaged 39% of total consumption. In 1990, consumption was essentially unchanged from that of the previous year at about 5.1 million tons or 29% of total consumption. The current level reflects a trend of the decreasing consumption by the steel

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF LIME

	Hydrated lime		Other lime		Total	
	Quantity (short tons)	Value[1] (thousands)	Quantity (short tons)	Value[1] (thousands)	Quantity (short tons)	Value[1] (thousands)
1987	39,734	$3,021	138,171	$7,558	177,905	$10,579
1988	54,419	4,031	155,497	8,541	209,916	12,572
1989	36,952	2,219	180,704	9,749	217,656	11,968
1990	29,920	2,147	143,277	8,245	173,197	10,392

[1]Customs value.

Source: Bureau of the Census.

TABLE 10

QUICKLIME AND HYDRATED LIME, INCLUDING DEAD-BURNED DOLOMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989	1990[e]
Algeria[e]	45	45	45	45	45
Australia[e]	1,210	1,210	1,210	r1,650	1,650
Austria	1,405	1,519	1,703	r1,788	1,700
Belgium	1,971	1,944	2,086	e2,100	1,980
Botswana	(3)	(3)	(3)	(3)	(3 4)
Brazil	5,411	5,842	r6,063	r6,316	6,280
Bulgaria	1,799	1,409	1,570	r1,581	1,540
Burundi	(3)	(3)	(3)	(3)	(3)
Canada	2,472	2,458	2,776	2,812	2,760
Chile[e]	r990	r1,100	r1,320	r1,430	1,430
China[e]	9,900	12,100	14,300	17,600	18,700
Colombia[e]	1,430	1,430	1,430	1,430	1,430
Costa Rica[e]	11	11	11	r25	22
Cuba	192	204	197	e200	200
Cyprus	8	8	8	8	8
Chechoslovakia	3,670	3,569	r3,650	r3,688	3,690
Denmark (sales)	147	132	148	re149	140
Dominican Republic[e]	37	40	40	39	39
Egypt[e]	105	105	105	105	105
Ethiopia	r6	r6	r4	e2	2
Fiji Islands	3	—	—	re2	—
Finland (sales)	r289	e300	224	e234	220
France	3,200	e3,300	3,405	e3,400	3,300
Germany, Federal Republic of:					
Eastern states	3,908	3,724	3,835	e3,750	3,300
Western states	7,139	6,736	r7,497	r7,753	7,940
Guatemala	41	88	79	r87	88
Hungary	916	916	938	r968	940
India[e]	660	770	830	r870	880
Iran[e]	700	700	700	700	700
Ireland	97	85	107	r123	110
Israel[e]	r143	r143	r 4143	r143	143
Italy[5]	3,969	4,292	e4,300	e4,300	4,240
Jamaica	101	99	88	re100	100
Japan (quicklime only)	7,404	7,435	8,516	r9,354	9,400
Jordan	5	4	r3	r3	3
Kenya	14	29	e28	r35	35
Korea, Republic of[e]	220	220	250	250	250
Kuwait	63	69	e72	e72	55
Lebanon[e]	11	11	11	11	11
Libya[e]	290	290	290	290	290
Malawi	3	3	e3	e3	3
Malta[e]	6	6	6	6	6
Martinique[e]	6	6	6	6	6
Mauritius[e]	8	8	8	8	8

See footnotes at end of table.

TABLE 10—Continued

QUICKLIME AND HYDRATED LIME, INCLUDING DEAD-BURNED DOLOMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989	1990[e]
Mexico	r6,662	6,889	6,614	e6,610	6,610
Mongolia[e]	r118	r134	r105	r100	100
Mozambique[e]	11	r6	r6	r6	6
Nepal	1	1	23	r45	50
New Zealand[e]	175	175	165	110	110
Nicaragua[e]	4	4	4	4	15
Norway[e]	110	110	110	110	110
Paraguay	97	102	94	114	116
Peru[e]	40	[4]14	14	14	14
Philippines	42	e20	4	e5	6
Poland	r4,528	r4,701	r4,883	r4,873	4,850
Portugal[e]	220	220	220	220	220
Romania[e]	4,100	4,000	3,900	3,600	3,530
Saudi Arabia[e]	13	13	13	13	13
South Africa, Republic of (sales)	2,143	1,744	2,112	2,138	[4]2,018
Spain[e]	1,300	1,300	1,300	1,380	1,320
Sweden	723	650	740	e740	720
Switzerland	39	44	e46	e44	44
Taiwan	e120	116	117	e110	110
Tanzania[e]	3	3	3	3	3
Tunisia[e]	720	720	720	720	720
Turkey[e]	1,200	1,200	1,600	r1,500	1,800
Uganda[e]	1	1	1	1	1
U.S.S.R.	33,204	33,203	r33,705	r33,486	30,860
United Arab Emirates[e]	50	50	50	50	50
United Kingdom[e]	2,750	3,100	3,100	3,100	2,870
United States including Puerto Rico (sold or used by producers)	14,498	15,758	17,077	17,178	[4]17,481
Uruguay	11	14	11	r13	13
Venezuela[e]	2	2	2	2	2
Yugoslavia	r2,927	2,754	r2,754	r2,658	2,200
Zaire	150	109	r111	110	110
Zambia	268	259	263	r353	330
Total	r136,234	r139,782	r147,872	r152,846	150,151

[e]Estimated. [r]Revised.
[1]Table includes data available through June 10, 1991.
[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]Less than 1/2 unit.
[4]Reported figure.
[5]Includes hydraulic lime.

industry. This trend is a result of the decreasing consumption of fluxing agents; thus, less lime is consumed per ton of steel.

The outlook for steel production in the U.S. is uncertain. Labor contracts will expire at major steel producers in 1991 and 1992 and Voluntary Restraint Agreements with foreign producers will expire in 1992. These uncertainties make forecasting U.S. steel production extremely difficult. One econometric model, based on the actual production from 1982 through 1989, assumes production will decrease from 1991 through 1994 and be followed by a strong recovery in 1995 and 1996. Steel production in 1991 is expected to decrease by 5% to 10% compared with that of 1990. Based on this forecast and the decreasing trend in flux consumption, lime consumption for steelmaking could

easily drop to 4.5 to 4.8 million tons per year by the early 1990's. This translates to a loss in consumption of several hundred thousand tons per year, most of which would be in commercial sales.

Other sectors of the lime market are more difficult to analyze. No other single end use consumes more than 10% of total consumption, although environmental uses when grouped together account for approximately 24%. FGD consumption has the greatest growth potential, having increased steadily since the U.S. Bureau of Mines began collecting consumption data for it in the early 1970's. With passage of the Clean Air Act Amendments of 1990, consumption of lime or FGD use is expected to grow dramatically during the 1990's.

New environmental legislation, a resurgence in environmental awareness and concern by the public, and expanded cleanup of hazardous waste sites may have an impact on environmental markets. Lime should be ideally situated to take advantage of a new emphasis on environmental cleanup. It is an important and economical component in the treatment of air, water, and solid wastes.

Other markets that have growth potential are in construction, precipitated calcium carbonate manufacture, gold mining, and caustic soda manufacture by the lime-soda process using trona (natural sodium carbonate) as the raw material. An attempt to address the problems in the Nation's transportation infrastructure could increase consumption in the construction sector, especially for soil stabilization in major projects such as airport and highway construction and as an antistripping agent in asphalt. Lime consumption for precipitated calcium carbonate (PCC) production will continue to increase dramatically as the push to build satellite PCC plants near paper mills continues. The continued expansion of western gold production will provide a growing market for lime consumed in the cyanide heap-leaching process. Two producers of soda ash in Wyoming have constructed facilities for the lime-soda production of caustic soda, and a third is in the planning stage. This could develop into a significant regional market for lime.

Consumption by the pulp and paper industry increased by 7% in 1990. However, the pulp and paper industry tends to lag the national economy by several months, and the effects of the recession will probably impact them during 1991. Industry forecasts call for an overall growth rate in the industry of 2% to 3% per year.

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[2]Boynton, R. S. Chemistry and Technology of Lime and Limestone. John Wiley & Sons, 1980, 578 pp.

[3]Pages 316-319 of work cited in footnote 2.

[4]U.S. Congress. Clean Air Act Amendments of 1990. Public Law 101-549, Nov. 15, 1990, 104 Stat. 2399.

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LITHIUM

By Joyce A. Ober

Mrs. Ober, a physical scientist with 13 years industry and U.S. Bureau of Mines experience, has been the commodity specialist for lithium since 1986. Domestic survey data were prepared by Carleen Militello, mineral data assistant; and international data tables were prepared by Harold D. Willis, international data coordinator.

The United States led the world in lithium mineral and compound production and consumption. Domestic estimated consumption has remained about the same for the past 3 years; world production has risen steadily. Domestic producers announced modest price increases for the fourth consecutive year.

Because lithium is electrochemically reactive and has other unique properties, there are many commercial lithium products. Producers sold lithium as mineral concentrate, brine, compound, or metal depending on the end use. Most lithium compounds were consumed in the production of ceramics, glass, and primary aluminum.

TABLE 1

SALIENT LITHIUM STATISTICS

(Metric tons of contained lithium)

	1986	1987	1988	1989	1990
United States:					
Production[1]	W	W	W	W	W
Producers' stock changes[1]	W	W	W	W	W
Imports[2]	610	820	1,000	630	790
Shipments of Government stockpile surplus[3]	2	4	2	—	—
Exports[4]	1,800	1,800	2,300	r2,600	2,600
Consumption:					
Apparent	W	W	W	W	W
Estimated	2,400	2,400	2,700	2,700	2,700
Rest of world: Production[1]	3,600	3,600	4,200	r5,100	e5,400

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.

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.

ANNUAL REVIEW

Legislation and Government Programs

The Department of Energy (DOE) planned to offer portions of its 36 million kilograms of lithium hydroxide monohydrate for sale. The DOE stocks were excess from a weapons program that used the lithium to make tritium, a compound necessary for nuclear fission reactions. The stockpile originally contained about 42,000 metric tons of material, from which about 75% of the lithium 6 isotope had been removed. This material possibly contained 8 to 9 parts per million of mercury, which could present an environmental hazard. DOE planned to offer the lithium hydroxide for sale in 1989, but delayed the disposal until an environmental impact study was complete. The study was completed in 1990; a final decision about disposal had not been made at yearend.

Production

The two companies that produced lithium in the United States in 1990 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.

Lithium carbonate is the most important lithium compound produced from both types of deposit. 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.

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.

Cyprus Foote Mineral Co. produced about 6,700 tons of lithium carbonate from its brine deposit in Silver Peak, NV, and produced about 15 thousand tons of spodumene concentrate at its mine in Kings Mountain, NC.[1] It operated processing facilities for downstream lithium products and metal in Frazer, PA, Sunbright, VA, and New Johnsonville, TN. Operations at Frazer were being phased out and transferred to Kings Mountain during the year. The company continued to maintain its lithium carbonate plant at Kings Mountain on a care- and-maintenance status as it had since mid-1986.

Demand for butyllithium, the most important organic lithium compound, was expanding, and both companies were preparing to meet that expansion. Cyprus Foote increased capacity 25% at its existing butyllithium facility in New Johnsonville,[2] and FMC began construction of a butyllithium plant in Bayport, TX.[3] Completion of the Texas operation will double the company's capacity.

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 remained about the same in 1990. Ceramics and glass production and aluminum smelters were the largest consumers of lithium carbonate and lithium concentrates in the United States. Aluminum producers consume little lithium carbonate in other countries.

Lithium carbonate and mineral concentrate additions in ceramics and glass manufacturing processes lower process melting points, reduce the coefficient of thermal expansion and the viscosity, and eliminate the use of more toxic chemicals. The manufacture of thermal-shock-resistant cookware (pyroceramics) consumed the majority of lithium used in the ceramics and glass industry domestically. The manufacture of black and white television picture tubes consumed significant amounts of lithium concentrates overseas. Low-iron spodumene and petalite (another lithium mineral) were a source of lithium used to improve the physical properties of container and bottle glass and as a source of alumina, another important component of the glass. Glass manufacturers used lithium in container and bottle glass, enabling them to produce lighter weight, thinner walled products.

Aluminum producers added lithium carbonate to cryolite baths in aluminum potlines. The chemistry of the potline converts it to lithium fluoride, lowering the melting point of the bath, allowing a lower operating temperature for the potline, and increasing the electrical conductivity of the bath. Operators used these factors to increase production or reduce power consumption.

The multipurpose grease industry was the third largest end use for lithium in 1990. Lithium hydroxide monohydrate was the compound used for the production of lithium lubricants. Lithium-base greases are favored for their retention of lubricating properties over a wide temperature range; good resistance to water, oxidation, and hardening; and formation of a stable grease on cooling after melting. These greases continued to be utilized in military, industrial, automotive, aircraft, and marine applications.

Almost all major battery manufacturers marketed some type of lithium batteries, and research and development continued for further substitution in applications that implement more conventional alkaline batteries. These batteries represent a growth area for lithium consumption, but sales have not increased as rapidly as originally expected. Eastman Kodak Co., the first company to offer a lithium battery to the U.S. consumer market, chose to discontinue production owing to low sales. Kodak's 9-volt lithium battery had at least twice the life of a comparable alkaline battery, but consumers were not willing to pay the higher price.

Lithium batteries offer improved performance over alkaline batteries at a slightly higher cost. They were used in watches, microcomputers, cameras, and, more recently, in small appliances, electronic games, and toys. The military purchased large and small lithium batteries for a variety of military applications. The Galileo spacecraft, launched in October of 1989 for its 6-year trip to explore the atmosphere of Jupiter, contained lithium sulfur dioxide batteries to power its scientific instruments when it reaches its destination. Recent modifications to the lithium sulfur dioxide battery have extended the life of the batteries to at least 10 years with little or no reduction of performance.

Aircraft manufacturers in several countries have designed new aircraft using aluminum-lithium alloys for wing and fuselage skin or structural members. Use of aluminum-lithium alloys can reduce the weight of the aircraft by more than 10%, allowing significant fuel savings during the life of the aircraft. The alloys, which are 2% to 3% lithium by weight, are attractive to the aircraft and aerospace industry because of their reduced density and superior corrosion resistance compared to those of conventional aluminum alloys. These alloys face direct competition, however, from composite materials consisting of boron, graphite, or aramid fibers imbedded in polymers.

Butyllithium was a catalyst in synthetic rubber production. Small quantities of other lithium compounds were important to many industries. Lithium chloride and lithium bromide were used in industrial air-conditioning systems, commercial dehumidification systems, and in the production of sophisticated textiles. Sanitizers for swimming pools, commercial glassware, and public restrooms contained lithium hypochlorite, as did dry bleach for commercial laundries. Patients diagnosed as suffering from manic-depressive mental disorders may take

medication containing a pharmaceutical grade of lithium carbonate. Lithium metal was used as a scavenger to remove impurities from copper and bronze, and anhydrous lithium chloride was used as a component in fluxes for hard-to-weld metals such as steel alloys and aluminum.

Prices

Both domestic companies increased prices for almost all lithium products for the fourth consective year. Prices averaged about 6% higher in 1990 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.

Foreign Trade

Total U.S. exports of lithium compounds were about the same in 1990 as they were in 1989. Exports of lithium carbonate increased, but lithium hydroxide and lithium metal exports decreased. The majority of U.S. exports of lithium compounds were to the Federal Republic of Germany, Japan, and the United Kingdom. Imports of lithium compounds reported by the Bureau of the Census increased 26%. Cyprus Foote Mineral Co. owns a lithium brine operation in Chile. Almost all lithium imports came from this source. Lithium concentrates entered the United States, but no data were available.

TABLE 2

DOMESTIC YEAREND PRODUCERS' AVERAGE PRICES OF LITHIUM AND LITHIUM COMPOUNDS

	1989		1990	
	Dollars per pound	Dollars per kilogram	Dollars per pound	Dollars per kilogram
Lithium bromide, 54% brine: Truckload lots, delivered in drums	4.82	10.63	5.10	11.24
Lithium carbonate, technical: Truckload lots, delivered	1.73	3.81	1.83	4.03
Lithium chloride, anhydrous, technical: Truckload lots, delivered	3.20	7.05	4.31	9.50
Lithium fluoride	5.99	13.21	6.35	14.00
Lithium hydroxide monohydrate: Truckload lots, delivered	2.19	4.83	2.32	5.11
Lithium metal ingot, standard-grade: 1,000-pound lots, f.o.b	28.30	62.39	30.00	66.14
Lithium sulfate, anhydrous	3.90	8.60	3.51	7.74
N-butyllithium in n-hexane (15%): Truckload lots, delivered	16.80	37.04	17.80	39.24

Source: U.S. lithium producers.

TABLE 3

U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY

Compound and country	1989		1990	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium carbonate:				
Argentina	1,041	$3,729	1,198	$4,976
Austria	1,873	6,709	15,423	61,534
Australia	18,960	77,385	—	—
Belgium	19,958	55,000	19,958	52,096
Brazil	34,336	111,114	82,845	304,272
Canada	362,663	1,422,124	1,237,195	4,014,028
France	—	—	19,958	55,000
Germany, Federal Republic of	2,882,128	8,506,932	3,325,696	10,516,167
India	4,542	14,169	18,147	82,161
Japan	1,429,825	4,662,880	1,090,131	4,938,599
Korea, Republic of	137,732	417,594	87,454	312,484
Malaysia	—	—	371	9,965
Mexico	76,699	318,681	82,798	339,228
Netherlands	362,946	1,036,790	250,068	746,861

TABLE 3—Continued

U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY

Compound and country	1989		1990	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium carbonate—Continued				
New Zealand	36	$1,585	150	$5,558
Singapore	8,642	89,865	—	—
South Africa, Republic of	29,808	100,991	16,164	66,284
Spain	59,874	165,000	31,558	253,288
Taiwan	8,990	30,027	—	—
United Kingdom	1,708,728	4,801,594	1,608,494	3,812,888
Venezuela	336,723	1,138,668	761,561	2,342,945
Total[1]	7,485,504	22,960,837	8,649,169	27,918,334
Lithium carbonate U.S.P.[2]				
Australia	123,854	296,165	51,478	202,529
Belgium	4,301	31,289	—	—
Canada	41,211	549,534	—	—
El Salvador	320	9,300	—	—
Germany, Federal Republic of	5,388	68,375	35,021	117,900
Honduras	328	8,727	—	—
India	25,242	100,666	3,050	17,503
Japan	386,512	1,202,469	243,060	814,426
Korea, Republic of	270,415	810,908	145,243	478,139
Mexico	12,994	8,557	10	6,578
Netherlands	—	—	1,479	3,000
New Zealand	1,498	18,685	699	10,430
South Africa, Republic of	1,700	60,264	3,200	12,640
Sweden	5,648	11,454	—	—
Taiwan	239,472	708,039	176,502	547,222
United Kingdom	1,107	23,220	3,992	30,924
Venezuela	440,238	1,345,378	—	—
Total	1,560,228	5,253,030	663,734	2,241,291
Lithium hydroxide:				
Argentina	146,044	559,459	37,852	173,887
Australia	70,778	286,205	139,809	620,590
Bangladesh	—	—	1,000	4,812
Belgium	110,369	384,065	9,617	17,187
Brazil	332,244	1,478,515	204,783	919,565
Canada	63,326	300,382	66,080	313,149
Chile	18,129	68,871	34,890	157,575
Colombia	32,114	127,308	27,660	122,607
Ecuador	5,000	23,326	14,600	66,644
Egypt	—	—	142,327	631,480
France	2,164	5,819	—	—
Germany, Federal Republic of	1,121,636	3,625,447	292,293	1,007,909
Guinea	572	183,960	5,816	28,860
India	345,276	1,325,356	234,390	1,459,325
Indonesia	22,680	104,600	—	—

See footnotes at end of table.

TABLE 3—Continued

U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY

Compound and country	1989		1990	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium hydroxide—Continued				
Israel	14,984	$69,485	10,993	$54,187
Italy	1,683	4,496	60	6,680
Japan	892,290	3,823,441	790,077	3,592,345
Korea, Republic of	113,148	462,802	156,592	614,326
Malaysia	2,599	12,608	1,996	10,282
Mexico	216,640	1,033,320	68,467	272,899
Netherlands	237,698	754,827	45,304	185,209
New Zealand	7,500	35,249	3,999	20,067
Nigeria	35,599	107,624	15,966	66,880
Pakistan	28,341	123,254	16,400	76,292
Peru	17,387	73,404	5,098	23,009
Philippines	14,337	55,807	36,218	94,185
Singapore	77,126	311,917	34,866	159,685
South Africa, Republic of	96,218	225,569	93,697	345,918
Sweden	36,580	138,920	79	56,800
Taiwan	21,763	73,244	—	—
Thailand	58,722	262,566	85,388	386,175
United Arab Emirates	18,414	74,435	6,985	31,108
United Kingdom	518,632	1,746,624	563,946	1,433,420
Uruguay	998	4,920	—	—
Venezuela	11,000	46,530	—	—
Total	4,691,991	17,914,355	3,147,248	12,953,057
Lithium metal:[3]				
Australia	r159	NA	—	NA
Belgium	r2,263	NA	319	NA
Brazil	r86	NA	—	NA
Colombia	—	NA	524	NA
Germany, Federal Republic of	r29,500	NA	34,500	NA
India	r1,397	NA	—	NA
Israel	r3,014	NA	349	NA
Japan	r52,609	NA	40,699	NA
Kenya	—	NA	2	NA
Malaysia	—	NA	61	NA
Netherland	—	NA	64	NA
Saudi Arabia	r41	NA	—	NA
Singapore	r22,739	NA	—	NA
South Africa, Republic of	r81	NA	149	NA
Spain	—	NA	4,936	NA
Syria	—	NA	38	NA
Taiwan	r785	NA	147	NA
Turkey	r35	NA	—	NA
United Kingdom	r28,516	NA	29,949	NA
Total	r141,225	NA	111,737	NA

rRevised. 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-BEARING MATERIALS

	Compounds			
	1989		1990	
	Quantity (kilograms)	Value[1]	Quantity (kilograms)	Value[1]
Lithium carbonate:				
Chile	3,236,541	$6,337,901	4,196,689	$8,337,590
Germany, Federal Republic of	52	3,595	20	1,849
India	17,500	80,981	—	—
Japan	127	25,501	20	29,008
Singapore	—	—	50	5,400
Switzerland	r7,200	174,604	—	—
United Kingdom	25	5,636	56	7,491
Total	3,326,245	6,627,218	[2]4,196,834	8,381,338
Lithium hydroxide:				
Germany, Federal Republic of	2,888	22,363	130	14,292
Japan	9,401	56,526	241	2,779
Sweden	545	27,411	—	—
Switzerland	10,348	58,164	—	—
United Kingdom	—	—	100	2,994
Total	23,182	164,464	471	20,065

rRevised.
[1]Customs value.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

World Review

A small number of countries throughout the world produced lithium ore and brine. The United States produced the most lithium; significant quantities also were produced in Australia, Canada, Chile, China, Portugal, the U.S.S.R., and Zimbabwe. Argentina, Brazil, and Namibia produced smaller quantities; production primarily consisted of concentrates. Rwanda, the Republic of South Africa, and Zaire are past producers of concentrates. Pegmatites containing lithium minerals have been identified in Austria, France, India, Ireland, Mozambique, Spain, and Sweden, but economic conditions have not favored development of the deposits. Lithium has been identified in subsurface brines in Israel. Companies in France, the Federal Republic of Germany, Japan, and the United Kingdom produced downstream lithium compounds from imported lithium carbonate.

Capacity.—The data in table 5 are rated capacity for mines and refineries as of December 31, 1990. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgement of the author, can be brought into production within a short period of time with minimum capital expenditure. Any restrictions to capacity utilization related to legal, political, or environmental restraints have been footnoted.

Lithium presented special problems during compilation of production capacities for different operations. Ore concentrate products are not comparable to lithium carbonate. Lithium carbonate was the primary compound produced at lithium chemical plants and the compound from which all other lithium chemicals were produced. Because even high-grade ore products usually contained less than 4% lithium and lithium carbonate contains almost 20% lithium, production capacities reported in tons per year represent large differences in the actual lithium content of the product. For that reason, capacities were reported based on the lithium content of the products also known as contained lithium.

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. FMC renewed its interest in Argentina due to recent events in Bolivia. Estimates of geologic resources have been reported at 130,000 tons of lithium contained in brine ranging from

TABLE 5

WORLD LITHIUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990 RATED CAPACITY[1]

(Metric tons of contained lithium)

Country	Capacity
North America:	
Canada	500
United States[2]	5,600
Total	6,100
South America:	
Argentina[e]	10
Brazil[e]	290
Chile	2,200
Total[e]	2,500
Europe:[e]	
Portugal	18
U.S.S.R.[3]	1,089
Total[4]	1,100
Africa:	
Namibia[e]	30
Zimbabwe	730
Total	760
Asia: China[e 3]	730
Oceania: Australia	1,300
World total[4]	12,000

[e]Estimated.
[1]Includes capacity at operating plants as well as plants on standby basis.
[2]Figures for the United States include 1,500 metric tons of capacity that has been idle since 1986.
[3]These estimates denote only an approximate order of magnitude; no basis for more exact estimates is available. Output from China and the U.S.S.R. has never been reported.
[4]Data do not add to total shown because of independent rounding.

0.22 to 1.08 grams per liter. The Salar del Rincon also was identified as a lithium resource in the Salta Province.[4]

Australia.—Greenbushes Ltd., parent company of Lithium Australia Ltd. (LAL), was acquired by the Gwalia Group. LAL mined high-grade, low-iron spodumene at its mine in Greenbushes, Western Australia. LAL produced two spodumene concentrate products through a flotation process for sale to the ceramics and glass industry. The majority of the company's spodumene concentrate was used in the manufacture of black and white television picture tube glass and pyroceramics in the Pacific rim countries and Europe. Glass-grade concentrate with lower lithium content was marketed in the same countries for consumption in container glass.

LAL was awarded the Outstanding Export Achievement Award by the Western Australia Department of Trade Developement for its growth in export sales and success in establishing a new export industry for Australia.[5]

Bolivia.—The Government of Bolivia and FMC reached an agreement for a joint-venture operation in the Salar de Uyuni, a lithium brine deposit considered to be a national asset. FMC's plans included an exploration program and a plant for recovery of lithium carbonate from the evaporated brines. Extreme political pressures prompted the Government of Bolivia to cancel the accord, and because the agreement had been reached without competitive bidding, a call for international bids was released. FMC was still considering pursuing its involvement in the Uyuni Project by participating in the bid process. The political climate in Bolivia may discourage other companies from pursuing business opportunities in that country.[6]

Preliminary studies of the Salar de Uyuni, which is more than 3,600 meters above sea level, indicated resources of 5.5 million tons of lithium, 110 million tons of potassium, and 3.2 million tons of boron. The salar may be the world's largest salt flat.[7]

FMC showed interest in the possibility of developing another deposit, the Salar de Coipasa in the Oruro Department. This deposit is not as large as Uyuni nor is it considered a national asset, making strong opposition to foreign development less likely.[8]

Brazil.—Brazil has produced small quantities of lithium minerals for quite some time. Companhia Brasileira de Litio was building a plant in Aquas Verhelhas, Minas Gerais, to produce 1,000 tons of lithium hydroxide and 200 tons of lithium carbonate. Production from the plant was expected by yearend and would make Brazil self-sufficient in these lithium compounds.

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.[9] 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 about 8,800 tons of lithium carbonate from the brines from this Salar, which has been worked since 1984.[10] The project originated as a joint venture between Foote and Corporación de Fomento de la Producción (CORFO), a Chilean Government agency. Production capacity for lithium carbonate increased steadily from a 6,300-ton-per-year capacity to reach the current level of almost 12,000 tons per year.

The possibility of a second lithium operation at the Salar de Atacama had been under investigation. Minera Salar de Atacama Ltda. (MINSAL), the consortium formed by AMAX Exploration Inc. (United States), CORFO, and Molibdenos y Metales S.A. (Chile), completed studying the feasibility of developing another lithium operation on the Salar in 1988. Evaluations of the results were analyzed, and AMAX announced its decision to sell its portion of the project in 1990.[11]

China.—Lithium pegmatite and brine deposits are worked in China, but specific information about any of the deposits is not available. Lithium carbonate and hydroxide from China has been marketed in the Federal Republic of Germany, Japan, and the Netherlands.

France.—Lithium metal is produced by Metaux Speciaux SA in 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.[12]

Germany, Federal Republic of—The Federal Republic of Germany has been a major producer of lithium compounds, although no lithium ore is mined there. Chemetall GmbH, a member of the Metallgesellschaft Group AG, produced downstream lithium compounds and metal from lithium carbonate imported from the United States and other countries. The company's lithium operations are in 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 was constructing a 100-ton-per-year battery-grade lithium metal operation in Kagawa. Yahagi Iron Co. also produced lithium metal in Nagoya.

Namibia.—Southwest Africa (SWA) Lithium Mines produced petalite concentrate at its Rubicon Mine near Karibib. Low-grade ores were beneficiated through a flotation process, while high-grade ores were handpicked. Small amounts of two other lithium minerals, lepidolite (lithia mica) and amblygonite (lithia alumina phosphate), were other products. The Federal Republic of Germany imported most of these concentrates. High-grade lepidolite was handpicked at the company's Helicon Mine for export to Western Europe and Japan.[13]

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

TABLE 6

LITHIUM MINERALS AND BRINE: WORLD PRODUCTION BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989	1990[e]
Argentina (minerals not specified)	184	178	119	[e]120	120
Australia, spodumene	12,703	22,279	[e]30,000	[e]40,000	40,000
Brazil:					
Amblygonite	49	52	[r]25	[re]25	25
Lepidolite	30	—	—	—	—
Petalite	1,614	2,946	[r]1,115	[re]1,200	1,200
Spodumene	366	505	[r]331	[re]350	350
Canada, spodumene[e 3]	7,500	11,500	14,000	14,000	14,000
Chile, carbonate from subsurface brine	4,458	6,139	7,332	[r]7,508	9,100
China (minerals not specified)[e 4]	15,000	15,000	15,000	15,000	15,000
Namibia:					
Amblygonite	52	106	147	[r]131	130
Lepidolite	52	61	18	[r]41	40
Petalite	751	749	1,477	[r]1,226	1,200
Portugal, lepidolite	1,800	[r]9,380	[r]14,109	[r]18,264	16,000
U.S.S.R. (minerals not specified)[e 4]	55,000	55,000	55,000	55,000	55,000
United States, spodumene and subsurface brine	W	W	W	W	W
Zimbabwe (minerals not specified)	32,760	14,959	15,073	[r]20,647	20,500

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Table includes data available through Apr. 10, 1991.
[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]Estimates based on imports by the United States.
[4]These estimates denote only an approximate order of magnitude; no basis for more exact estimates is available. Output by China and the U.S.S.R. has never been reported.

available. Past lithium production has been lepidolite.

U.S.S.R.—Lithium ores, compounds, and metal are produced in the U.S.S.R., but no details are available.

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 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.[14]

OUTLOOK

The aluminum industry experienced a slowdown in 1984, and, as a result, domestic lithium consumption decreased dramatically that year. Lithium consumption has increased slightly every year since that time. This increase was due primarily to the recovery of the aluminum industry as well as increased demand for lithium compounds and minerals in the ceramics and glass industry. Similar increases are expected for the future.

Demand for butyllithium is expected to increase, and both domestic producers are increasing production capacity to meet that demand. Demand for lithium metal for batteries and alloys should increase, but total consumption of the metal will remain small in comparison to the demand for lithium chemicals. Markets should remain relatively stable with slight growth, although new applications for mineral concentrates could increase demand for those materials significantly in the next few years. Lithium demand could increase dramatically if any of the new technology areas such as nuclear fusion were perfected. This is not expected to occur within the remainder of this century and probably not within the next 25 years.

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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 7 years. Domestic survey data were prepared by Tony E. Morris, mineral data assistant; and international data tables were prepared by William Zajac, Chief, Section, International Data.

Domestic production of primary magnesium decreased by about 8% in 1990 because U.S. producers faced competition from increasing quantities of imports, primarily from Canada. Two primary magnesium facilities opened in Canada during the year, increasing annual world production capacity by 52,500 metric tons. Most of the magnesium produced at these plants was exported to the United States, resulting in a dramatic increase in the quantity of total imports in 1990.

Aluminum alloys remained the principal end use for magnesium, but diecastings showed the largest increase in primary magnesium consumption between 1989 and 1990. Magnesium diecastings were used in a greater number of automotive applications, because automakers looked to reduce total vehicle weight without reducing vehicle size. The potential for a significant increase in Corporate Average Fuel Economy standards in the near future could result in an even larger increase in magnesium consumption by the U.S. automotive industry.

Domestic production and consumption of magnesium compounds declined slightly in 1990. Imports supplied about 25% of domestic demand, about the same as in 1989, although the total quantity of imports decreased.

Seawater and brines were the principal raw materials used to manufacture magnesium compounds, accounting for about 69% of the total, with dolomite, magnesite, and olivine as the other sources. Refractories were the largest use for dead-burned magnesia; caustic-calcined magnesia principally was used in the agricultural and chemical industries.

Producers in Czechoslovakia, Ireland, and Mexico were upgrading their facilities to produce higher grade dead-burned magnesia for consumers throughout the world in the iron and steel, nonferrous metals, cement, and glass industries. In general, these consumers were seeking material with high magnesium oxide (MgO) content, low boron content, and large particle size.

DOMESTIC DATA COVERAGE

Data for magnesium metal are collected from two voluntary surveys of U.S. operations. Of the 129 companies canvassed for magnesium consumption data, 97% responded, representing 65% of the primary magnesium consumption shown in tables 4 and 6. Data for the four 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 20 companies canvassed, 90% responded, representing 70% of the magnesium compounds shipped and used shown in table 14. Data for the two 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 are 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 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 and processing plants in Indiana, North Carolina, and Washington, and Olivine operates one mine and one processing plant in Washington.

Electrolytic plants in Canada, Norway, the U.S.S.R., and the United States represent 75% of the world magnesium metal production capacity. Smaller thermal plants are in Brazil, Canada, China, France, India, Italy, Japan, and Yugoslavia.

The largest magnesite production facilities in the world are in China, North Korea, and the U.S.S.R. Together, these three countries account for 53% of the world magnesite production capacity. Japan and the United States account for 58% of the world's magnesium compounds production capacity from seawater or brines. Fused magnesia is produced in Canada, France, Israel, Japan, the United Kingdom, and the United States.

Norway is the world's principal producer of olivine, and in addition to supplying its domestic needs, Norway is a major world supplier of this mineral. Countries with smaller output are Austria, Italy, Japan, Mexico, Spain, Sweden, and the United States.

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

TABLE 1

U.S. MAGNESIUM METAL PRODUCERS, BY LOCATION, RAW MATERIAL, AND PRODUCTION CAPACITY IN 1990

Company	Plant location	Raw material	Annual capacity (metric tons)
The Dow Chemical Co.	Freeport, TX	Seawater	109,000
Magnesium Corp. of America	Rowley, UT	Lake brines	35,000
Northwest Alloys Inc.	Addy, WA	Dolomite	35,000
Total			179,000

TABLE 2

U.S. MAGNESIUM COMPOUND PRODUCERS, BY RAW MATERIAL SOURCE, LOCATION, AND PRODUCTION CAPACITY IN 1990

Raw material source and producing company	Location	Capacity (metric tons of MgO equivalent)
Magnesite: Basic 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	300,000
Morton Chemical Co.	do.	10,000
Seawater:		
Barcroft Co.	Lewes, DE	5,000
Basic Magnesia Inc.	Port St. Joe, FL	50,000
The Dow Chemical Co.	Freeport, TX	20,000
Marine Magnesium Co.	South San Francisco, CA	15,000
National Refractories & Minerals Corp.	Moss Landing, CA	177,000
Total		1,012,000

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 is fed directly to electrolytic cells.

Magnesium Corp. of America (MagCorp) and Norsk Hydro A/S use an anhydrous magnesium chloride feed for their electrolytic cells. MagCorp uses solar evaporation initially to concentrate magnesium chloride brines from the Great Salt Lake. After adding calcium chloride to precipitate sulfate impurities and removing boron by solvent extraction, the brine is concentrated further and dehydrated in a spray dryer. The resulting powder is purified, concentrated, prilled, and dehydrated to produce anhydrous magnesium chloride.[4] Norsk Hydro starts with concentrated magnesium chloride brine. The brine is purified, concentrated, prilled, and dehydrated to produce anhydrous magnesium chloride.

Electrolytic cells used to recover magnesium from either hydrous or anhydrous magnesium chloride differ from company to company, and most information about cell design and operating conditions usually are not disclosed. Essentially, magnesium chloride fed to an electrolytic cell is broken down into magnesium metal and chlorine gas by direct current at 700° C. Magnesium is removed from the cell and cast into ingots, and the chlorine gas is recycled or sold.

Magnesium International Corp. developed a one-step process for producing anhydrous magnesium chloride that was demonstrated at Magnesium Co. of Canada Ltd.'s (MagCan) new plant that opened in 1990. 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.

Economic Factors

Costs to produce magnesium metal vary greatly, depending on 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. Total production costs from seawater sources were lower than from brines or dolomite sources. Magnesium compound operating costs also vary depending on source material and processing techniques. Operating costs range from $24 to $425 per ton for magnesium compound production, with seawater as the most costly source. Energy costs also represent the largest component of total operating costs.[6]

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.

ANNUAL REVIEW

Magnesium

Legislation and Government Programs.—On January 23, the Environmental Protection Agency (EPA) finalized rules proposed in September 1989 on the regulation of 20 special wastes from mineral processing under subtitle C of the Resource Conservation and Recovery Act (RCRA). Process wastewater from primary magnesium by the anhydrous process was temporarily excluded from regulation under subtitle C of RCRA. In a draft report to Congress, prepared by EPA in August, the Agency recommended that this waste product be regulated under subtitle D of RCRA.[7]

Production.—Domestic production of primary magnesium declined by about 8% and was about 78% of rated yearend capacity. An increase in U.S. imports of magnesium from new plants in Canada and an effort from the domestic producers to control their inventory levels were partially responsible for the production decrease.

Dow announced that its magnesium businesses, which did not have a formal corporate identity, were officially united under the name Dow Magnesium. The company also planned to invest an estimated $16 million in its Freeport, TX, facility to broaden its product line. One of the components to be added was a 50-million-pound-per-year direct chill vertical caster. It would enable Dow to produce T-bar ingot in sizes greater than 250 pounds and would allow production of primary and alloyed round billet. Caster installation was expected to be completed in the first quarter of 1992.

Consumption and Uses.—Although consumption of primary magnesium decreased slightly in 1990, the use of magnesium diecastings continued to grow as more applications were developed,

TABLE 3

U.S. IMPORT DUTIES

Item	HTS No.	Most favored nation (MFN) Jan. 1, 1990	Non-MFN Jan. 1, 1990
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 cent per kilogram on Mg content + 3.5% ad valorem	88 cent 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 cent per kilogram.
Caustic-calcined magnesia	2519.90.2000	$2.07 per ton	$20.70 per ton.
Other magnesia	2519.90.5000	Free	15.4 cent 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)

	1986	1987	1988	1989	1990
United States:					
Production:					
Primary magnesium	125,639	124,396	141,983	152,066	139,333
Secondary magnesium	41,807	45,164	50,207	51,200	54,529
Exports	39,909	44,182	49,802	56,631	51,834
Imports for consumption	8,355	10,851	14,407	12,289	26,755
Consumption, primary	78,961	94,620	100,793	105,226	96,108
Price per pound	$1.53	$1.53	$1.58–$1.63	$1.63	$1.43–$1.63
World: Primary production	322,408	323,930	r334,348	r344,043	e351,198

eEstimated. rRevised.

particularly in the automotive industry. The current estimate of the magnesium content of U.S.-produced vehicles was about 4 pounds per vehicle, but this was expected to increase significantly within the next few years.

General Motors Corp. planned to introduce new V-8 engines in some of its 1992 Cadillac models that contain about 5 pounds of magnesium, and the automaker announced that these cars would contain an additional 10 pounds of magnesium in the induction system and the transmission. Chrysler Corp. used magnesium diecastings for the accessory drive brackets in its 2.5- and 4.0-liter 1991 Jeep engines. Using magnesium to replace aluminum in these components represented a weight savings of 2.75 pounds per vehicle. Dow produced a prototype magnesium V-8 engine block that weighed less than 50 pounds for the Dow-owned demonstration Corvette to promote the advantages of using magnesium in automotive applications. The prototype engine block replaced a 135-pound standard cast-iron engine block.[8]

Foreign auto manufacturers also were using magnesium in several applications. Audi AG of the Federal Republic of Germany equipped some of its sedans with a magnesium dashboard bulkhead, which was one of the most critical structural components of the car's body. By using magnesium, tooling requirements and additional fabrication costs could be reduced. Nissan Motor Co. of Japan developed an alumina-reinforced magnesium piston that could yield a 40% weight reduction from conventional cast-iron pistons. Normally magnesium is not suitable for parts that are subject to a lot of wear, but by adding alumina reinforcement, it became about five times as wear-resistant as aluminum.

To capitalize on the interest on magnesium in structural applications such as automotive components, two research and development centers opened in 1990. The Institute of Magnesium Technology Inc. in Sainte-Foy, Quebec, officially opened in September. The Institute is funded by its membership, which consisted of primary producers, processors, converters, and users, and by the Canadian Government. Its principal function is to conduct research for the private and public sectors and to expand the world markets for magnesium products.[9] Norsk Hydro opened its Magnesium Market Development Center in Southfield, MI, in January. The center's main goal is to provide more comprehensive service to end users, especially in the automotive industry, and to work with the end users to develop new applications for magnesium. In addition to equipment at the center, Norsk Hydro will be able to use the resources of the Institute of Magnesium Technology Inc., of which it is a member.

Nippon Light Metal Co. and Diemakers Inc. planned to establish joint ventures in the United States and Japan to collaborate on the development, manufacturing, and marketing of magnesium die-cast products. The U.S. joint venture, to be called Nikkei Diemakers USA and funded 65% by Diemakers and 35% by Nippon Light Metal, will promote sales of magnesium diecastings to Japanese automakers operating in the United States. The Japanese joint venture, Nikkei Diemakers Co., funded 65% by Nippon Light Metal and 35% by Diemakers, will provide technical services and support for sale of Diemakers' products in Japan. Diemakers was acquired in May by Kanematsu USA Inc., a wholly owned subsidiary of the Japanese trading company Kanematsu Corp., and it reportedly was the third largest magnesium diecastings producer in the United States.

Bicycle frames were another emerging use for magnesium. In the *Tour de France* run during the year, some entrants rode bicycles with magnesium frames and claimed that the bicycles were very durable in crashes and could corner faster than conventional racing bicycles. A process to make a one-piece bicycle frame that took 52 seconds to complete was developed in the United Kingdom. In the process, molten magnesium was quickly injected into a mold and allowed to solidify there. Traditionally, individual sections of aluminum or steel were welded together to construct the frame. With the increased interest in magnesium bicycles, Norsk Hydro planned to construct a plant in Chelmsford, United Kingdom, to produce magnesium bicycle frames. Plant construction was expected to be completed early in 1991.

Dow Magnesium announced that it would stop production of its Pelamag™ granules at the beginning of 1991. The granules consisted of a spherical core of magnesium encased in a coating of mixed inorganic salts and were used for steel desulfurization. The capacity at the company's Freeport, TX, plant was expected to be used to produce other magnesium products that were preferred for desulfurization.

In April, Reactive Metals & Alloys Corp. (REMACOR) announced the sale of its Reade Manufacturing Div. to Magnesium Elektron Ltd., a unit of Alcan Aluminium Ltd. Reade Manufacturing produced magnesium powder, chips, and granules and supplied these materials to REMACOR for manufacturing desulfurization reagents. The transaction included a long-term contract for Reade Manufacturing to continue supplying REMACOR with its magnesium powder requirements.

Because of a combination of characteristics, including light weight, strength, and durability, magnesium was selected as the housing for the first totally self-powered

TABLE 5

MAGNESIUM RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1986	1987	1988	1989	1990
KIND OF SCRAP					
New scrap:					
Magnesium-base	991	845	2,641	3,951	3,992
Aluminum-base	17,822	20,867	19,926	19,278	19,464
Total	18,813	21,712	22,567	23,229	23,456
Old scrap:					
Magnesium-base	3,958	3,857	3,882	4,269	4,277
Aluminum-base	19,036	19,595	23,758	23,702	26,796
Total	22,994	23,452	27,640	27,971	31,073
Grand total	41,807	45,164	50,207	51,200	54,529
FORM OF RECOVERY					
Magnesium alloy ingot[1]	3,925	4,001	3,930	4,494	4,290
Magnesium alloy castings	551	447	438	795	857
Magnesium alloy shapes	31	—	1,065	635	301
Aluminum alloys	37,293	40,711	43,827	43,125	46,528
Zinc and other alloys	3	W	W	W	W
Chemical and other dissipative uses	W	W	943	W	W
Cathodic protection	W	—	W	W	W
Total	41,807	45,164	50,207	51,200	54,529

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.

radar detector, produced by Cincinnati Microwave Inc. The magnesium housing, die-cast in three pieces with no additional machining required, weighed 1.5 ounces before assembly. Cincinnati Microwave's goal was to create a receiver that would fit in a shirt pocket, take abuse, and operate by battery power alone for months.

Stocks.—Consumer stocks of primary magnesium ingot rose from 5,350 tons at yearend 1989 to 5,428 tons at yearend 1990. Consumer stocks of magnesium alloy ingot also increased from 849 tons at yearend 1989 to 879 tons at yearend 1990. Producer stocks of primary magnesium decreased slightly from 20,133 tons at yearend 1989 to 19,535 tons at yearend 1990.

Markets and Prices.—Quoted producer prices for both primary magnesium and diecasting alloy, AZ91D, remained stable during most of the year. Primary magnesium was quoted at $1.63 per pound, and diecasting alloy was quoted at $1.43 per pound. In December, Dow announced that it was reducing its price by 20 cents to $1.43 per pound, effective December 3 for spot customers and as terms permit for contract customers. The company cited the need to bring quoted prices closer to actual market prices in both the United States and abroad. MagCorp maintained its primary magnesium price at $1.63 per pound. At yearend, primary magnesium was quoted at $1.43 to $1.63 per pound, and diecasting alloy was quoted at $1.43 per pound.

Foreign Trade.—Plant openings in Canada resulted in a dramatic increase in imports of primary metal from that country. Canada supplied 76% of the total U.S. magnesium imports in 1990, which more than doubled from the 1989 level. Although total magnesium exports decreased, the United States remained a net exporter of magnesium in 1990.

World Review.—According to the International Magnesium Association, world inventories of primary magnesium rose to 43,800 tons at yearend 1990 from 35,000 tons at yearend 1989. Yearend 1990 inventories represented a 63-day supply compared with a 52-day supply at yearend 1989.

Canada.—Norsk Hydro Canada Inc., a unit of the Norwegian firm Norsk Hydro, reportedly reached full-scale production by the end of June at its new 40,000-ton-per-year magnesium plant in Becancour, Quebec. By the end of March, the plant was producing a variety of pure magnesium and magnesium alloy products. In addition, magnesium produced at the plant entered the qualification stages with the major aluminum-can-stock producers. Near the end of the year, Norsk Hydro announced that it would expand its casting facilities at the Becancour plant to include production of magnesium alloy billet in addition to primary magnesium billet. This expansion, planned for completion in 1992, would give the plant a total annual billet production capacity of 30,000 tons. The company also announced that it would spend $6 million to construct a magnesium recycling plant to process home scrap as well as scrap from customers. The recycling plant was scheduled to reach full operation by 1992.

During 1990, MagCan was plagued with operational problems at its new magnesium plant in High River, Alberta. Initially MagCan had planned to be operating at its full capacity of 12,500 tons per year by the end of the first quarter, but was only running at about one-third of design capacity by the end of April because the plant was unable to get enough power out of the reactor transformers. Because of these problems, Alberta Natural Gas Co., one of the equal-share partners in the MagCan project along with Magnesium International Corp., reportedly invested an additional $40 to $45 million in the project in September to take a controlling interest. MagCan reached an operating rate of 6,250 tons per year for 2 weeks in December until technical problems with some of the equipment occurred, and the company was forced to curtail production. Despite these operational problems, MagCan expected that production would reach its full capacity by mid-1991.

Noranda Inc. and Lavalin Industries reportedly were seeking a third partner in a joint-venture project to construct a 50,000-ton-per-year magnesium plant in East Broughton, Quebec. The companies

TABLE 6

U.S. CONSUMPTION OF PRIMARY MAGNESIUM, BY USE

(Metric tons)

Use	1986	1987	1988	1989	1990
For structural products:					
Castings:					
Die	3,646	3,710	4,383	5,627	7,479
Permanent mold	748	1,121	943	811	875
Sand	1,373	1,454	1,743	1,017	724
Wrought products:					
Extrusions	6,285	6,804	6,907	6,712	7,848
Other[1]	r1,452	r1,496	r3,231	r2,941	3,096
Total	r13,504	r14,585	r17,207	r17,108	20,022
For distributive or sacrificial purposes:					
Alloys:					
Aluminum	r39,290	r52,172	r53,671	r53,821	45,060
Other	5	8	7	9	8
Cathodic protection (anodes)	6,342	5,537	6,234	5,474	5,421
Chemicals	1,449	1,047	780	594	800
Iron and steel desulfurization	e9,000	e10,000	W	10,463	9,853
Nodular iron	1,622	1,811	2,037	1,635	1,424
Reducing agent for titanium, zirconium, hafnium, uranium, beryllium	5,235	5,286	8,467	10,798	8,989
Other[2]	2,514	4,174	12,390	5,324	4,531
Total	r65,457	r80,035	r83,586	r88,118	76,086
Grand total	78,961	94,620	100,793	105,226	96,108

eEstimated. rRevised. 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. STOCKS AND CONSUMPTION OF NEW AND OLD MAGNESIUM SCRAP[1]

(Metric tons)

Year	Stocks, Jan. 1	Receipts	Consumption			Stocks, Dec. 31
			New scrap	Old scrap	Total	
1989	787	7,233	3,052	4,269	7,321	699
1990	699	6,913	2,948	4,277	7,225	387

[1]Cast scrap, solid wrought scrap, borings, turnings, and drosses.

began a feasibility study in 1988 on a plant to recover magnesium from asbestos tailings with technology developed by Noranda and were satisfied with results to date. Government agencies, both Federal and provincial, reportedly financed one-half of the cost for the feasibility study and may provide further support in the forms of tax incentives and a break on real estate costs. The proposed plant, named Magnola, would use available asbestos tailings from a nearby mine that have a 25% magnesium content as the feed material.

India.—Officials from Southern Magnesium and Chemicals Ltd. stated that magnesium production from plants with a combined annual capacity of 1,200 tons began in April. Production from these plants was expected to be sufficient to supply the country's annual demand of 800 to 1,000 tons.

Norway.—Norsk Hydro planned to temporarily close 8,000 to 10,000 tons of annual capacity at its Porsgrunn magnesium complex early in the year for what the company termed as rearrangements. With additional production capacity available from its new Canadian plant, Norsk Hydro estimated that total 1990 production from both its plants would be 75,000 to 80,000 tons.

Brazil's Rima Group and Elkem A/S reportedly were negotiating to construct a 20,000- to 25,000-ton-per-year magnesium plant in Norway using Rima's technology. A feasibility study was underway, and if the decision is made to construct a plant, construction was expected to begin in 1991. The proposed plant, scheduled for completion in 1993, would be near one of Elkem's existing plants to take advantage of infrastructure already in place.

United Kingdom.—Norsk Hydro reportedly completed construction of a 4,500-ton-per-year magnesium granule production plant in Immingham in November. Magnesium ingots were imported from Norway and were reduced to granules 0.2 to 1 millimeter in diameter. These granules were to be used for steel desulfurization, and magnesium powder was produced as a byproduct for use in the pyrotechnic and chemical industries. European markets were the main target for the plant's output.

Magnesium Compounds

Production.—Caustic-calcined magnesia production was stable during the year, and dead-burned magnesia production declined about 4%. Production of olivine dropped by about 5%, and the average value decreased approximately 6%.

In June, National Refractories & Minerals Corp. signed an agreement with Radex Heraclith AG of Austria for Radex to acquire 50% ownership of National Refractories & Minerals over a 5-year period. The transaction was designed to broaden the geographical markets for both companies; National Minerals &

TABLE 8

U.S. EXPORTS OF MAGNESIUM, BY COUNTRY

Country	Waste and scrap		Metal		Alloys (gross weight)		Powder, sheets, tubing, ribbons, wire, other forms (gross weight)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989:								
Argentina	—	—	483	$1,652	—	—	26	$136
Australia	—	—	2,143	6,871	—	—	215	915
Bahrain	—	—	125	356	—	—	—	—
Brazil	152	$397	811	2,534	1	$4	496	1,685
Canada	48	129	7,225	17,254	1,410	5,615	4,906	13,135
China	—	—	199	698	—	—	—	—
Germany, Federal Republic of	18	37	—	—	1,209	5,229	135	792
Ghana	—	—	279	960	—	—	—	—
Hong Kong	—	—	(1)	5	21	36	1	13
India	—	—	508	1,829	5	196	1	24
Italy	73	205	73	1,255	17	80	14	264
Japan	42	70	11,233	32,701	157	714	647	3,490
Korea, Republic of	33	89	838	2,563	193	1,062	141	629
Mexico	925	2,079	989	3,209	99	319	357	807
Netherlands	21	43	14,990	39,522	164	477	394	1,207
Norway	—	—	1,211	3,485	2	5	—	—
Spain	—	—	738	2,446	—	—	—	—
Sweden	—	—	42	395	(1)	4	21	119
Taiwan	—	—	512	1,692	20	68	44	123
Turkey	20	40	—	—	—	—	—	—
United Arab Emirates	9	21	161	694	—	—	13	76
United Kingdom	19	41	202	1,171	30	126	124	1,526
Venezuela	17	70	61	133	—	—	228	767
Other	r29	r65	r410	r2,084	r521	r1,560	r380	r2,376
Total	1,406	3,286	43,233	123,509	3,849	15,495	8,143	28,084
1990:								
Argentina	—	—	432	1,337	—	—	40	163
Australia	—	—	2,468	7,175	—	—	149	639
Bahrain	—	—	507	1,277	—	—	—	—
Brazil	244	797	425	1,401	53	135	95	290
Canada	42	107	5,246	15,886	3,325	9,786	1,033	4,706
China	—	—	267	726	—	—	(1)	29
Germany, Federal Republic of	20	45	—	—	54	267	175	2,556
Ghana	—	—	122	366	—	—	—	—
Hong Kong	—	—	39	116	199	1,612	1	12
India	—	—	184	421	1	11	24	174
Italy	55	162	91	1,108	318	888	5	62
Japan	9	17	11,839	39,379	56	458	519	3,721
Korea, Republic of	—	—	873	2,206	129	664	442	1,115
Mexico	285	641	1,221	3,508	91	245	667	1,699
Netherlands	169	424	14,721	38,215	289	741	231	761

See footnotes at end of table.

TABLE 8—Continued

U.S. EXPORTS OF MAGNESIUM, BY COUNTRY

Country	Waste and scrap		Metal		Alloys (gross weight)		Powder, sheets, tubing, ribbons, wire, other forms (gross weight)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1990—Continued								
Norway	—	—	924	$2,431	[1]	$14	[1]	$7
Spain	—	—	650	2,412	—	—	[1]	3
Sweden	—	—	243	782	1	40	34	131
Taiwan	—	—	591	1,587	3	17	23	116
Turkey	125	$288	—	—	[1]	4	7	26
United Arab Emirates	—	—	183	505	1	12	1	5
United Kingdom	10	17	58	662	12	215	184	1,046
Venezuela	—	—	357	1,084	2	11	237	753
Other	8	24	441	2,130	99	930	485	3,113
Total	967	2,522	41,882	124,714	4,633	16,050	4,352	21,127

[r]Revised.
[1]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF MAGNESIUM, BY COUNTRY

Country	Waste and scrap		Metal		Alloys (magnesium content)		Powder, sheets, tubing, ribbons, wire, other forms (magnesium content)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989:								
Canada	3,015	$6,890	247	$998	651	$3,147	32	$127
France	—	—	—	—	31	232	—	—
Germany, Federal Republic of	60	113	—	—	26	77	—	—
Italy	—	—	—	—	129	440	—	—
Mexico	333	249	1	2	—	—	774	2,740
Netherlands	155	264	—	—	—	—	—	—
Norway	—	—	3,479	10,895	2,747	8,431	1	2
United Kingdom	60	111	54	173	245	2,375	1	59
Other	150	229	98	305	—	—	—	—
Total	3,773	7,856	3,879	12,373	3,829	14,702	808	2,928
1990:								
Canada	3,346	7,221	14,562	42,489	2,436	9,540	57	224
France	—	—	248	688	2	37	—	—
Germany, Federal Republic of	64	105	—	—	2	29	—	—
Italy	34	78	—	—	36	98	—	—
Mexico	214	161	33	82	—	—	1,107	3,981
Netherlands	281	434	—	—	—	—	—	—
Norway	—	—	1,166	3,481	2,624	7,946	—	—
United Kingdom	1	2	—	—	238	2,911	32	208
Other	135	136	130	285	6	165	1	7
Total	4,075	8,137	16,139	47,025	5,344	20,726	1,197	4,420

Source: Bureau of the Census.

TABLE 10

WORLD ANNUAL PRIMARY MAGNESIUM PRODUCTION CAPACITY,[1] DECEMBER 31, 1990

(Metric tons)

Continent and Country	Capacity
North America:	
Canada	61,500
United States	179,000
Total	240,500
South America: Brazil	10,600
Europe:	
France	15,000
Italy	10,000
Norway	41,000
U.S.S.R.	95,000
Yugoslavia	7,000
Total	168,000
Asia:	
China	9,000
India	600
Japan	13,000
Total	22,600
World total	441,700

[1]Includes capacity at operating plants as well as at plants on standby basis.

Refractories' products were sold primarily in the United States and the Pacific rim, and Radex's were marketed mainly in Europe. In addition to marketing cooperation, the two companies were planning on technical cooperation. During the same month, National Refractories & Minerals announced that it opened a new research center in Livermore, CA, for developing and testing refractories and minerals used in chemical and building material markets. A review of minerals producers in the Southwest United States discussed processing at National Refractories & Minerals, as well as Marine Magnesium Corp. and Basic Inc.[10]

In January, Asea Brown Boveri Inc. announced that it planned to sell the minerals subsidiaries of Combustion Engineering Inc. that it acquired in late 1988. Combustion Engineering owned the country's sole magnesite producer, Basic Inc., as well as Basic Magnesia Inc., which produced magnesium compounds from seawater in Florida. By yearend, no buyer was found for these operations.

Consumption and Uses.—Dead-burned magnesia refractories for use in metal, cement, and glass production furnaces continued to be the primary application for magnesium compounds in the United States. In 1990, agricultural applications (animal feed and fertilizer) were the dominant use for caustic-calcined magnesia, accounting for 36% of U.S. shipments. Chemical processing was the next largest segment, with 19% of total shipments. The following categories, with the individual components in parentheses in declining order, were the remaining end-use sectors for caustic calcined magnesia: metallurgical (refractories, electrical, water treatment, stack-gas scrubbing, and foundry), 18%; manufacturing (rayon, fuel additives, rubber, pulp and paper, and uranium processing), 17%; construction (oxychloride and oxysulfate cements, general construction, and insulation), 3%; pharmaceuticals and nutrition (medicinal and pharmaceutical, sugar, and candy), 3%; and unspecified uses, 4%.

Magnesium carbonate and magnesium sulfate were used principally in the chemical and pharmaceutical industries. Magnesium sulfate also was used in smaller quantities for animal feed and pulp and paper manufacturing. Magnesium hydroxide was used primarily in the pulp and paper and chemical industries. Magnesium chloride was used for oxychloride cements and in the chemical industry. Magnesium chloride brines were used for road dust control and chemical production.

Foundry applications accounted for 74% of domestic olivine shipments. Refractory uses represented 10%, slag control accounted for 5%, and the remaining 11% of olivine consumption was unspecified.

Markets and Prices.—Yearend prices for magnesium compounds, quoted in the Chemical Marketing Reporter, did not change from those at yearend 1989, with the exception of magnesium sulfate prices, which increased 1 cent per pound.

Foreign Trade.—Trade data for olivine were combined with data for other material by the Bureau of the Census and could not be separately identified. The Journal of Commerce Port Import/Export Reporting Service (PIERS) provides some data on materials that are transported by ship and gives some data on olivine. According to PIERS, 110,573 tons of olivine was imported from Norway during 1990. U.S. exports of olivine were 2,107 tons; Chile, 53%, and Peru, 39%, were the primary recipients.

TABLE 11

MAGNESIUM: WORLD PRIMARY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989	1990[e]
Brazil	4,356	5,488	5,865	6,200	8,700
Canada[e]	5,100	8,800	7,600	7,200	25,300
China[e]	3,000	3,000	3,200	3,200	3,400
France	13,361	13,601	r13,776	r14,600	14,000
Italy	12,417	7,626	5,436	r5,469	5,400
Japan	8,116	8,180	9,012	r8,381	2,12,843
Norway	56,522	56,907	50,300	49,827	2,48,222
U.S.S.R.[e]	89,000	90,000	91,000	91,000	88,000
United States	125,639	124,396	141,983	152,066	2,139,333
Yugoslavia	4,897	5,932	6,176	r6,100	6,000
Total	322,408	323,930	r334,348	r344,043	351,198

[e]Estimated. [r]Revised.
[1]Table includes data available through June 21, 1991.
[2]Reported figure.

TABLE 12

MAGNESIUM: WORLD SECONDARY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989	1990[e]
Brazil	1,767	1,376	r1,519	re1,600	1,600
Japan	r13,400	10,284	r10,109	r12,075	12,500
U.S.S.R.[e]	8,000	8,000	8,000	8,000	7,500
United Kingdom[e]	1,000	1,000	1,000	1,000	1,000
United States	41,807	45,165	50,207	51,200	[2]50,262
Total	r65,974	65,825	r70,835	r73,875	72,862

[e]Estimated. [r]Revised.
[1]Table includes data available through June 21, 1991.
[2]Reported figure.

TABLE 13

SALIENT MAGNESIUM COMPOUND STATISTICS

(Thousand metric tons and thousand dollars)

	1986	1987	1988	1989	1990
United States:					
Caustic-calcined and specified magnesias:[1]					
Shipped by producers:[2]					
Quantity	86	103	124	135	135
Value	$33,969	$27,565	$36,500	$39,529	$37,850
Exports, value[3]	$13,295	$14,167	$13,322	$2,263	$1,406
Imports for consumption, value[3]	$11,493	$4,575	$2,371	$13,657	$13,957
Refractory magnesia:					
Shipped by producers:[2]					
Quantity	249	296	371	348	335
Value	$73,172	$80,760	$103,400	$97,673	$94,962
Exports, value	$5,488	$3,240	$9,262	$10,685	$19,709
Imports for consumption, value	$36,718	$41,333	$42,885	$38,555	$32,858
Dead-burned dolomite:					
Sold and used by producers:					
Quantity	385	259	r413	r365	342
Value	$27,789	$21,766	r$30,182	r$28,294	$26,988
World production (magnesite)	r12,348	r11,356	r11,381	r11,343	e10,713

[e]Estimated. [r]Revised.
[1]Excludes caustic-calcined magnesia used in the production of refractory magnesia.
[2]Includes magnesia used by producers.
[3]Caustic-calcined magnesia only.

***World Review.*—Australia.**—Development of the Kunwarara magnesite deposit near Rockhampton, Queensland, progressed considerably during 1990. The three partners in the project, Pancontinental Mining Ltd., Australia; Radex-Heraclith, Austria; and Queensland Metals Corp. NL (QMC), Australia, awarded a contract for construction of the mine and beneficiation plant in August. These companies also reached an agreement with Bridge Oil Ltd. and Petroz NL for the purchase of natural gas to fuel the plant. Commissioning of the first stage of the plant was scheduled for the third quarter of 1991. At full annual capacity, the plant will produce 150,000 tons of dead-burned magnesia and 25,000 tons of fused magnesia. Reserves at the deposit were estimated to be 800 million tons, with 400 million tons of low-iron cryptocrystalline magnesite.

During the year, QMC was operating a pilot plant to produce high-purity magnesium chloride as feed for magnesium metal production, and the company was producing caustic-calcined magnesia at the pilot plant. QMC was engaged in joint research with Queensland Cement Ltd. to develop new stable magnesium cements and building products.

Mineral Holdings Australia Pty. Ltd. reportedly was seeking a partner to start a fused magnesia, alumina, and zirconia industry in Tasmania. This project would use the Cann Creek magnesite deposit and some magnesite from the company's mines to the south of Cann Creek. Imported feed would be used for the fused alumina and zirconia.

Czechoslovakia.—The State magnesite producer, Slovenske Magnezitove Zavody (SMZ), planned to implement two projects to improve its competitiveness in a free market economy. Although much of its production was exported predominantly to the U.S.S.R. and other centrally planned economy countries in the past, which have less advanced steel and cement operations, SMZ wanted to improve its technology and products without losing this market. The first of the new projects involved chemical treatment of magnesite to produce a low-iron magnesite with a grade of 99.5% MgO for magnesia-chrome brick manufacture. The second was production of the highest quality magnesite by flotation for brick manufacture. Planned annual capacities for these projects, which were due on-stream in 1991, were 26,000 tons and 15,000 tons, respectively.[11]

Greece.—Exploration and drilling work by Grecian Magnesite S.A. at its Carkara magnesite deposit resulted in defining the deposit to contain 1.6 million tons of proven reserves. A number of grades were identified, including a low-iron grade, averaging 46.5% MgO. After completing the exploration work, Grecian Magnesite planned to begin mining the deposit in late 1990 at an estimated kiln-feed production rate of 50,000 tons per year. Part of the new production will be for dead-burned

TABLE 14

U.S. MAGNESIUM COMPOUNDS SHIPPED AND USED

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined[1] and specified (USP and technical) magnesias	134,641	$39,529	134,727	$37,850
Magnesium hydroxide [100% $Mg(OH)_2$][1]	341,933	70,260	366,016	69,280
Magnesium sulfate (anhydrous and hydrous)	63,432	19,819	55,411	17,366
Precipitated magnesium carbonate[1]	2,332	641	2,821	703
Refractory magnesia	348,316	97,673	335,341	94,962

[1]Excludes material produced as an intermediate step in the manufacture of other magnesium compounds.

TABLE 15

YEAREND MAGNESIUM COMPOUND PRICES

Material		Price
Magnesia, natural, technical, heavy, 85%, f.o.b. Nevada	per short ton	$232
Magnesia, natural, technical, heavy, 90%, f.o.b. Nevada	do.	265
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	do.	.15

Source: Chemical Marketing Reporter.

magnesia and part for caustic-calcined magnesia.

Iran.—A 21,000-ton-per-year MgO production facility reportedly came on-stream in Birjand at the end of the first quarter. Ore for the $28 million plant was mined from seven deposits nearby, with total reserves estimated at 2.5 million tons.

Ireland.—By November, two new shaft kilns were operational at Premier Periclase Ltd.'s seawater magnesia plant in Drogheda, County Louth. The 50,000-ton-per-year kilns replaced existing rotary kilns at a cost of $16.5 million. With the commissioning of these new kilns, Premier will have the capability to produce large-crystal-size, low-boron magnesia for a wide range of applications, including magnesia-carbon refractories, for the most severe wear areas in oxygen and electric steelmaking furnaces. All of the company's production was exported, with its major markets in Austria, the Federal Republic of Germany, the United Kingdom, and the United States.[12]

Mexico.—Química del Mar SA de CV completed modifications at its seawater magnesia plant near Tampico early in the

TABLE 16

U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined magnesia:				
Canada	2,228	$1,022	66	$30
Germany, Federal Republic of	199	128	351	262
Mexico	871	306	170	92
Netherlands	858	536	1,444	800
Other	219	271	282	222
Total	4,375	2,263	2,313	1,406
Dead-burned and fused magnesia:				
Australia	1,027	316	24	34
Belgium	417	138	326	112
Canada	11,574	5,960	53,742	16,990
France	2,626	676	1,253	321
Israel	—	—	569	397
Korea, Republic of	482	249	424	229
Mexico	5,357	2,804	577	819
Taiwan	585	298	388	157

TABLE 16—Continued

U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Dead-burned and fused magnesia—Continued				
Venezuela	206	$59	993	$449
Other	251	185	314	201
Total	22,525	10,685	58,610	19,709
Other magnesia:				
Australia	311	456	164	201
Brazil	102	91	49	50
Canada	505	282	26,672	9,679
Colombia	180	309	229	388
France	187	77	820	274
Germany, Federal Republic of	2,273	1,206	101	58
Israel	1,942	643	6	38
Italy	190	63	203	156
Korea, Republic of	55	37	131	125
Mexico	548	747	6,396	2,864
Netherlands	41	515	216	76
Panama	116	11	71	57
Spain	2,023	1,016	1,320	688
Sweden	302	100	174	87
Taiwan	159	103	179	83
Thailand	123	63	191	104
United Kingdom	141	84	256	309
Venezuela	6,319	2,743	353	217
Other	r326	r667	216	654
Total	15,843	9,213	37,747	16,108
Crude magnesite:				
Australia	124	117	77	90
Belgium	185	331	204	454
Brazil	394	906	404	1,114
Canada	1,365	668	309	127
Germany, Federal Republic of	433	542	708	1,032
Greece	180	226	162	192
Hong Kong	—	—	195	171
Italy	1,214	1,119	895	1,105
Korea, Republic of	215	109	125	74
Martinique	—	—	519	83
Mexico	4,583	2,757	1,033	426
Netherlands	217	277	1,107	1,213
New Zealand	90	117	288	194
Romania	165	98	—	—
Spain	468	389	435	498
Taiwan	255	194	395	473
Venezuela	—	—	836	250
Other	r492	r449	317	564
Total	10,380	8,299	8,009	8,060

See footnote at end of table.

TABLE 16—Continued

U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Calcined dolomite:				
Canada	22,109	$6,323	1,398	$277
Colombia	1,046	185	200	25
Germany, Federal Republic of	—	—	360	122
Mexico	9,330	1,977	7,658	1,594
Peru	1,500	476	—	—
Saudi Arabia	—	—	505	60
Spain	2,000	659	—	—
Trinidad	956	163	—	—
Venezuela	2,500	847	—	—
Other	198	53	258	135
Total	39,639	10,683	10,379	2,213

[r]Revised.

Source: Bureau of the Census.

TABLE 17

U.S. EXPORTS OF MAGNESIUM COMPOUNDS

Year	Magnesium hydroxide and peroxide		Magnesium chloride (anhydrous and other)		Magnesium sulfate (natural kieserite and epsom salts)		Magnesium sulfate (other)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989	12,072	$3,673	2,201	$1,812	95	$96	483	$519
1990	6,342	6,245	4,763	6,468	241	393	2,816	1,059

Source: Bureau of the Census.

TABLE 18

U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined magnesia:				
Canada	56,069	$10,996	48,859	$9,988
China	7,569	808	18,896	1,525
Greece	6,456	789	9,939	1,406
Mexico	3,203	416	2,390	325
Spain	—	—	2,200	266
Turkey	2,108	534	1,482	328
Other	179	114	119	119
Total	75,584	13,657	83,885	13,957
Dead-burned and fused magnesia:				
Canada	9,746	4,582	3,743	2,095
China	61,382	4,914	67,905	7,293
Czechoslovakia	12,159	948	2,549	374
Greece	45,346	7,800	28,242	4,079
Hong Kong	4,230	414	—	—

TABLE 18—Continued

U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Dead-burned and used magnesia—Continued				
Ireland	13,551	$4,467	7,892	$2,694
Israel	1,122	404	7,592	2,818
Japan	11,384	2,955	6,616	2,451
Mexico	25,050	7,832	24,954	9,224
Netherlands	3,186	1,056	2,110	683
United Kingdom	15,484	3,107	3,233	1,008
Other	150	76	174	139
Total	202,790	38,555	155,010	32,858
Other magnesia:				
Canada	390	123	280	57
China	—	—	162	347
Germany, Federal Republic of	60	86	101	299
Israel	181	305	602	1,382
Japan	4,226	7,591	3,440	5,972
Mexico	335	156	—	—
United Kingdom	370	394	148	195
Other	r312	r539	304	321
Total	5,874	9,194	5,037	8,573
Crude magnesite:				
Canada	1,077	225	52	7
China	6,344	645	23	4
Denmark	—	—	100	23
France	158	66	18	10
Germany, Federal Republic of	55	8	524	66
Italy	259	127	622	180
Japan	424	250	526	360
Other	r55	r33	92	72
Total	8,372	1,354	1,957	722
Calcined dolomite:				
Canada	20,854	2,755	38,074	3,596
Germany, Federal Republic of	194	41	36	11
Ireland	10	4	—	—
Mexico	730	71	331	32
Total	21,788	2,871	38,441	3,639

rRevised.

Source: Bureau of the Census.

TABLE 19

U.S. IMPORTS FOR CONSUMPTION OF MAGNESIUM COMPOUNDS

Year	Magnesium hydroxide and peroxide		Magnesium chloride (anhydrous and other)		Magnesium sulfate (natural kieserite)		Magnesium sulfate (natural epsom salts)		Magnesium sulfate (other)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989	1,792	$3,091	5,994	$1,202	11,781	$540	166	$33	9,269	$2,076
1990	3,548	5,456	6,914	1,477	12,548	612	44	37	9,992	1,656

Source: Bureau of the Census.

TABLE 20

WORLD MAGNESIUM COMPOUNDS ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1990

(Thousand metric tons, MgO equivalent)

Continent and Country	Raw material	
	Magnesite	Seawater or brines
North America:		
Canada	160	—
Mexico	—	170
United States	100	912
Total	260	1,082
South America: Brazil	345	—
Europe:		
Austria	576	—
Czechoslovakia	700	—
France	—	30
Greece	652	—
Ireland	—	100
Italy	—	125
Netherlands	—	120
Norway	—	25
Poland	10	—
Spain	205	—
Turkey	285	—
U.S.S.R.	2,100	100
United Kingdom	—	200
Yugoslavia	240	—
Total	4,768	700
Africa:		
Kenya	170	—
South Africa, Republic of	119	—
Zimbabwe	2	—
Total	291	—
Asia:		
China	1,000	10
India	214	—
Israel	—	70
Japan	—	485
Korea, North	1,250	—
Korea, Republic of	—	50
Nepal	125	—
Total	2,589	615
Oceania: Australia	24	—
Grand total	8,277	2,397

[1]Includes capacity at operating plants as well as at plants on stand-by basis.

TABLE 21

MAGNESITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989	1990[e]
Australia	41,441	53,941	56,446	[e]55,000	60,000
Austria	1,084,360	946,943	1,121,585	[r]1,205,000	1,200,000
Brazil[2]	296,792	390,182	[r]404,126	[r]259,508	350,000
Canada[e 3]	144,000	150,000	150,000	150,000	150,000
China[e]	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
Colombia	14,936	[r]15,444	[r]17,760	[r]20,425	20,000
Czechoslovakia	666,000	671,000	630,786	[e]600,000	600,000
Greece	[r]944,000	[r]842,000	[r]847,000	[r]850,000	860,000
India	422,000	430,000	[r]507,873	[r]479,530	500,000
Iran[e 4]	[r]2,240	[r]2,240	[r]2,500	[r]2,800	3,000
Kenya	[e]300,000	—	—	—	—
Korea, North[e]	1,900,000	[r]1,500,000	[r]1,500,000	[r]1,500,000	1,500,000
Mexico	7,530	7,351	[r]7,538	[r]4,229	3,200
Nepal	63,190	38,388	45,000	[r]27,978	25,000
Pakistan	1,757	[r]3,824	3,081	[r]8,750	8,000
Philippines[e]	650	650	650	700	700
Poland	20,900	22,300	[r]23,900	[e]23,000	24,000
South Africa, Republic of	61,186	74,961	74,088	[r]75,695	[5]104,182
Spain[e]	700,000	710,000	[r 5]624,216	[r]620,000	600,000
Turkey	[r]1,306,645	[r]1,189,667	[r]1,125,844	[r]1,238,123	800,000
U.S.S.R.[e]	1,925,000	1,875,000	1,825,000	1,825,000	1,600,000
United States	W	W	W	W	W
Yugoslavia	423,000	403,000	383,000	[r]364,000	275,000
Zimbabwe	22,649	28,991	30,121	[r]33,423	30,000
Total	[r]12,348,276	[r]11,355,882	[r]11,380,514	[r]11,343,161	10,713,082

[e]Estimated. [r]Revised. 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 3, 1991.

[2]Series reflects output of marketable concentrates. Production of crude ore was as follows, in metric tons: 1986—648,752; 1987—860,163; 1988—810,837; 1989—1,385,565; and 1990—1,000,000 (estimated).

[3]Magnesitic dolomite and brucite. Figures are estimated on the basis of reported tonnage dollar value.

[4]Year beginning Mar. 21 of that stated.

[5]Reported figure.

year. As a result of these modifications, the company switched from producing a 95% dead-burned magnesia to a low-boron, 97% dead-burned magnesia. Annual plant capacity was reduced temporarily from 70,000 tons to 45,000 tons during the switch, but by yearend, additional equipment was installed to reach the original 70,000-ton-per-year capacity. Química del Mar also was upgrading its caustic-calcined magnesia from 95% MgO to 97% MgO.[13]

South Africa, Republic of.—Mintek, a minerals and metals research organization, conducted laboratory-scale tests on seawater production of high-grade magnesia. Magnesia in the Republic of South Africa was produced from magnesite, but the grade was not high enough to be used for refractories, so the country relied on imports to meet this need. From Mintek's calculations, a 50,000-ton-per-year plant would yield an annual rate of return on investment of 15%.

Current Research.—The world's first magnesium oxide ceramic fiber reportedly was produced by a new process developed at the Department of Energy's

Argonne National Laboratory. The new process involved mixing magnesium oxide particles with a plastic binder, exposing a thin stream of the mixture to turbulent air, and firing it. Normally, ceramic fibers are made commercially by a variety of techniques that are specifically tailored to the type of fiber manufactured, and the fibers are made in batches. Researchers claimed this new process could be carried out continuously and could be used on any sinterable ceramic. Possible future uses for new ceramic fibers made by this process include electrodes for high-temperature batteries and porous substrates for catalysts.

The Lithium Div. of FMC Corp. opened a pilot plant at its Bessemer City, NC, plant to treat books by a company-developed process to extend the books' useful life. This process, which retards brittleness during aging, involves immersing the book in an organic solvent containing a magnesium compound and then removing the solvent. The magnesium compound remains in the paper and forms a buffer. FMC claims that this process can preserve the book for an additional 10 to 12 years. The pilot plant can treat up to 300,000 books per year. If the treatment is widely accepted by libraries, FMC planned to build four commercial plants that can treat 2 to 5 million books per year at a projected cost of $6 per book.

In a review of refractories consumption by the cement industry, average consumption rates of various refractories by the U.S. industry were estimated. Of the total average consumption of refractories of 1.99 pounds per ton of clinker produced, magnesia-chrome refractories constituted 29% and magnesia-spinel constituted 13% of the total. Additional information was presented on the specific areas of the kiln in which these types of refractories were normally installed.[14]

OUTLOOK

In its annual review of magnesium supply and demand, the International Magnesium Association predicted an average annual growth rate of about 3% for world primary magnesium shipments from 1989 to 1995, with the largest growth occurring in Western Europe and North America. Diecasting, at a predicted average annual growth rate of almost 10%, was the end use contributing the most to the total forecast. About 70% of magnesium diecastings worldwide were used by the automotive industry, and with the potential increase in the Corporate Average Fuel Economy rates in the United States, automobile manufacturers will continue to increase their use of magnesium components to reduce total vehicle weight.[15]

Refractories, which were the dominant use for magnesium compounds, continued to have the greatest effect on overall demand. As producers develop magnesia-base refractories that are longer lived and that can be substituted for other refractories, the overall use of these refractories will increase. Conversely, because of these characteristics, refractory linings in these furnaces will not have to be replaced as often, which will decrease demand. The synergistic effects of these trends likely will result in a stagnant demand for magnesia-base refractories.

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TABLE 22

MAGNESIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons of contained magnesium)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
WORLD PRODUCTION											
United States:											
Nonmetal	727	690	512	567	574	420	412	464	r573	r513	499
Metal	[1]153	140	93	104	144	136	125	124	142	152	139
Total	880	830	605	671	718	556	537	588	r715	r665	638
Rest of world:											
Nonmetal	4,726	4,668	4,371	4,777	4,676	4,807	r5,009	r4,723	r4,780	r4,769	e4,588
Metal	162	169	161	156	184	189	196	200	192	r192	e212
Total	4,888	4,837	4,532	4,933	4,860	4,996	r5,205	r4,923	r4,972	r4,961	e4,800
World total	5,768	5,667	5,137	5,604	5,578	5,552	r5,742	r5,511	r5,687	r5,626	e5,438
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
U.S. production:											
Nonmetal	727	690	512	567	574	420	412	464	r573	r513	499
Primary metal	153	140	93	104	144	136	125	124	142	152	139
Secondary metal (old scrap)	16	22	21	23	24	24	23	23	28	28	31
Imports:											
Nonmetal	46	50	39	61	115	134	160	164	198	171	147
Metal	4	6	5	5	9	8	8	11	14	12	27
Industry stocks, metal, Jan. 1	40	44	57	42	25	32	39	39	28	25	26
Total U.S. supply	986	952	727	802	891	754	767	825	r983	r901	869
Distribution of U.S. supply:											
Exports:											
Nonmetal	59	32	20	15	27	25	25	20	34	26	59
Metal	52	32	36	43	44	36	40	44	50	57	52
Industry stocks, metal, Dec. 31	44	57	42	25	32	39	39	28	25	26	26
Industrial demand[2]	831	831	629	719	788	654	663	733	r874	r792	732
U.S. DEMAND PATTERN											
Nonmetal:											
Refractories	629	609	446	508	531	402	376	453	r535	r470	413
Chemicals	85	99	85	105	131	127	171	155	r202	r188	174
Total	714	708	531	613	662	529	547	608	r737	r658	587
Metal:											
Cans and containers	19	20	17	19	23	23	22	39	39	42	45
Transportation	36	38	25	31	36	38	33	38	38	36	38
Machinery	34	34	33	34	29	22	27	19	20	17	20
Chemicals	7	8	6	7	8	5	3	2	1	1	1
Nonferrous metal production	10	13	7	6	9	12	9	5	11	12	11
Iron and steel desulfurization	NA	NA	NA	NA	10	12	12	13	15	15	16
Iron and steel foundries	5	5	4	3	4	3	3	2	3	2	1
Other	6	5	6	6	7	10	7	7	10	9	13
Total	117	123	98	106	126	125	116	125	137	134	145
Total industrial demand	831	831	629	719	788	654	663	733	r874	r792	732
Total U.S. primary demand[3]	815	809	608	696	764	630	640	710	r846	r764	701
Total U.S. demand for primary metal[4]	101	101	77	83	102	101	93	102	109	106	114

eEstimated. rRevised. NA Not available; included in "Other."

[1]Derived from production data published by the International Magnesium Association and the Canadian Department of Energy, Mines and Resources.

[2]Sum of total nonmetal and total metal demands.

[3]Total U.S. demand less U.S. recovery from secondary metal.

[4]U.S. demand for metal less U.S. recovery from secondary metal.

MANGANESE

By Thomas S. Jones

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Manganese is essential to iron and steel production by virtue of its sulfur-fixing, deoxidizing, and alloying properties. Currently, no practical approaches exist for replacing it with other materials or for obtaining the bulk of U.S. requirements from domestic sources. Strategic concerns of the United States for manganese largely apply also to Japan and Western Europe.

In 1990, ironmaking and steelmaking continued to account for about 90% of domestic manganese demand. Unit consumption rates for manganese were lower in ironmaking and higher in steelmaking than in 1989. Government inventories of manganese, all forms, still represented more than 2 years of apparent consumption. As reflected by the data in table 1, U.S. imports of key manganese materials decreased overall compared with those of 1989. Imports of ore were the least since 1984.

For the third consecutive year, the actual price of metallurgical-grade manganese ore rose substantially to a new record high. This increase was stimulating development of modest amounts of additional ore production in Australia and Canada. Major producers were yet to carry out any significant expansions in output capability.

The level and nature of manganese use by the United States is not expected to change significantly in the near future, but the level will be subject to fluctuations in domestic and global steel production. Political and economic developments have made uncertain the U.S.S.R.'s future status as a major ore producer and supplier of ore to Eastern Europe.

DOMESTIC DATA COVERAGE

Data on domestic consumption of manganese ore, exclusive of that consumed within the steel industry, are collected by means of the "Manganese Ore and Products" survey. The approximately 20 firms canvassed by means of this survey process ore by such methods as grinding and roasting or consume it in the manufacture of manganese ferroalloys, metal, and chemicals. In 1990, responses were obtained from all firms canvassed, whose collective consumption is believed to represent that of the United States except for negligible quantities consumed by other firms, if any. The aggregated consumption data so obtained were incorporated into table 5 but only displayed within totals to avoid disclosing proprietary data.

TABLE 1

SALIENT MANGANESE STATISTICS

(Thousand short tons, gross weight)

	1986	1987	1988	1989	1990
United States:					
Manganese ore (35% or more Mn):					
Exports	42	63	68	57	77
Imports for consumption	463	341	512	639	338
Consumption	e500	e533	e554	616	548
Stocks, Dec. 31: Consumers	e455	e456	e458	518	418
Ferromanganese:					
Exports	4	3	3	9	8
Imports for consumption	396	368	531	476	419
Consumption	376	409	468	440	455
Stocks, Dec. 31: Consumers and producers	93	48	91	75	62
World:					
Production of manganese ore	r27,523	r26,006	r26,817	r27,626	e27,192

e Estimated. r Revised.

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. Govern-

ment 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 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 1990, with the cost of manganese in metallurgical ore taken as 1.0, the corresponding approximate costs per manganese unit were 2.2 for high-carbon ferromanganese, 1.7 for silicomanganese, 3.3 for medium-carbon ferromanganese, and 5.5 for manganese metal. Metallic manganese is little used per se because it is typically brittle and unworkable.

Manganese is added to aluminum using aluminum-manganese master alloys that typically contain 25% Mn, briquets of compacted aluminum and manganese powders that typically contain 75% Mn, and electrolytic manganese metal.

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).

Other manganese materials and some of their uses include manganese sulfate and manganous oxide (MnO) for animal feed and soil conditioners, ground manganese ore for brick coloring, and potassium permanganate for water treatment.

Industry Structure

Makeup of the world's manganese ore producers is chiefly as follows: Australia, Groote Eylandt Mining Co. Pty. Ltd. (GEMCO); Brazil, Cia. Vale do Rio Doce (CVRD) 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); Ghana, Ghana National Manganese Corp.; India, more than 200 mines, with Manganese Ore India Ltd. the most prominent company; Mexico, Cía. Minera Autlán de C.V. (Autlán); Republic of South Africa, The Associated Manganese Mines of South Africa Ltd. (AMMOSAL) and Samancor Ltd.; and the U.S.S.R., two large complexes, mining the Chiatura Basin in Georgia and the Nikopol' Basin in the Ukraine. Most ore produced goes into metallurgical applications.[1] Ore for nonmetallurgical uses generally is supplied by the large-scale producers mentioned plus smaller ones elsewhere.[2]

In recent years, the U.S.S.R. has been supplying more than 1 million tons[3] of ore annually to Eastern Europe. Such exports were notably lower in 1987 and appear likely to decline considerably in the future. Otherwise, the principal source of ore to the international market has been an oligopolistic-like group of countries consisting of Australia (GEMCO), Brazil (ICOMI and CVRD), Gabon (COMILOG), and the Republic of South Africa (AMMOSAL and Samancor).

Smelting of ore into manganese ferroalloys is much more diversified than ore production. Leading ferroalloy producers are as follows: Brazil, Cia. Paulista de Ferro-Ligas (a number of plants); China, many plants; France, Société du Ferromanganèse de Paris-Outreau (SFPO); Federal Republic of Germany, Thyssen Stahl AG; Japan, Japan Metals & Chemicals Co. Ltd. and Mizushima Ferroalloy Co. Ltd.; Mexico, Autlán; Norway, Elkem A/S; Republic of South Africa, Metalloys Ltd., a subsidiary of Samancor; and the U.S.S.R., a number of plants. The U.S.S.R. is by far the largest producer.

Four market economy countries (MEC's) currently produce metal, all electrolytically, in decreasing order of capacity: the Republic of South Africa, the United States, Japan, and, beginning in 1989, Brazil. China and the U.S.S.R. produce metal, including that produced metallothermically in the U.S.S.R. World productive capacity for metal was given as 84,000 tons annually as of 1985,[4] and would be approximately the same in 1990.

Annual world capacity for EMD was assessed as 218,000 tons in 1989, including capacities of 78,000 tons for Japan and 39,000 tons for the United States.[5] The principal producer of CMD is Belgium's Sedema S.A., with annual capacity of about 40,000 tons.

Geology-Resources

The world's major land-based economic resources of manganese are of two principal types: marine chemical sediments and secondary enrichment deposits.[6] Marine chemical deposits represent a majority of known resources. In 1985, the Manganese Centre (name changed in 1989 to International Manganese Institute) estimated that known relatively high-grade deposits (those with a manganese content of at least 44%) contained about 360 million tons of manganese.[7] As given in the "World Review" section of this chapter, the reserve base for manganese can be considered more than 10 times this size. The world's potential supply of manganese also includes extensive marine accumulations, such as oxide nodules on deep ocean floors and oxide crusts on midocean ridges, whose commercial future is indeterminate. Among the more common minerals occurring in manganese ores are oxides, including pyrolusite, a mineral form of manganese dioxide; the oxysilicate braunite; and rhodochrosite, a mineral manganese carbonate.

Technology

Exploration.—Highly selective methods of locating land manganese deposits do not exist, but interpretation of geologic environments can assist prospecting.[8]

Mining.—Most manganese ore is produced by mechanized operations. Stan-

dard earth-moving equipment is used in surface mining. Underground mining generally is by room-and-pillar techniques. Selective mining may be practiced in producing battery- and chemical-grade ores from a deposit being worked principally for metallurgical-grade ore.

Beneficiation.—Crushing, screening, washing, jigging, and tabling as well as flotation, heavy-medium, and high-intensity magnetic separation are being or have been used to upgrade raw manganese ore into usable concentrates. Carbonate ore may be calcined. Ore fines are sintered into bulkier shapes at some ferroalloy plants, a practice being adopted increasingly by ore producers as well.

Processing.—Electrothermy is the predominant method of manufacturing manganese ferroalloys, as by the submerged-arc-furnace process.[9] 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.[10] Chemical manganese dioxide can be prepared by precipitating manganese carbonate from a sulfate solution and decomposing the carbonate to oxide.[11]

Recycling.—Scrap recovery specifically for manganese is insignificant. Considerable manganese reenters processing as a minor component of steel scrap, steel slag, and nonferrous scrap.

Economic Factors

As noted in a study of the Minerals Availability Program (MAP) of the U.S Bureau of Mines, transportation is the most significant cost element in the production of manganese concentrates.[12] In a recent MAP assessment of costs for most major mines in MEC's, transportation accounted for about two-thirds of concentrate cost. Transportation costs were about equally divided between transportation to the port and transportation to the market. Also according to this assessment, the major mines for metallurgical-grade ore of the MEC's are quite competitive as to ore production cost. Of the considerable resources evaluated, about 80% had estimated production costs within 20% of the lowest cost.

Operating Factors

Environmental Requirements.—In 1988, the Environmental Protection Agency (EPA) imposed an annual requirement of reporting releases to the environment of manganese chemical compounds and metal (40 CFR 372). This initially applied to operations classifiable within SIC 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. The threshold for annual use of these materials other than in their manufacturing and processing was 10,000 pounds.

Toxicity.—Manganese is an essential element for people, animals, and plants. In excess, it can be harmful to the respiratory and nervous systems.[13] Thus, manganese can be an industrial poison, but normally is not a hazard.

ANNUAL REVIEW

Legislation and Government Programs

Manganese, including ferromanganese and silicomanganese, was on a revised list of 10 strategic minerals currently imported from the Republic of South Africa that the U.S. Department of State certified to be essential for the economy or defense of the United States and unavailable from reliable and secure suppliers. The revised list was published on January 18 (55 FR 1764) in accordance with section 303(a)(2) of the Comprehensive Anti-Apartheid Act of 1986, as amended. It replaced the prior list of January 7, 1987, that also included manganese.

The U.S. Department of the Interior's Minerals Management Service and the Department of Business and Economic Development of the State of Hawaii jointly released a final environmental impact statement for a proposed marine mineral lease sale that could lead to eventual mining of cobalt-rich manganese crusts in the Pacific Ocean near the Hawaiian Archipelago and Johnston Island. The proposed lease area was in the Exclusive Economic Zone and was estimated to contain significant resources of cobalt, manganese, and nickel. The impact statement analyzed several processing schemes, one of which involved pyrometallurgical recovery of manganese.[14]

Among new regulatory programs affecting manganese materials, the 1990 amendments to the Clean Air Act included manganese compounds among substances to be regulated under the provisions of that act (Public Law 101-549, effective November 15, 1990). The EPA placed manganese and 26 other new substances on a new priority list of candidates for regulation under the Safe Drinking Water Act. The list was effective as of December 31, 1990 (56 FR 1470).

Strategic Considerations

Security of Supply.—Manganese, for which there is no economical substitute, is essential to steelmaking. Steel producers in the MEC's of the United States, Japan, and Western Europe shared a common concern about lack of economically minable domestic manganese deposits. Also, MEC ore supply was 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. According to one analysis, an index for security of manganese ore supply to such MEC steel producers declined during 1979–87.[15] The United States was additionally concerned about supply of manganese ferroalloys because its domestic ferroalloy industry had declined well below self-sufficiency in manganese.

Stockpile.—The status of goals and inventories of manganese materials in the National Defense Stockpile at the end of 1990 is given in table 2. The only change in goals during 1990 was reduction of that for natural battery ore from 62,000 tons to 25,000 tons, effective late in June. Changes in yearend inventories and sales during 1990 are summarized in table 3. Actual physical changes occurred only for metallurgical ore and high-

TABLE 2

U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND INVENTORIES FOR MANGANESE MATERIALS IN 1990

(Short tons, gross weight)

Material	Stockpile goals	Physical inventory, Dec. 31				
		Uncommitted			Sold, pending shipment	Grand total
		Stockpile grade	Nonstockpile grade	Total		
Natural battery ore	25,000	169,511	33,425	202,936	787	203,723
Synthetic manganese dioxide	25,000	3,011	—	3,011	—	3,011
Chemical ore	170,000	172,655	89	172,744	417	173,161
Metallurgical ore	2,700,000	1,812,039	890,839	2,702,878	15,718	2,718,596
High-carbon ferromanganese	439,000	868,540	—	868,540	—	868,540
Medium-carbon ferromanganese	—	29,072	—	29,072	—	29,072
Silicomanganese	—	23,574	—	23,574	—	23,574
Electrolytic metal	—	14,172	—	14,172	—	14,172

carbon ferromanganese. The changes for chemical ore and medium-carbon ferromanganese resulted from accounting adjustments, which also caused a small adjustment for high-carbon ferromanganese. Most of the change for high-carbon ferromanganese occurred in June when the Defense Logistics Agency accepted into inventory 56,152 tons produced under the stockpile upgrading program. On an overall basis, these changes insignificantly diminished the reserve of approximately 2 million tons of contained manganese being held by the Government.

Issues

The United States has been lacking in reserves and significant production of manganese almost since the start of domestic steel production. Extensive efforts to discover worthwhile ore deposits or effective methods of using low-grade resources, including steel slags, have resulted in little commercial promise. In a 1985 report, the U.S. Congressional Office of Technology Assessment (OTA) concluded that improvements in steel production technology offered the best prospect for reducing U.S. manganese import vulnerability.[16] In so doing, OTA discounted ocean mining for the present, a view shared by most participants at a December 1989 conference on marine mining.[17]

The setting up and maintenance of a large stockpile has been the most tangible aspect of Government manganese programs. Management of this stockpile is a key part of Government policy. Current law limits use of the stockpile to emergency situations, but its mere presence has had economic implications. Questions that have arisen from time to time include what the makeup and size of the manganese stockpile should be and whether it should be used for economic purposes.

Production

Ore and Concentrate.—Production and shipments consisted only of manganiferous material having a natural manganese content of 5% to 15% mined in Cherokee County, SC, for use in coloring brick. Shipments data were not published to avoid disclosing proprietary data. Some use of this manganiferous material to color brick was being displaced by use of ground manganese ore.

Ferroalloys, Metal, and Synthetic Dioxide.—Production statistics for these materials were not published to avoid disclosing proprietary data. Plant sites and products are given in table 4. The production program at the Marietta, OH, plant of Elkem Metals Co., the only producer of manganese ferroalloys, included high-carbon ferromanganese for the Government stockpile and silicomanganese to compensate for shutdowns at other plants of the parent company in Canada and Norway.

Consumption, Uses, and Stocks

Metallurgical applications accounted for most manganese consumption, about 90% for steelmaking. This can be deduced from the data relating to manganese end use in tables 5 and 6 plus certain other information. Table 7 presents industry averages for pounds of manganese used in ironmaking and steelmaking operations per ton of raw steel produced. These 1990 consump-

TABLE 3

SALES AND INVENTORY CHANGES FOR MANGANESE MATERIALS IN U.S. GOVERNMENT STOCKPILE, 1990

(Short tons, gross weight)

Material	Sales		Change in yearend inventory
	Stockpile grade	Nonstockpile grade	
Chemical ore	—	—	+938
Metallurgical ore	—	12,320	−146,818
High-carbon ferromanganese	—	—	+56,383
Medium-carbon ferromanganese	—	—	+15

TABLE 4

DOMESTIC PRODUCERS OF MANGANESE PRODUCTS IN 1990

Company	Plant location	Products[1]				Type of process
		FeMn	SiMn	Mn	MnO_2	
Chemetals Inc.	Baltimore, MD	—	—	—	X	Chemical.
Do.	New Johnsonville, TN	—	—	—	X	Electrolytic.
Elkem Metals Co.	Marietta, OH	X	X	X	—	Electric furnace and electrolytic.
Kerr-McGee Chemical Corp.	Hamilton, MS	—	—	X	—	Electrolytic.
Do.	Henderson, NV	—	—	—	X	Do.
Ralston Purina Co.:						
Eveready Battery Co.	Marietta, OH	—	—	—	X	Do.
RAYOVAC Corp.: Materials Div.	Covington, TN	—	—	—	X	Do.

[1] FeMn, ferromanganese; SiMn, silicomanganese; Mn, electrolytic manganese metal; MnO_2, synthetic manganese dioxide.

tion rates, derived from the reported data in tables 5 and 6, were lower for ironmaking but higher for steelmaking than in 1989.

Relatively small quantities of manganese were used for alloying with nonferrous metals, chiefly aluminum. For alloying with aluminum in 1990, the proportion of manganese added as metal was significantly less in relation to that added as manganese-aluminum briquets and other forms than in immediately prior years.

Nonmetallurgical applications for manganese included dry cell batteries, plant fertilizers, animal feed, brick coloring, and manganese chemicals.[18] Two U.S. firms discontinued operations involving manganese in battery production. Bright Star Industries, Clifton, NJ, ended its small production of dry cells, and Eastman Kodak Co. stopped the production of lithium-manganese dioxide batteries that had begun only in 1986 at its Newark, NY, plant.

In addressing environmental concerns associated with dry cell batteries, domestic producers and their foreign affiliates joined in international efforts to minimize mercury usage in such batteries. Mercury contents, used mainly to control hydrogen gassing, were being reduced to zero in carbon-zinc cells (based on natural manganese dioxide) and to 0.025% by weight or less in alkaline cells (based on synthetic manganese dioxide).[19]

Markets and Prices

Manganese Ore.—For the third successive year, the price of metallurgical manganese ore increased significantly and set a new record high for price in commercial transactions. Prices paid by West European and Japanese consumers showed advances in the range of 50% in the face of reported tightness in the supply of high-grade ore and no expansions by major ore producers. The process for setting prices for annual contracts was relatively protracted, extending into August before agreement was reached between South African ore suppliers and Japanese buyers.

The average price, c.i.f. U.S. ports, for metallurgical ore containing 48% manganese was assessed as $3.78 per metric ton unit (mtu), an increase of about 40% over that of $2.76 per mtu in 1989. The mtu is 1% of a metric ton or 22.05 pounds of contained manganese. Dividing the mtu price by 22.05 gives the price per pound of manganese in ore, which was 17.1 cents in 1990 and 12.5 cents in 1989. The price of a metric ton of ore is obtained by multiplying the mtu price by the percentage manganese content of the ore. Mtu pricing has superseded long ton unit (ltu) pricing; in the latter system, the respective 1990 and 1989 prices were $3.84 and $2.80 per ltu.

The ore market consists of a number of submarkets because of differences between ores according to the various end uses such as ferroalloy production, blast furnace ironmaking, and battery manufacture. Table 8 gives the trend for metallurgical ore during the past two decades.

Manganese Ferroalloys.—The general price trend for manganese ferroalloys, as given by quotations for imports, was similar to that in 1989: upward in the first part of the year, then downward, and finally some firming of prices near yearend. The increased cost of ore to ferroalloy producers and little change in the rate of raw steel production, at least domestically, appeared to support prices for high-carbon ferromanganese and

TABLE 5

U.S. CONSUMPTION AND INDUSTRY STOCKS OF MANGANESE ORE,[1] BY USE

(Short tons, gross weight)

Use	Consumption		Stocks, Dec. 31	
	1989	1990	1989	1990
Manganese alloys and metal	W	W	W	W
Pig iron and steel	135,000	90,000	167,000	101,000
Dry cells, chemicals, miscellaneous[2]	W	W	W	W
Total	616,000	548,000	518,000	418,000

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 6

U.S. CONSUMPTION, BY END USE, AND INDUSTRY STOCKS OF MANGANESE FERROALLOYS AND METAL IN 1990

(Short tons, gross weight)

End use	Ferromanganese			Silico-manganese	Manganese metal
	High carbon	Medium and low carbon	Total		
Steel:					
Carbon	256,022	87,152	343,174	74,121	(1)
Stainless and heat-resisting	13,897	(1)	13,897	5,117	3,101
Full alloy	34,883	8,612	43,495	18,013	725
High-strength, low-alloy	27,364	5,202	32,566	5,969	(1)
Electric	(1)	(1)	(1)	(1)	(1)
Tool	259	3	262	(1)	46
Unspecified	134	639	773	231	1,815
Total steel[2]	332,559	101,608	434,167	103,451	5,687
Cast irons	12,938	1,000	13,938	1,732	—
Superalloys	W	—	W	—	180
Alloys (excluding alloy steels and superalloys)	950	W	950	W	[3]19,047
Miscellaneous and unspecified	6,067	233	6,300	2,767	510
Total consumption	352,514	102,841	455,355	[4]107,950	25,424
Total manganese content[5]	275,000	82,000	357,000	71,000	25,000
Stocks, Dec. 31:					
Consumers and producers	47,592	13,949	61,541	8,328	3,807

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1] Withheld to avoid disclosing company proprietary data; included with "Steel: Unspecified."
[2] Includes estimates.
[3] Approximately 90% of this subtotal was for consumption in aluminum alloys.
[4] Internal evaluation indicates that silicomanganese consumption is considerably understated.
[5] Estimated based on typical percent manganese content (rounded).

TABLE 7

U.S. UNIT CONSUMPTION OF MANGANESE IN IRONMAKING AND STEELMAKING

(Pounds per ton of raw steel unless otherwise specified)

	Form used	1989	1990
	IRONMAKING		
Basis:	Production of raw steel, million tons[1]	97.9	98.9
	Ore[2]	1.2	.8
	STEELMAKING		
Basis:	Production of raw steel and steel castings, million tons	99.1	[e]100.0
	Ore[2]	(3)	(3)
	Ferromanganese	6.7	6.8
	Silicomanganese	1.3	1.4
	Manganese metal	.1	.1
	Total, steelmaking	8.1	8.3

[e] Estimated.
[1] As ingots, continuous- or presssure-cast blooms, billets, slabs, etc.
[2] Containing 35% or more manganese.
[3] None reported.

manganese metal. The year-average price for high-carbon ferromanganese was about 4% higher than that of 1989. Silicomanganese reportedly was in oversupply, so that its year-average price was about 28% lower than that of 1989. Possibly also contributing to a comparative weakness in silicomanganese price was an excess of ferrosilicon, which at least some steel producers could use in combination with ferromanganese in place of silicomanganese.

For high-carbon ferromanganese containing 78% manganese, the price range of imported material, f.o.b. Pittsburgh or Chicago warehouse, began 1990 at $625–$645 per long ton of alloy, which was almost unchanged from that at the end of 1989 and only slightly below the range of $630–$650 at the end of 1990. A peak of $650–$665 was reached in early March.

The price range for imported silicomanganese with 2% carbon, in cents per pound of alloy, f.o.b. Pittsburgh or Chicago warehouse, also showed little net

TABLE 8

TIME-PRICE RELATIONSHIPS FOR MANGANESE IN METALLURGICAL ORE

Year	Average annual U.S. price, dollars per metric ton unit	
	Actual price	Based on constant 1982 dollars
1970	0.53	1.27
1971	.59	1.33
1972	.59	1.27
1973	.64	1.29
1974	.89	1.64
1975	1.36	2.29
1976	1.43	2.26
1977	1.46	2.16
1978	1.38	1.91
1979	1.38	1.75
1980	1.67	1.95
1981	1.69	1.80
1982	1.56	1.56
1983	1.36	1.31
1984	1.40	1.30
1985	1.41	1.27
1986	1.32	1.16
1987	1.27	1.08
1988	1.75	1.44
1989	2.76	2.18
1990	3.78	2.87

movement in 1990, beginning the year at 26-28 and ending at 25.75-26.5. The peak came early in June at 28.25-29.

As given by Metals Week, domestic producer prices (Elkem Metals) for high-carbon ferromanganese and silicomanganese were the same throughout 1990 as at the end of 1989. These prices, f.o.b. plant or warehouse, were $695 for high-carbon ferromanganese and 35 cents for silicomanganese.

Manganese Metal.—For bulk shipments of domestic material, f.o.b. shipping point, trade journals listed a price range of 91-96 or 91-95 cents per pound, the same as at the end of 1989, until mid-November. At that point, citing the high cost of ore, domestic producers raised their price for the balance of the year to $1.04 or $1.05 per pound.

Foreign Trade

Data for exports are summarized in table 9. For ore, unit values again indicated exports to Canada, the majority of exports to countries other than Canada and Mexico, and reexports of 14,243 tons (all to Canada) were metallurgical ore. All reported ore exports to Mexico appeared to have been transshipments of Gabonese ore. Reported exports of spiegeleisen were 855 tons having relatively low unit value, as compared to imports of 187 tons having relatively high unit value.

For all aggregated categories of imports for which data are given in table 10, quantities were less in 1990 than in 1989 except for manganese dioxide. In terms of contained manganese, the decline was less for the sum of ferroalloy plus metal than for the sum of ore plus dioxide; the corresponding ratio, ferroalloy plus metal divided by ore plus dioxide, was the greatest since 1982. Overall imports of ore were the least since 1984 and those of ferromanganese decreased for the third consecutive year. For ore and ferromanganese, average contents returned to values more typical of those in recent years. Content of ore increased to 48.5% and that of ferromanganese to 78.4%.

Among imports of manganese chemicals, all those of dioxide apparently were synthetic dioxide except for 4 tons from Morocco. The quantity of potassium permanganate imported from China rose again to a record amount. Entries for Mexico listed under imports classified as "Other sulfates," which includes manganese sulfate, totaled 11,052 tons valued at $5.1 million.

The schedule of tariffs that applied during 1990 to U.S. imports of selected manganese materials is given in table 11.

World Review

Capacity.—The rated capacity data in table 12 are as of December 31, 1990, and are only slightly changed from those of the previous year. 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;[20] no domestic deposits qualify.[21] World reserves of manganese, on the same basis as capacity, are given in table 13 with no distinction between ore type or application. This table excludes perhaps 1% to 2% of total known reserves. These are in nonlisted countries having a similar proportion of world production, as can be seen from table 15.

Australia.—An approximate one-tenth decrease in production of manganese ore by GEMCO was attributed by trade journals partly to the U.S.S.R. not

TABLE 9

U.S. EXPORTS OF MANGANESE ORE, FERROALLOYS, AND METAL, BY COUNTRY

Country	1989		1990	
	Gross weight (short tons)	Value (thousands)	Gross weight (short tons)	Value (thousands)
ORE AND CONCENTRATES WITH 20% OR MORE MANGANESE				
Canada	16,624	$1,413	20,958	$1,535
Mexico[1]	35,952	2,957	52,641	6,807
Other	4,615	643	3,502	955
Total[2]	57,191	5,014	77,101	9,297
FERROMANGANESE, ALL GRADES				
Belgium	510	490	295	332
Canada	3,108	2,650	5,744	4,302
Chile	1,451	688	15	21
Mexico	1,593	1,240	465	443
United Kingdom	454	405	466	533
Other	[3]1,898	[3]1,838	1,047	932
Total[2]	9,014	7,310	8,032	6,565
SILICOMANGANESE				
Canada	1,690	990	1,141	1,031
Mexico	3,466	2,578	200	145
Trinidad	246	159	389	249
Other	457	342	244	242
Total[2]	5,858	4,068	1,974	1,666
METAL, INCLUDING ALLOYS AND WASTE AND SCRAP				
Canada	1,097	2,422	1,882	5,217
Japan	756	1,194	1,188	2,036
Luxembourg	422	668	983	1,568
Netherlands	1,378	2,609	1,256	2,191
Other	[3]2,012	[3]3,738	1,467	3,031
Total[2]	5,667	10,632	6,773	14,043

[1] Virtually all apparently transshipments from Gabon.
[2] Data may not add to totals shown because of independent rounding.
[3] Unspecified group of countries differs from that in the 1989 Minerals Yearbook.

Source: Bureau of the Census, adjusted by the U.S. Bureau of Mines.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS, METAL, AND SELECTED CHEMICALS, BY COUNTRY

Country	1989			1990		
	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)
ORE AND CONCENTRATES WITH 20% OR MORE MANGANESE						
All grades						
Australia	115,844	60,436	$9,492	68,986	35,873	$9,201
Brazil	216,526	[1] 93,283	10,481	51,895	22,776	3,170
Canada[2]	2,173	1,086	49	—	—	—
Gabon[3]	218,039	[1] 109,637	19,196	150,059	74,766	20,928
Ghana	5,692	2,562	148	5,589	2,515	434
Mexico[1]	25,366	9,828	1,425	7,309	3,012	895
Morocco	39	[4] 20	9	39	[4] 20	11
Norway[2]	—	—	—	25,822	14,242	3,553
South Africa, Republic of	54,821	21,618	2,988	28,504	10,977	1,871
United Kingdom[2]	24	16	5	—	—	—
Total[5]	638,524	298,485	43,794	338,200	164,180	40,054
More than 20% but less than 47% manganese						
Brazil	184,121	77,230	7,700	35,919	15,049	973
Ghana	5,692	2,562	148	5,589	2,515	434
Mexico[1]	24,411	9,369	1,279	7,309	3,012	885
South Africa, Republic of	52,657	20,562	2,776	28,504	10,977	1,871
Total[5]	266,881	109,724	11,903	77,320	31,552	4,164
47% or more manganese						
Australia	115,844	60,436	9,492	68,986	35,873	9,201
Brazil	32,405	[1] 16,053	2,781	15,976	7,727	2,197
Canada[2]	2,173	1,086	49	—	—	—
Gabon[3]	218,039	[1] 109,637	19,196	150,059	74,766	20,928
Mexico	955	[1] 459	146	[1] —	[1] —	[1] —
Morocco	39	[4] 20	9	39	[4] 20	11
Norway[2]	—	—	—	25,822	14,242	3,553
South Africa, Republic of	2,164	1,056	212	—	—	—
United Kingdom[2]	24	16	5	—	—	—
Total[5]	371,643	188,761	31,891	260,880	132,628	35,890
FERROMANGANESE						
All grades						
Australia	28,987	21,536	8,407	16,295	12,355	5,049
Brazil	15,786	11,980	7,558	26,328	20,167	13,766
Canada	5,139	3,887	1,878	16,102	12,638	7,263
China	8,893	6,787	3,934	10,113	7,909	6,058
France	146,727	115,217	72,988	113,168	89,052	64,147
Germany, Federal Republic of	16,149	13,124	13,643	19,321	16,174	16,501
Mexico	37,775	30,218	28,018	49,472	39,412	31,665
Norway	19,636	16,239	15,730	8,169	6,789	7,103
South Africa, Republic of	181,402	139,267	83,496	144,300	112,015	73,708
Other	15,570	12,228	10,887	15,422	11,839	9,071
Total[5]	476,063	370,483	246,540	418,688	328,352	234,329
1% or less carbon						
France	8,805	7,761	12,552	7,991	7,133	10,945
Italy	[r] 2,083	[r] 1,838	[r] 2,737	836	745	1,140
Norway	5,153	4,402	5,645	2,172	1,801	2,046
Other	[r] 1,134	[r] 1,005	[r] 1,454	1,745	1,532	1,942
Total[5]	17,175	15,006	22,388	12,744	11,212	16,073

See footnotes at end of table.

TABLE 10—Continued

U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS, METAL, AND SELECTED CHEMICALS, BY COUNTRY

Country	1989			1990		
	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)
			More than 1% to 2% or less carbon			
Brazil	—	—	—	3,638	2,910	$2,778
China	331	265	$226	3,629	2,948	2,762
France	1,378	1,144	1,306	2,800	2,252	2,187
Germany, Federal Republic of	16,133	13,112	13,631	19,306	16,162	16,485
Mexico	34,777	27,987	26,829	27,701	22,307	21,232
Norway	11,386	9,384	8,631	5,997	4,988	5,057
South Africa, Republic of	1,093	867	955	3,069	2,465	2,582
Other	[6]2,204	[6]1,682	[6]1,729	2,755	2,094	2,142
Total[5]	67,302	54,441	53,307	68,895	56,126	55,225
			More than 2% to 4% or less carbon			
Canada	—	—	—	112	88	44
Mexico	73	58	29	—	—	—
Total	73	58	29	112	88	44
			More than 4% carbon			
Australia	28,987	21,536	8,407	16,295	12,355	5,049
Brazil	15,786	11,980	7,558	22,690	17,257	10,988
Canada	5,139	3,887	1,878	15,990	12,550	7,219
China	8,562	6,522	3,708	5,933	4,509	2,940
France	136,544	106,312	59,130	102,377	79,667	51,015
Mexico	2,925	2,173	1,160	21,771	17,105	10,433
South Africa, Republic of	180,309	138,400	82,541	141,231	109,550	71,126
Other	[6]13,261	[6]10,168	[6]6,434	10,650	7,933	4,217
Total[5]	391,513	300,978	170,816	336,937	260,926	162,987
			SILICOMANGANESE			
Argentina	1,149	752	737	12,013	7,901	5,417
Australia	41,281	26,962	16,057	44,815	29,552	19,004
Brazil	24,657	16,147	15,596	24,554	16,059	11,051
France	474	305	375	10,846	7,230	5,318
Mexico	42,854	28,207	24,053	[1]42,691	[1]28,110	[1]19,651
South Africa, Republic of	81,929	52,940	50,948	56,204	37,335	27,664
Yugoslavia	38,715	25,213	25,281	24,493	15,550	11,115
Other	[6]24,332	[6]15,958	[6]18,194	31,823	20,875	18,627
Total[5]	255,391	166,484	151,241	247,439	162,612	117,847
			METAL			
Unwrought:						
China	99	XX	142	280	XX	291
South Africa, Republic of	12,075	XX	16,354	10,073	XX	13,852
Other	—	XX	—	110	XX	265
Total[5]	12,175	XX	16,497	10,463	XX	14,407
Other:						
South Africa, Republic of	3,467	XX	4,388	3,643	XX	4,585
Other	468	XX	1,375	170	XX	746
Total[5]	3,936	XX	5,763	3,815	XX	5,331
Waste and scrap:						
Canada	36	XX	23	1	XX	3

See footnotes at end of table.

TABLE 10—Continued

U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS, METAL, AND SELECTED CHEMICALS, BY COUNTRY

Country	1989			1990		
	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)
			MANGANESE DIOXIDE			
Belgium	1,284	XX	$1,637	1,200	XX	$1,629
Brazil	1,914	XX	2,045	1,707	XX	2,018
Ireland	377	XX	465	1,349	XX	1,733
South Africa, Republic of	2,651	XX	2,293	3,081	XX	3,862
Other	[6]475	XX	[6]773	349	XX	635
Total[5]	6,701	XX	7,212	7,687	XX	9,877
			POTASSIUM PERMANGANATE			
China	1,038	XX	1,117	1,262	XX	1,182
Germany, Federal Republic of: Eastern states	335	XX	434	[7]382	XX	[7]366
Spain	690	XX	1,274	447	XX	812
Other	136	XX	411	28	XX	216
Total[5]	2,198	XX	3,236	2,119	XX	2,576

[r] Revised. XX Not applicable.
[1] Includes U.S. Bureau of Mines revision of part of reported data.
[2] Country of transshipment rather than original source.
[3] Includes quantities believed transshipped to Mexico, about 36,000 tons in 1989 and 51,000 tons in 1990.
[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 1989 Minerals Yearbook.
[7] Includes data listed under the Federal Republic of Germany in Oct.-Dec. 1990.

Source: Bureau of the Census, adjusted by the U.S. Bureau of Mines.

taking all of the shipments for which it had originally contracted. Mine operations at GEMCO, a subsidiary of Broken Hill Pty. Co. Ltd., were at a more normal pace as compared with 7-day, 3-shift schedules worked in 1989.

A 50–50 joint venture between Pilbara Port Railway Resources, a wholly owned subsidiary of Hancock Mining Ltd., and Portman Mining Ltd., partly owned by Pennant Resources Ltd., reestablished manganese ore production in the Woodie Woodie area of the east Pilbara region in Western Australia. Surface mining to yield 275,000 tons per year of product was projected for at least 5 years. The two main products of the operation, both low in phosphorus, were a siliceous ore containing about 43% manganese and a higher grade ore with 46% to 47% manganese. Transportation was by road trains over a distance of about 240 miles to ocean shipping at Port Hedland. Initial customers for the ore were in the Far East, with shipments beginning late in 1990 to China, the Republic of Korea, and Taiwan.

TABLE 11

U.S. IMPORT DUTIES ON MANGANESE MATERIALS[1]

Item	HTS No.	Rate of duty effective Jan. 1, 1990	
		Most favored nation (MFN)	Non-MFN
Manganese dioxide	2820.10.00	4.7% ad valorem[2 3 4]	25% ad valorem.
Ore and concentrate	2602.00.00	Free	1 cent per pound Mn.
Ferromanganese:			
Low-carbon	7202.19.10	2.3% ad valorem[2 3 5]	22% ad valorem.
Medium-carbon, 1% to 2% carbon	7202.19.50	1.4% ad valorem[2 3 5 6]	6.5% ad valorem.
High-carbon	7202.11.50	1.5% ad valorem[2 5]	10.5% ad valorem.
Silicomanganese	7202.30.00	3.9% ad valorem[2 3 5 7]	23% ad valorem.
Metal	8111.00.45	14% ad valorem[2 8]	20% ad valorem.

[1] All subject to (1) 0.17% ad valorem user fee except for products from beneficiary countries under the Caribbean Basin Economy Recovery Act (CBERA) and least-developed developing countries and (2) 0.04% ad valorem harbor-maintenance fee for cargo unloaded from waterborne vessels at U.S. ports open to public navigation.
[2] Free from beneficiary countries under CBERA and for products of Israel.
[3] Free from certain countries under Generalized System of Preferences.
[4] 2.8% 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] 11.2% ad valorem for products of Canada.

Brazil.—Shipments of manganese ores from the Serra do Navio, Amapá Territory, operations of ICOMI, a subsidiary of Cia. Auxiliar de Empresas de Mineração S.A. (Caemi), decreased 16% overall to 617,000 tons. Shipments, via Porto de Santana on the Amazon River, declined only moderately for exports to 529,000 tons, but dropped by about one-half, to 88,000 tons, for those to Brazilian consumers. About three-fifths of total shipments consisted of low-grade and

TABLE 12

WORLD ANNUAL MANGANESE MINE PRODUCTION CAPACITY, DECEMBER 31, 1990

(Thousand short tons of manganese content)

	Rated capacity
North America:	
Mexico	230
United States	—
Total	230
South America:	
Brazil	1,100
Chile	20
Total	1,120
Europe:	
Bulgaria	15
Hungary	30
U.S.S.R.	3,300
Other	40
Total	3,385
Africa:	
Gabon	1,350
Ghana	150
Morocco	30
South Africa, Republic of	2,300
Total	3,830
Asia:	
China	600
India	600
Other	15
Total	1,215
Oceania:	
Australia	1,250
World total (rounded)	11,000

carbonate ores.

Caemi expanded its manganese operations in Amapá Territory by inaugurating production of ferromanganese in the second half of the year at Cia. Ferroligas do Amapá (CFA), a recently formed subsidiary. Like a sinter plant completed by ICOMI in 1989, CFA's one-furnace ferroalloy plant was in the Porto de Santana area. ICOMI was the source of a mix of medium-grade metallurgical ore, carbonate ore, and sinter being fed to CFA's 12.4-megawatt-ampere furnace, rated for ferromanganese at 25,000 tons per year. Output of sinter during 1990 was about 80,000 tons.

Total manganese ore shipments from the Azul Mine of CVRD in the Carajás region declined by about one-fifth to 477,000 tons. Shipments to Brazilian consumers rose to 219,000 tons, but exports decreased by more than one-third to 258,000 tons.[22] Urucum Mineração S.A., about 47% owned by CVRD, was engaged in fulfilling a multiyear agreement to supply ore to Romania from its operations near the Bolivian border in the State of Mato Grosso do Sul.

Production of manganese ferroalloys declined just slightly from 1989's record-high total to 427,000 tons. With approximately the same output of high-carbon ferromanganese, a small increase in production of silicomanganese to a new record of 239,000 tons counterbalanced a one-third decrease in production of medium- and low-carbon ferromanganese to 19,000 tons. Investment in manganese ferroalloy facilities reportedly was adversely affected by Federal and State economic and tax programs.

Production of electrolytic manganese metal was initiated early in 1990 by the Metalman S.A. subsidiary of Metalur Ltda. at its plant near São Luís, Maranhão State. However, plant output did not progress to the 13,000-ton-per-year level projected for the latter part of 1990. CVRD was supplying ore to Metalman from its Azul Mine nearby.

Bulgaria.—Four state-owned Bulgarian companies entered into an agreement with Norway's Elkem under which Elkem was to be furnished with about 28,000 tons per year of manganese ore and in turn supply Bulgaria with ferromanganese and technology. The agreement, valued at more than $150 million, extended for 5 to 7 years and stipulated that Bulgaria would not restart ferromanganese production, which had ended late in 1989. Bulgarian companies involved were Kremikovtzi, Mangan, Metalsnab, and Rudmetal, the latter a trading company. The Obrochishte Mine near Varna on the Black Sea Coast in eastern Bulgaria presumably would be the ore source.

Canada.—In the latter part of the year, a test lot of a 45% manganese lump product was shipped by Hollinger North Shore Exploration Inc., a subsidiary of La Fosse Platinum Group Inc. Operations being conducted near Schefferville in northeastern Quebec adjacent the Labrador border included initial startup of a heavy-medium ore-beneficiating plant. Progression into commercial production of several manganese ore products at a total annual rate approaching 300,000 tons was projected within 5 years. Mining was to be by surface methods and confined to the mid-May to mid-October warmer season.

Gabon.—Capacity for ore production and actual ore output of COMILOG remained well below shipping capabilities provided by the dual routes of the new rail-to-port system within Gabon and the original aerial tramway-to-rail-to-port system terminating at Pointe-Noire in neighboring Congo. Transport of ore at the Moanda Mine was now benefiting from two conveyor systems, one for moving ore from the truck receiving point within the mine to the washing plant and another for carrying ore from the mine stockyard to the railhead of the Trans-Gabon Railroad. Production of 2,858,000 tons of ore in 1989, the highest annual total to that point, included 101,000 tons of battery-grade ore.

Ghana.—A total of 281,000 tons of ore was exported from the Nsuta Mine of Ghana National Manganese Corp.

TABLE 13

WORLD MANGANESE RESERVES AND RESERVE BASE

(Million short tons of manganese content)

	Reserves	Reserve base
North America:		
Mexico	4	10
South America:		
Brazil	23	65
Europe: U.S.S.R.	325	500
Africa:		
Gabon	58	180
Ghana	1	5
South Africa, Republic of	407	2,900
Total	466	3,085
Asia:		
China	15	32
India	19	28
Total	34	60
Oceania: Australia	44	170
World total (rounded)	900	3,900

through the Port of Takoradi compared with 314,000 tons exported in 1989. Shipments were made to Japan, the United States, and, in Europe, to Finland, Greece, Ireland, the Netherlands, Norway, Romania, and Spain.[23] Shipments in 1990 descended to a level just 4% below that of the annual average for 1984–89.

India.—The Government recentralized manganese ore exports through the State-owned Minerals and Metals Trading Corp. and raised to 550,000 tons the quantity of ore that could be exported during the 1990 fiscal year beginning April 1. This followed a brief period beginning during the latter part of the 1989 fiscal year when such exports were decentralized. Ore exports during the 1989 fiscal year had been limited to 440,000 tons of low- and medium-grade ore, with exports of high-grade ore permitted only on a selective basis and provided the ore had a relatively high phosphorus content of more than 0.18%.

Japan.—The slightly increased total of 584,000 tons for production of manganese ferroalloys was the greatest since 1985. Ferromanganese output rose 15% to 499,000 tons, the highest level since 1984. Production of silicomanganese was adversely affected by mishaps affecting two large units and fell 37% to 85,000 tons.

Foreign trade in manganese ferroalloys was diminished from that in 1989, except that imports of ferromanganese approximately doubled to 48,000 tons. Imports of silicomanganese decreased 39% to 215,000 tons, of which China supplied more than 40%. Exports declined about 60% for both ferromanganese, to 6,200 tons, and silicomanganese, to 1,200 tons.

In synthetic dioxide, production of EMD decreased more than 7% to 56,700 tons, again the least since 1985. Exports of EMD decreased further to 33,200 tons, the least since 1981. In October, Daiichi Carbon Co. Ltd. ended production of EMD, partly because of waste disposal problems. With an annual capacity of about 3,000 tons, Daiichi Carbon had been Japan's smallest EMD producer. At about the same time, Chuo Denki Kogyo Co. began commercial production of a high-grade chemical manganese dioxide (CMD-U) intended to compete with EMD in battery applications. This was at the company's Taguchi plant in Niigata Prefecture, about 100 miles northwest of Tokyo. The plant was designed on the basis of research and development involving cooperation between Toshiba Battery Co. and Sumitomo Metal Industries Ltd. and had an annual capacity for CMD-U of 6,600 tons.

Production of electrolytic manganese metal was up slightly to 5,040 tons. Imports of unwrought manganese metal, including scrap, rose by more than one-fourth to 15,100 tons, of which more than 60% was from the Republic of South Africa and approximately one-third was from China.

Mexico.—Operations of Autlán in the Molango District of Hidalgo State were the principal source of manganese ore products. Autlán's production for 1990 and 1989, respectively, were, in tons, 737,000 and 700,000 for carbonate ore, 368,000 and 388,000 for oxide nodules produced by calcining carbonate ore, and 23,900 and 19,700 for battery ore from the Nonoalco Mine.

Following a 2-year development program, Ferroaleaciones de México, S.A. added medium-carbon ferromanganese to high-carbon ferromanganese and silicomanganese as regular products of its plant at Gómez Palacio, Durango State. Using a 13-ton converter, the company worked out practices giving 91% manganese recovery in oxygen decarburization of high-carbon ferromanganese.[24]

South Africa, Republic of.—Total ore production advanced slightly, rising for the third consecutive year. Production in 1990 of the various categories of ore was as given in table 14.

Manganese ore shipments by AMMOSAL decreased more than one-fourth to 1,445,000 tons.

South African ore producers were looking to expand both their marketing to Eastern Europe and capability for producing high-grade ore from key underground mines in the Cape Province's Kalahari Field. AMMOSAL was studying the feasibility of sinking a new vertical shaft that would increase capacity of its N'Chwaning Mine significantly. Samancor progressed with development work aimed at expanding production from the western block of its Wessels Mine. Ore depletion caused Samancor's Hotazel surface mine to be closed as of the end of June.

TABLE 14

SOUTH AFRICAN MANGANESE ORE PRODUCTION, 1990

Grade	Quantity (thousand short tons, gross weight)[1]
METALLURGICAL ORE	
30% to 40% Mn	1,100
Over 40% to 45% Mn	800
Over 45% to 48% Mn	569
Over 48% Mn	1,487
Total	3,956
CHEMICAL ORE	
35% MnO_2 and less	10
Over 35% to 65% MnO_2	76
Over 65% to 75% MnO_2	6
Total	92

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

Production capacities for silicomanganese and ferromanganese were increased by about 50,000 tons each. In February, the Transalloys Div. of Highveld Steel & Vanadium Corp. Ltd. commissioned a fifth silicomanganese furnace at its works at Witbank in Transvaal Province. In the latter half of 1990, the Feralloys Ltd. subsidiary of AMMOSAL added a ferromanganese furnace at its plant at Cato Ridge, Natal Province. AMMOSAL also then shut down three smaller furnaces indefinitely.

U.S.S.R.—Reports in trade journals indicated the quantity of manganese ore imported by the U.S.S.R. from such principal current sources as Australia and Gabon was much reduced. Receipts may not have exceeded one-half the quantities contracted for because of a shortage of hard currency on the part of the U.S.S.R.

The U.S.S.R.'s production of potassium permanganate was ended in the first part of the year when the country's facilities for producing this chemical were closed because of problems with waste disposal. These facilities, in the Crimean Black Sea city of Saki, had an annual capacity of about 6,000 tons. Because of their closure, an antidumping duty imposed in June by the Commission of the European Commu-

nity (EC) on imports of potassium permanganate from the U.S.S.R. was only provisional. This action had joined the U.S.S.R. with other permanganate producers in Eastern Europe and China against which the EC had established antidumping controls.

Ore exports of 987,000 tons in 1989 were 9% less than those in 1988, with those to Poland decreasing 22% and those to Czechoslovakia increasing 42%. Destinations for 1989 exports were, in tons, Poland, 506,000; Czechoslovakia, 280,000; German Democratic Republic, 90,000; North Korea, 32,000; Yugoslavia, 29,000; Bulgaria, 12,000; and unspecified, 38,000.

Current Research

Methods of economically utilizing low-grade domestic manganese resources continued to be investigated. In the United States, the U.S. Bureau of Mines explored use of calcium fluoride to facilitate sulfuric acid leaching of manganese silicate minerals. Tests in which manganese extractions of more than 90% were achieved were conducted on material typifying pyroxmangite ores of the Sunnyside district of San Juan County, CO.[25] The manganese content was about 34%. In Italy, laboratory studies were conducted to determine the best conditions for solubilizing manganese from manganese dioxide-type ore by percolation leaching with aqueous sulfur dioxide and by bioleaching. For either approach, up to 20 days was required to achieve high extraction of manganese. The ore samples were from central western Italy and contained about 18% manganese.[26]

Geological investigation indicated a correlation between development of an economic manganese deposit and the existence of certain oxygen-poor, sulfur-rich conditions of the marine environment during deposition. This conclusion was reached from examination of organic carbon and sulfide sulfur contents of manganese ores and their host

TABLE 15

MANGANESE ORE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	Range percent Mn[e 3]	Gross weight					Metal content				
		1986	1987	1988	1989	1990[e]	1986	1987	1988	1989	1990[e]
Australia[4]	37–53	1,818	2,043	2,189	2,341	[5]2,191	867	972	[e]1,041	1,111	[5]1,009
Brazil[6 7]	30–50	2,973	2,279	2,194	2,293	2,200	1,277	842	[r]841	[r]871	840
Bulgaria	29	41	42	[r]39	[r e]67	72	12	12	[r]11	[r e]19	20
Chile	30–40	35	35	48	48	[5]44	12	12	16	15	[5]16
China[6 8]	20–30	3,000	[r]2,900	[r]3,500	[r e]3,500	3,500	600	[r]580	[r]700	[r]700	700
Gabon[6 9]	50–53	2,767	2,649	2,485	[r]2,858	2,900	1,277	1,223	1,147	[r]1,319	1,340
Ghana[6]	30–50	335	303	286	[r]308	280	122	108	106	[r]121	110
Hungary[6 10]	30–33	69	86	89	[r]93	94	21	28	29	[r]29	29
India[6 9 11]	10–54	1,337	1,435	[r]1,469	[r]1,471	1,500	498	534	[r]547	[r]548	560
Iran[6]	25–35	[r]37	[r]33	[r]34	[r]39	39	[r]11	[r]10	[r]10	[r]12	12
Mexico[12]	27–50	[e]506	[e]425	[e]489	[r e]435	447	192	161	186	[r]165	170
Morocco[6]	50–53	44	47	33	[r]35	35	24	25	18	[r]19	19
Romania[6 10]	30	74	[e]72	[e]72	[e]66	60	22	21	21	20	19
South Africa, Republic of[6 9]	30–48+	4,100	3,188	3,807	3,994	[5]4,048	1,663	1,337	1,571	1,675	1,710
U.S.S.R.	29–30	10,300	10,400	10,000	[r e]10,000	9,700	3,100	3,100	[e]3,000	[r e]3,000	2,900
Yugoslavia	25–45	46	46	44	[r]43	44	16	16	[e]15	15	15
Other[e 13]	XX	[r]40	[r]25	[r]39	[r]36	37	[r]16	[r]10	[r]17	[r]16	17
Total[14]	XX	[r]27,523	[r]26,006	[r]26,817	[r]27,626	27,192	[r]9,730	[r]8,991	[r]9,276	[r]9,655	9,486

[e] Estimated. [r] Revised. XX Not applicable.

[1] Table includes data available through May 17, 1991. Data pertain to concentrates or comparable shipping product, except that in a few instances the best data available appear to be for crude ore, possibly after some upgrading.

[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 short tons, gross weight: Argentina (19% to 30% Mn), 1986—11, 1987—7 (revised), 1988—10 (revised), 1989—7, and 1990—6 (estimated); 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] Reported figure.

[6] Gross weight reported; metal content estimated. Estimated metal content figures have been revised as necessary.

[7] Reported gross-weight figures are the sum of (1) sales of direct-shipping manganese ore and (2) production of beneficiated ore, both as reported in Anuário Mineral Brasileiro.

[8] Includes manganiferous ore.

[9] Calculated metal content includes allowance for assumed moisture content.

[10] Concentrate.

[11] Much of India's production grades below 35% Mn; average content was reported as 38% Mn in 1985.

[12] Estimated product total, mostly oxide nodules; may include smaller quantities of direct-shipping carbonate and oxide ores for metallurgical and battery applications.

[13] Category represents the combined totals of Greece, Indonesia, Italy (from wastes), Japan, the Republic of Korea, Pakistan, the Philippines, Thailand, Turkey, and Zambia.

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

rocks for deposits in China, Mexico, and Newfoundland.[27]

Steels are tending to be produced with progressively lower contents of residual elements. Increased emphasis on making steels with a phosphorus specification of 0.02% or less has implications for manganese-bearing materials used in ironmaking. One method for controlling phosphorus content of steels is to be selective in using low-phosphorus manganese ores in blast furnace feed.[28] Another approach for minimizing steel phosphorus content is to eliminate recycling of steelmaking slag to the blast furnace.[29]

In electric furnace steelmaking, technology is being developed for stirring the bath by injecting gases through the furnace bottom. Metallurgical improvements attained include increased manganese yield, as in the Federal Republic of Germany at Thyssen Stahl, where stirring was done with nitrogen followed by argon.[30] An electric furnace steelplant in Mexico raised manganese yield by 40% by stirring with natural gas.[31]

Manganese has been used in stainless steel as a substitute for nickel in times of nickel shortage. The thesis was advanced recently that, to avoid letting the economics of nickel supply limit future growth of the stainless steel market, nickel supply could be extended by using manganese and nitrogen in such steels.[32] The super collider to be built by the U.S. Department of Energy is a potential user of manganese-nitrogen stainless steel.[33]

The equilibrium diagram of the manganese-nitrogen system at temperatures up to 1,400° C was reviewed by the U.S. Bureau of Mines. The thermodynamics and crystal structure of the solid and liquid phases within this system were described.[34]

In the plant world, research into the complexities of photosynthesis has revealed aspects of the key role of manganese in enabling cells to derive their energy by dissociating water molecules. Manganese assists this aerobic process, which liberates life-giving oxygen as a byproduct, through the ability of manganese to exist in different oxidation states.[35]

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

TABLE 16

MANGANESE SUPPLY-DEMAND RELATIONSHIPS[1]

(Thousand short tons, manganese content)

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mines[2]	31	23	24	4	4	11	2	1	2	1	1
Shipments of Government stockpile excesses	264	159	128	28	35	10	91	8	105	−2	−6
Imports, ore and dioxide[1]	244	330	301	111	178	180	204	237	181	262	303
Imports, ferroalloy and metal	708	530	615	430	364	426	405	452	422	581	553
Industry stocks, Jan. 1	811	749	710	702	576	463	420	380	315	279	316
Total U.S. supply	2,058	1,791	1,778	1,275	1,157	1,090	1,122	1,078	1,025	1,121	1,167
Distribution of U.S. supply:											
Industry stocks, Dec. 31	749	710	702	576	462	420	380	315	279	316	324
Exports, ore	29	26	32	14	10	30	31	23	38	35	29
Exports, ferroalloy and metal	30	26	17	13	17	13	13	10	9	18	17
Industrial demand	1,250	1,029	1,027	672	668	627	698	730	699	752	797
U.S. DEMAND PATTERN[3]											
Appliances and equipment	59	49	51	30	33	36	32	27	31	19	12
Batteries	17	17	16	21	25	34	39	43	43	48	45
Cans and containers	61	49	46	31	28	38	35	31	35	31	23
Chemicals[4]	59	50	50	29	22	34	22	23	44	46	43
Construction	291	243	252	152	151	170	164	148	165	244	152
Machinery	217	167	171	92	90	97	78	65	77	110	83
Oil and gas industries	70	79	89	40	28	36	34	25	30	21	10
Transportation	296	214	214	115	129	139	124	95	105	102	54
Other[5]	180	161	138	162	162	43	170	273	169	131	375
Total U.S. primary demand	1,250	1,029	1,027	672	668	627	698	730	699	752	797

[1] Where available, data for manganese dioxide included beginning in 1984.
[2] Including manganiferous ore.
[3] New series for steel-related end uses beginning in 1989.
[4] Includes miscellaneous nonmetallurgical uses of ore beginning in 1987.
[5] 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. Beginning in 1989, includes nonidentified uses of steel corresponding to about one-third of total steel shipments.

than for steel production, but will have only a minor effect on overall manganese demand.

U.S. apparent consumption of manganese has been in the range of approximately 700,000 to 800,000 tons of contained manganese during 1985–89, as given in table 16. How this measure of domestic demand will vary on a year-to-year basis in 1991–95 is affected by uncertainties in the outlook for domestic steel production, as discussed in the annual report for "Iron and Steel." Particular uncertainty is associated with effects related to foreign trade, in which trends are sensitive to Government policy and currency exchange rates. Forecasts such as those of the International Iron and Steel Institute (IISI) generally indicate little growth in U.S. steel output through 1995. The range for U.S. apparent consumption of manganese in 1991–95 could well be much the same as that during the preceding 5 years, assuming no significant changes 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 the average annual growth rate for world manganese demand in 1991–95 should be close to 1%. Evolving political and economic developments could have a significant impact on traditional manganese supply-demand relationships in the near future. A significant potential appears to exist for a decline in the U.S.S.R.'s ore production and exports, 90% or more of which have been to Eastern Europe since at least 1978.

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MERCURY

By Robert G. Reese, Jr.

Mr. Reese, a physical scientist with the Branch of Metals, has been the commodity specialist for mercury for 3 years. Domestic survey data were prepared by Kevin Bacon, statistical assistant, and international data tables were prepared by Virginia Woodson, international data coordinator.

Mercury was used in the production of a variety of products in 1990. Its combination of properties such as liquidity at ordinary temperatures, high specific gravity, and electrical conductivity were important considerations in many applications. For many of mercury's uses, however, satisfactory substitutes were known, and it appeared probable that others could be developed. As a result of the availability of substitutes, the health hazard of mercury poisoning, and the potential for mercury to be an environmental pollutant, the mercury market continued to shrink in 1990. This was a disappointing year for the mercury-producing industry. In the United States, the only primary mercury-producing mine was closed, and the use of mercury in interior latex paints was banned. In response to lower mercury demand by domestic manufacturers, mercury prices declined. Elsewhere, other countries restricted the quantity of mercury entering their environments by reducing imports or by restrictions on the manufacture of mercury-containing products.

DOMESTIC DATA COVERAGE

Domestic data for mercury are developed by the U.S. Bureau of Mines from three separate, voluntary surveys of U.S. operations. Typical of these surveys was "Mercury," a survey of mercury consumption. Of the 97 firms to which this survey form was sent, 93% responded, representing an estimated 81% of the reported U.S. consumption shown in tables 1 and 4. Consumption for the nonrespondents was estimated using prior years consumption levels.

PRODUCTION

Mercury was produced as a principal product at one mine in Nevada, the McDermitt Mine, and as a byproduct at eight gold mines in Nevada, California, and Utah. Nearly all of the newly mined mercury came from Nevada. Actual production figures were withheld by the U.S. Bureau of Mines to avoid disclosing company proprietary data. Domestic mine production data reported in some of the accompanying tables represents only the quantity produced at the McDermitt Mine, as published in

TABLE 1

SALIENT MERCURY STATISTICS

		1986	1987	1988	1989	1990
United States:						
Producing mines		8	9	10	10	9
Mine production[1]	metric tons	483	34	379	414	NA
Secondary production:						
Industrial	do.	219	265	278	137	93
Government[2]	do.	106	117	214	180	193
Industry stocks, yearend[3]	do.	W	W	W	W	W
Shipments from the National Defense Stockpile[4]	do.	16	128	52	170	52
Imports for consumption	do.	696	636	329	131	15
Exports[5]	do.	NA	NA	NA	221	311
Industrial demand	do.	1,588	1,446	1,593	1,214	720
Price: New York, average per flask		$232.79	$295.50	$335.52	$287.72	$249.22
Employment, mine and mill, average		22	9	12	25	21
World:						
Mine production	metric tons	r7,782	r5,534	6,595	p6,263	e5,785

eEstimated. pPreliminary. rRevised. NA Not available. W Withheld to avoid disclosing company proprietary data.

[1]Comprises only the mercury produced at the McDermitt Mine, as reported in Placer Dome Inc. annual and 10-K reports.

[2]Secondary mercury shipped from U.S. Department of Energy stocks.

[3]Stocks at mines, consumers, and dealers.

[4]Primary mercury.

[5]Mercury export data were not available from 1986 through 1988.

Placer Dome Inc.'s annual and 10-K reports. In late November, the McDermitt Mine was closed, idling approximately 20 workers.

Company officials attributed the closure to several factors, including poor market conditions, a ban on the use of mercury in certain paints, and excessive sales from Federal Government stockpiles. Although mining and processing operations were suspended, the company expected to meet its contract obligations from the mine's stocks.

Secondary mercury was recovered from scrapped mercury-containing products, from industrial waste and scrap, and from the sale of surplus Government stocks of scrap mercury. These source materials were processed by five companies: Adrow Chemical Co., Wanaque, NJ; Bethlehem Apparatus Co. Inc., Hellertown, PA; D.F. Goldsmith Chemical and Metals Corp., Evanston, IL; Mercury Refining Co. Inc., Latham, NY; and Wood Ridge Chemical Co., Newark, NJ.

CONSUMPTION AND USES

Industrial consumption of refined mercury metal fell more than 40% in 1990, as demand by the paint, chloralkali, battery, and wiring device industries plummeted.

The drop of almost 90% in demand by the paint industry was attributed to the ban in mid-August, by the Environmental Protection Agency, of the use of a mercury-containing antifungal compound in interior latex paints, and to the paint industry's anticipatation of the ban and expectation that it would in time be extended to exterior latex paints. The mercury compound was considered a health risk, especially in freshly painted, poorly ventilated areas. Alternative antifungal compounds were available to the paint industry.

The 58% fall in demand by battery manufacturers reflected the adoption of new batteries requiring much less mercury per unit and the shift of manufacture of mercury-containing batteries to countries having less stringent environmental regulations than the United States.

The 50% drop in the use of mercury in wiring devices and switches was attributed partly to an accelerated shift to solid-state devices and other alternative less environmentally dangerous devices, and partly to the economic recession that began during the year.

The 35% decline in demand by the chloralkali industry was due to the closing of several mercury cell plants during the year, to anticipation of stricter environmental regulations governing mercury-containing sludges and effluent, and probably to the economic recession.

There was much concern in the United States and other countries about pollution of the environment by mercury-containing products, several of which represent dissipative uses, from which little or no mercury is ever recovered for recycling or controlled disposal. Environmental subjects examined during the year included the makeup of waste in landfills and the potential for either voluntary or mandatory recycling of mercury-containing products.

STOCKS

Stocks of refined mercury held by consumers and dealers fell by almost 7% in 1990 and at yearend were equivalent to about 3 month's industrial consumption. Figures on stocks held at mines were withheld to avoid disclosing company proprietary data.

All of a large inventory of used (scrap) mercury held by the Department of Energy (DOE) at Oak Ridge, TN, was considered surplus, and limited quantities were offered for sale at monthly auctions by the Defense Logistics Agency (DLA), which acted as DOE's agent. DLA shipped 193 metric tons during the year, leaving yearend stocks at 439 metric tons.

MARKETS AND PRICES

The New York dealer price for delivered primary mercury, reported in Metals Week as a range, declined throughout the year. The price at the low end of the range began the year at $290 per flask. From this peak, the low-end price declined steadily until mid-December when it reached $180 per flask, its low for the year. The low-end price remained at $180 through the end of the year. The price at the high end of the range tracked the movement of the low-end price fairly closely, but was $8 to $30 per flask higher. The annual average of the weekly low-end price was $249.22 compared with $287.72 in 1989.

WORLD REVIEW

Mercury was mined in at least 11 countries in 1990. Together, the U.S.S.R. and Spain accounted for more than 60% of the world's mercury production.

Contamination of the environment by mercury remained a concern. In Brazil, many of the small gold mines in the Amazon basin recover gold by amalgamation with mercury. Separating the gold from the amalgam often results in mercury loss and the subsequent pollution of the Amazon River and its tributaries. In response to the growing pollution of this water source, the Government of Brazil reportedly requested aid to combat the problem. Wire service reports in late January announced that Japan would provide Brazil with gold recovery technology that does not use mercury. In late October, it was reported that the Federal Republic of Germany would fund a study on mercury pollution in Brazil. The study was expected to investigate the extent of mercury poisoning and possible alternatives for cleaning the rivers. The Government of Denmark reportedly banned the importation of mercury and mercury-containing products in July. Batteries containing mercury and mercury for chlorine production were exempted. Other uses for mercury were granted transition periods during which a switch to alternative products would be accomplished.

In Japan, guidelines concerning the use of mercury for battery manufacture were issued near yearend. The guidelines were expected to significantly reduce Japan's use of mercury for battery manufacture. The use of mercury in manganese batteries was reportedly suspended,and the mercury content of alkaline batteries was reduced from 0.1% to 0.025%. The guidelines, effective beginning in 1991, applied only to batteries manufactured in Japan for internal consumption. Batteries manufactured in Japan for export were not specifically covered by the guidelines and were not expected to be affected. Also not covered by the guidelines was the manufacture of button cells used mainly for hearing aids. It appeared probable that button cell manufacturing was not covered because these cells are being replaced by the newly developed zinc-air button cell.

OUTLOOK

The world market for mercury was characterized, as it had been for at least two decades, by abundant supply and a slowly shrinking demand. The increasing recognition around the world of the danger posed by mercury's toxicity has led over the last quarter century to curtailment of its use in some applications and elimination from others. This trend is expected to continue. Although it is unlikely that the consumption

of mercury will be totally eliminated in the near future, constant vigilance to safeguard the health of persons exposed to mercury, as well as to protect the environment in which we live is required.

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TABLE 2

BYPRODUCT MERCURY-PRODUCING MINES IN THE UNITED STATES IN 1990

Mine	County and State	Operator
Borealis Project	Mineral, NV	Echo Bay Minerals Co.
Carlin Mines Complex	Eureka, NV	Newmont Gold Co.
Hog Ranch	Washoe, NV	Western Hog Ranch Co.
Jerritt Canyon (Enfield Bell)	Elko, NV	Independence Mining Co Inc.
McLaughlin	Napa, CA	Homestake Mining Co.
Mercur	Tooele, UT	Barrick Mercur Gold Mines Inc.
Paradise Peak	Nye, NV	FMC Gold Co.
Pinson and Kramer Hill	Humboldt, NV	Pinson Mining Co.

TABLE 3

U. S. INDUSTRIAL CONSUMPTION OF REFINED MERCURY METAL, BY USE[1]

SIC code	Use	1986	1987	1988	1989	1990
28	Chemical and allied products:					
2812	Chlorine and caustic soda manufacture	259	311	445	381	247
2819	Laboratory uses	20	20	26	18	32
2851	Paint	179	198	197	192	22
—	Other chemical and allied products[2]	90	59	86	40	33
36	Electrical and electronic uses:					
3641	Electric lighting	41	45	31	31	33
3643	Wiring devices and switches	103	131	176	141	70
3692	Batteries	750	533	448	250	106
38	Instruments and related products:					
382	Measuring and control instruments	63	59	77	87	108
3843	Dental equipment and supplies	52	56	53	39	44
—	Other uses[3]	31	34	55	35	25
	Total[4]	1,588	1,446	1,593	1,214	720

[1]The input of refined liquid mercury to domestic manufacturing establishments.
[2]Pigments, pharmaceuticals, catalysts for plastics, and miscellaneous catalysts, shown as separate items in previous editions of this table, have been included in this category.
[3]Other electrical and electronic uses, other instruments and related products, shown as separate items in previous editions of this table, have been included in this category.
[4]Data may not add to totals shown because of independent rounding.

of mercury will be totally eliminated in the near future, constant vigilance to safeguard the health of persons exposed to mercury, as well as to protect the environment in which we live is required.

OTHER SOURCES OF INFORMATION:

Bureau of Mines Publications

Mercury. Ch. in Mineral Commodity Summaries, annual.

Other Sources

American Metal Market.
Chemical Marketing Reporter.
Engineering and Mining Journal.
London Metal Bulletin.
Metals Week.

TABLE 2

BYPRODUCT MERCURY-PRODUCING MINES IN THE UNITED STATES IN 1990

Mine	County and State	Operator
Borealis Project	Mineral, NV	Echo Bay Minerals Co.
Carlin Mines Complex	Eureka, NV	Newmont Gold Co.
Hog Ranch	Washoe, NV	Western Hog Ranch Co.
Jerritt Canyon (Enfield Bell)	Elko, NV	Independence Mining Co Inc.
McLaughlin	Napa, CA	Homestake Mining Co.
Mercur	Tooele, UT	Barrick Mercur Gold Mines Inc.
Paradise Peak	Nye, NV	FMC Gold Co.
Pinson and Kramer Hill	Humboldt, NV	Pinson Mining Co.

TABLE 3

U. S. INDUSTRIAL CONSUMPTION OF REFINED MERCURY METAL, BY USE[1]

SIC code	Use	1986	1987	1988	1989	1990
28	Chemical and allied products:					
2812	Chlorine and caustic soda manufacture	259	311	445	381	247
2819	Laboratory uses	20	20	26	18	32
2851	Paint	179	198	197	192	22
—	Other chemical and allied products[2]	90	59	86	40	33
36	Electrical and electronic uses:					
3641	Electric lighting	41	45	31	31	33
3643	Wiring devices and switches	103	131	176	141	70
3692	Batteries	750	533	448	250	106
38	Instruments and related products:					
382	Measuring and control instruments	63	59	77	87	108
3843	Dental equipment and supplies	52	56	53	39	44
—	Other uses[3]	31	34	55	35	25
	Total[4]	1,588	1,446	1,593	1,214	720

[1]The input of refined liquid mercury to domestic manufacturing establishments.
[2]Pigments, pharmaceuticals, catalysts for plastics, and miscellaneous catalysts, shown as separate items in previous editions of this table, have been included in this category.
[3]Other electrical and electronic uses, other instruments and related products, shown as separate items in previous editions of this table, have been included in this category.
[4]Data may not add to totals shown because of independent rounding.

TABLE 8

MERCURY: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
Algeria	756	705	690	586	600
China[e]	700	700	700	700	750
Czechoslovakia	168	164	168	131	130
Dominican Republic	(2)	(2)	(2)	(2)	(2)
Finland	146	144	130	159	160
Mexico	r185	124	345	e345	345
Spain	2,757	r1,085	1,716	e1,380	1,500
Turkey	r262	211	97	197	130
U.S.S.R.[e]	2,250	2,300	2,300	2,300	2,100
United States[3]	483	34	379	414	NA
Yugoslavia	75	67	70	51	70
Total	r7,782	r5,534	6,595	6,263	5,785

[e]Estimated. [p]Preliminary. [r]Revised. NA Not available.
[1]Table includes data available through Apr. 26, 1991.
[2]Less than 1/2 unit.
[3]Comprises only the mercury produced at the McDermitt Mine, as reported in Placer Dome Inc. annual and 10-K reports.

TABLE 9

WORLD ANNUAL MERCURY PRODUCTION CAPACITY, DECEMBER 31, 1990

(Metric tons)

	Rated capacity[1 2]
North America:	
Mexico	400
United States	1,200
Total	1,600
Europe:	
Spain	2,600
U.S.S.R.	2,800
Other	800
Total	6,100
Africa: Algeria	1,200
Asia:	
China	700
Turkey	300
Total	1,000
World total	9,900

[1]At operating plants and at plants on standby basis.
[2]Data may not add to totals shown because of independent rounding.

MICA

By Lawrence L. Davis

Mr. Davis, a physical scientist with 35 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, mineral data assistant; and international data tables were prepared by Audrey Wilkes, international data coordinator.

In 1990, about 109,000 metric tons of scrap and flake mica was produced in the United States, a decrease of 8% from 1989 production. Ground mica sales were 97,000 tons valued at $22 million, a decrease in tonnage of about 4%.

Almost all sheet mica supply continued to be imported. Consumption of muscovite block mica decreased 20% to 6.0 tons. Consumption of mica splittings decreased 24% to 842 tons. The value of sheet mica exports increased 5% to $7.8 million. The value of imports for consumption of sheet mica increased 8% to $9.5 million.

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, 16 operations, or 89%, responded, representing 86% of the production shown in table 1. Of the 17 operations to which the ground mica form was sent, 15 responded, representing 93% of the production in table 1. Of the five canvassed operations to which the mica block and film consumption form was sent, two, or 40%, responded, representing 65% of the consumption shown in table 1. Of the nine canvassed operations to which the mica splittings consumption form was sent, eight operations, or 89%, responded, representing more than 99% of the splittings consumption shown in table 1. Consumption for the nonrespondents was estimated using prior-year production data.

TABLE 1

SALIENT MICA STATISTICS

		1986	1987	1988	1989	1990
United States:						
Production (sold or used by producers):						
Scrap and flake mica	thousand metric tons	134	146	130	119	109
Value	thousands	$7,108	$8,201	$6,793	$6,273	$5,841
Ground mica	thousand metric tons	112	113	109	101	97
Value	thousands	$21,872	$22,376	$23,687	$22,443	$21,610
Consumption:						
Block, muscovite	metric tons	23	26	14	7	6
Value	thousands	$755	$982	$628	$599	$554
Splittings	metric tons	1,010	960	1,104	1,108	842
Value	thousands	$1,252	$1,417	$1,544	$1,703	$1,414
Exports	metric tons	7,685	5,828	7,168	5,327	5,659
Imports	do.	11,761	11,450	14,478	15,834	15,876
World: Production	do.	r274,030	r276,342	r251,856	r229,523	e214,560

eEstimated. rRevised.

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, 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 kaolin, feldspar, 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 is 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. (MITCO) 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 kaolin, feldspar, and lithium beneficiation. Nearly all flake mica is ground to final specifications depending on the use. Other countries producing significant amounts of flake mica are Canada, China, India, the Republic of Korea, and the U.S.S.R. Many other countries produce small amounts.

Geology-Resources

Sheet muscovite is obtained from coarse-grained igneous rocks called pegmatites. Pegmatites also contain quartz, feldspar, 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 2 centimeters or so in width.

The United States has no reserves of sheet mica. Small U.S. reserves were extensively worked in the past, and the high cost of labor has kept the mines shut down since the Government's purchase program ended in 1962. The primary sheet mica resources are in New England, the southeastern Piedmont from Virginia to Alabama, the Blue Ridge Mountains in North Carolina, the Black Hills of South Dakota, and northern New Mexico. Other States with some sheet mica resources are California, Colorado, Idaho, Montana, and Wyoming.

No formal evaluation of world resources of sheet mica has been made, mainly because of the sporadic occurrence of this mineral. The most productive sheet mica districts in the world are in the States of Bihar, Andhra Pradesh, and Rajasthan in India. India's large reserves and resources of sheet mica have been the primary world sources for many years. Large reserves of sheet mica also are found in Brazil and western Africa. In the U.S.S.R., sheet mica reserves are known in the Lake Baikal and Sayan upland areas as well as in the South Eniessy Range. Smaller but substantial reserves occur in Argentina, Australia, and Zimbabwe.

Phlogopite deposits are in areas of metamorphosed sedimentary rocks intruded by masses of pegmatite-rich granitic rocks. The phlogopite is found as veins or pockets in pyroxenite interlayered with or intersecting marble or gneiss. Canada and Madagascar have the world's major reserves of phlogopite. Additional reserves are known in the Sludyanka River district and Alden area of the U.S.S.R., Sri Lanka, and Mexico.

The primary domestic source of flake mica for grinding purposes is weathered alaskite bodies and pegmatites in North Carolina, where most domestic flake mica is produced. The mica is recovered as a coproduct of feldspar and kaolin beneficiation. Flake mica is also recovered from muscovite schists. These schists bodies range in size from 3 to more than 100 meters thick and several kilometers long. The mica content ranges up to 90%. Another form of flake mica is fine-grained muscovite called sericite, which is an alteration product of various aluminosilicate minerals.

World reserves and resources of scrap and flake mica are not well known but are considered to be very large. All countries with sheet mica reserves or resources have even larger quantities of scrap mica because only a small fraction of the mica present is of sheet quality. Many other countries have reserves or resources of mica that, while not of sheet quality, are suitable for grinding.

ANNUAL REVIEW

Legislation and Government Programs

The Government inventory of stockpile-grade mica remained about the same at 10,000 tons. The U.S. Department of Defense sold 25 tons of muscovite splittings, 5 tons of phlogopite splittings, and 2 tons of muscovite block, stained and better.

Strategic Considerations

Sheet mica and high-quality scrap mica used for making mica paper are important in the electronic and electrical industries. The United States is not self-sufficient in these materials and imports all its supplies, mostly from India. The U.S.S.R. and other countries with centrally planned economies are currently India's largest customers. The United

TABLE 2

STOCKPILE GOALS AND GOVERNMENT INVENTORIES FOR MICA, DECEMBER 31, 1990

(Metric tons)

Material	Inventory				
	Goal	Stockpile grade	Non-stockpile grade	Available for disposal	1990 sales
Block:					
Muscovite, stained and better	1,134	2,268	94	154	2
Phlogopite	95	8	52	—	—
Film: Muscovite, 1st and 2d qualities	41	533	(1)	468	—
Splittings:					
Muscovite	5,728	6,501	—	315	25
Phlogopite	422	676	—	254	5

[1]Less than 1/2 unit.

States and other market economy countries compete for the remaining mica, and availability is sometimes limited, particularly for high-quality mica. Long delivery times and quality inconsistency also adversely affect sheet mica availability.

In a short-supply situation during an emergency, the National Defense Stockpile (NDS) would be able to meet short-term demand until substitutes could be made available. It is unlikely that domestic sheet mica production could replace or significantly reduce imports. Of the five strategic stockpile categories, only muscovite block mica has ever been produced domestically in significant quantities, and then only under the stimulus of above-market prices paid by the Government. Domestic production in this century never provided more than a small fraction of domestic requirements.

The domestic supply of flake mica is adequate. Scrap and flake mica are not considered to be strategic materials. The United States is self-sufficient in flake mica, but does rely on imports of high-quality scrap for the manufacture of mica paper.

Production

Scrap and Flake Mica.—North Carolina remained the major producing State, with 60% of the total production. The remainder was produced in Connecticut, Georgia, New Mexico, Pennsylvania, South Carolina, and South Dakota. Most mica was recovered from mica schist, high-quality sericite schist, and as a byproduct of kaolin, feldspar, and lithium beneficiation.[3] The five largest producers were, in alphabetical order; The Feldspar Corp., Spruce Pine, NC; Franklin Mineral Products, division of Mearl Corp., Hartwell, GA; KMG Minerals Inc., Kings Mountain, NC; Lithium Corp. of America, Gastonia, NC; and Unimin Corp., Spruce Pine, NC. These five companies produced 67% of the national total.

Falconbridge Ltd., of Toronto, sold its Indusmin Div., which includes a mica mine at Spruce Pine, NC, to Unimin. The operation was subsequently acquired from Unimin by Hecla Mining Co. of Coeur d' Alene, ID.

Low-quality sericite, used primarily in brick manufacturing, is excluded from tabulated data contained in this report. In 1990, four companies, one in North Carolina and three in South Carolina, mined 23,000 tons of low-quality sericite and reported an average value of $3.83 per ton.

Ground Mica.—Eleven companies operated 14 grinding plants in 6 States. Ten plants produced dry-ground and four produced wet-ground mica. The dry-ground mica plants of Deneen Mica Co., Micaville, NC, and J. M. Huber Corp., Kings Mountain, NC, were inactive during the year as was the wet-ground plant of Concord Mica Corp. at Penacook, NH. The five largest producers accounted for 73% of the total. They were, in alphabetical order; KMG Minerals, Kings Mountain, NC; MICA-A Franklin Limestone Co., Santa Fe, NM; Spartan Minerals Corp., Pacolet, SC; Unimin, Spruce Pine, NC; and USG Corp., Spruce Pine, NC.

Several operations changed hands or were put up for sale during the year. Mineral Mining Corp.'s mica mine and grinding plant near Kershaw, SC, were purchased by Piedmont Mining Co. Inc. of Charlotte, NC. The operation, now a wholly owned subsidiary, was renamed Mineral Mining Co. Inc. Mineral Industrial Commodities of America Inc., Santa Fe, NM, was purchased by Franklin Industries, Nashville, TN. The mine and plant now operate as MICA-A Franklin Limestone. J. M. Huber announced plans to sell its mica operations at Kings Mountain and Spruce Pine, NC. At yearend, the facilities were still for sale.

Consumption and Uses

Sheet Mica.—Sheet mica is used principally in the electronic and electrical industries. Its usefulness in these applications stems from its unique electrical and thermal insulating properties and its mechanical properties, which allow it to be cut, punched, or stamped to close tolerances.

The largest use of block mica is as an electrical insulator in electronic equipment. High-quality block mica is also used to line the gauge glasses of high-pressure steam boilers. Transparency, flexibility, and resistance to heat and chemical attack are the properties that make mica suitable for this use. Other uses include diaphragms for oxygen-breathing equipment, marker dials for navigation compasses, optical filters, retardation plates in helium-neon lasers, pyrometers, thermal regulators, and stove windows.

Muscovite film mica is used as a dielectric in capacitors. Only high-quality mica, at or near the top of the quality scale, is used. The highest quality goes into capacitors that are to be used as standards. The next highest qualities are used for transmitting capacitors. Receiving capacitors use slightly lower quality film.

Consumption of muscovite block (ruby and nonruby) totaled 6.0 tons, a 20% decrease from that of 1989. Consumption of stained and lower-than-stained quality decreased 21%, but remained in greatest demand, accounting for 86% of consumption. About one-half of the muscovite consumed was grade No. 5 or smaller. The decrease in consumption

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
1986	134	7,108
1987	146	8,201
1988	130	6,793
1989	119	6,273
1990:		
North Carolina	65	3,796
Other States[2]	44	2,045
Total	109	5,841

[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 Connnecticut, Georgia, New Mexico, Pennsylvania, South Carolina, and South Dakota.

TABLE 4

GROUND MICA SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY METHOD OF GRINDING[1]

(Thousand metric tons and thousand dollars)

Year	Dry-ground		Wet-ground		Total	
	Quantity	Value	Quantity	Value	Quantity	Value
1986	99	14,682	13	7,190	112	21,872
1987	101	15,140	12	7,237	113	[2]22,376
1988	95	14,570	14	9,117	109	23,687
1989	88	13,409	13	9,034	101	22,443
1990	W	W	W	W	97	21,610

W Withheld to avoid disclosing company proprietary data.
[1]Domestic and some imported scrap. Low-quality sericite is not included.
[2]Data do not add to total shown because of independent rounding.

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 24% to 842 tons. Muscovite splittings from India accounted for nearly all of the consumption. The remainder was phlogopite splittings from Madagascar. The splittings were fabricated into various built-up mica products by nine companies operating nine plants in seven States.

Built-up Mica.—The primary use of this mica-base product, made by mechanical or hand setting of overlapping splittings and alternate layers of binders and splittings, was as electrical insulation material. Principal built-up mica products are segment plate, molding plate, flexible plate, heater plate, and tape.

Segment plate acts as insulation between the copper commutator segments of direct-current universal motors and generators. Phlogopite built-up mica is preferred because it will wear at the same rate as the copper segments. Muscovite has a greater resistance to wear, causing uneven ridges that may interfere with the operation of the generator.

Molding plate is sheet from which V-rings are cut and stamped for use in insulating the copper segments from the steel shaft at the ends of a commutator. Molding plate is also fabricated into tubes and rings for insulation in transformers, armatures, and motor starters.

Flexible plate is used in electric motor and generator armatures, field coil insulation, and magnet and commutator core insulation. Heater plate is used where high-temperature insulation is required.

Some types of built-up mica have the bonded splittings reinforced with special paper, silk, linen, muslin, glass cloth, or plastic. These products are very flexible and are produced in wide, continuous sheets that either are shipped in rolls or cut into ribbons, tapes, or any desired dimensions.

Total production, sold or used, of built-up mica decreased 13% from that of 1989. Molding plates and segment plates were the major end products, accounting, respectively, for 35% and 33% of the total. Other end products included flexible plates, heater plates, and tapes.

Reconstituted Mica (Mica Paper).—Primary end uses for mica paper are the same as those for built-up mica. Three companies consumed scrap mica to produce mica paper. The principal source of this scrap mica was India. Manufacturing companies in 1990 were Corona Films Inc., West Townsend, MA; General Electric Co., Coshocton, OH; and US Samica Corp., Rutland, VT.

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

TABLE 5

FABRICATION OF MUSCOVITE BLOCK MICA IN THE UNITED STATES IN 1990, BY QUALITY

(Kilograms)

Quality	1989	1990
Good stained or better	886	817
Stained or lower[1]	6,595	5,193
Total	7,481	6,010

[1]Includes punch mica.

TABLE 6

CONSUMPTION AND STOCKS OF MICA SPLITTINGS IN THE UNITED STATES, BY SOURCE

	India		Madagascar		Total[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Consumption:						
1986	r996	$1,136	13	$116	1,010	$1,252
1987	930	1,231	30	185	960	1,417
1988	1,069	r1,338	30	206	1,104	1,544
1989	1,062	1,448	46	255	1,108	1,703
1990	W	W	W	W	842	1,414
Stocks on Dec. 31:						
1986	566	NA	43	NA	610	NA
1987	408	NA	4	NA	412	NA
1988	439	NA	5	NA	444	NA
1989	496	NA	9	NA	505	NA
1990	W	NA	W	NA	632	NA

rRevised. NA Not available. W Withheld to avoid disclosing company proprietary data.
[1]Data may not add to totals shown because of independent rounding.

TABLE 7

BUILT-UP MICA[1] SOLD OR USED IN THE UNITED STATES, BY PRODUCT

Product	1989		1990	
	Quantity (metric tons)	Value (thousand)	Quantity (metric tons)	Value (thousand)
Flexible (cold)	85	$545	96	$588
Heater plate	18	74	W	W
Molding plate	316	1,011	291	1,623
Segment plate	378	2,216	284	1,777
Tape	51	277	W	W
Other	141	1,607	190	2,223
Total	[2]990	5,730	861	6,211

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.

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 1990, the major end uses were joint cement, 55%; paints, 14%; and well-drilling muds, 7%.

Stocks

Reported yearend consumer stocks of sheet mica increased 23% to 668 tons; of this, mica splittings represented 95%, and mica block represented 5%.

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 1990 compared with 1989 were as follows: Block increased 15% to $92 per kilogram, and splittings increased 14% to $1.55 per kilogram. The average value of phlogopite block increased 18% to $26 per kilogram, while the value of phlogopite splittings decreased 20% to $4.43 per kilogram. The large changes in average value are more a reflection of the quality of mica consumed during the year than actual changes in price. The average value of crude flake mica, including high-quality sericite, was $54 per ton. The average value per ton for North Carolina flake mica, predominantly a flotation product, was $59.

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

TABLE 8

GROUND MICA SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY END USE

(Thousand metric tons and thousand dollars)

End use	1989		1990	
	Quantity	Value	Quantity	Value
Joint cement	58	11,198	53	8,984
Paint	10	1,512	14	2,894
Plastics	3	876	2	675
Well-drilling mud	7	816	7	1,114
Other[1]	23	8,041	21	7,944
Total[2]	101	22,443	97	21,610

[1]Includes mica used for molded electrical insulation, rubber, textile and decorative coatings, welding rods, and miscellaneous.
[2]Data may not add to totals shown because of independent rounding.

TABLE 9

AVERAGE REPORTED PRICE FOR DRY- AND WET-GROUND MICA SOLD OR USED BY U.S. PRODUCERS IN 1990

(Dollars per metric ton)

Kind	Price
Wet-ground	663
Dry-ground	151
End uses:	
Joint cement	168
Paint	212
Plastics	288
Well-drilling mud	162
Other[1]	381

[1]Includes mica used for molded electrical insulation, roofing, rubber, textile and decorative coating, welding rods, and miscellaneous.

TABLE 10

U.S. EXPORTS OF CRUDE AND RIFTED MICA, MICA POWDER, AND MICA WASTE IN 1990, 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)
Australia	—	—	15	$35	32	$17	—	—
Barbados	15	$5	—	—	18	14	—	—
Belgium	60	28	—	—	230	97	—	—
Brazil	18	10	—	—	38	32	—	—
Canada	98	31	—	—	2,152	777	11	$3
China	—	—	48	75	—	—	—	—
Colombia	—	—	7	15	103	34	—	—
France	9	3	—	—	110	35	—	—
Germany, Federal Republic of	—	—	1	11	189	51	—	—
Italy	—	—	2	12	64	34	—	—
Japan	116	41	72	77	288	157	—	—
Korea, Republic of	—	—	3	21	459	283	—	—
Mexico	39	14	1	19	124	113	—	—
Norway	48	17	—	—	—	—	—	—
Philippines	8	3	—	—	30	22	—	—
Sweden	—	—	—	—	73	45	—	—
Taiwan	—	—	—	—	114	109	—	—
Thailand	—	—	—	—	32	56	—	—
United Kingdom	—	—	1	7	18	56	—	—
Venezuela	—	—	—	—	11	12	141	485
Other[1]	12	4	—	—	235	104	5	3
Total[2]	424	155	148	272	4,319	2,050	156	491

[1]Includes the Bahamas, Chile, Ecuador, Hong Kong, Indonesia, Ireland, Israel, Malaysia, the Netherlands, Pakistan, Peru, Saudi Arabia, and Singapore.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11

U.S. EXPORTS OF WORKED MICA, BY COUNTRY

Country	Plates, sheets		Other	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	45	$334	—	—
Austria	19	120	—	—
Bahamas	5	13	12	$43
Brazil	51	618	1	12
Canada	231	2,281	48	1,134
France	(1)	8	4	79
Germany, Federal Republic of	1	22	11	51
Italy	33	765	—	—
Japan	(1)	10	1	31
Korea, Republic of	4	38	(1)	7
Mexico	33	572	17	252
Netherlands	2	38	—	—
New Zealand	44	210	—	—
Peru	—	—	2	47
Singapore	(1)	24	2	71
South Africa, Republic of	1	34	3	18
Spain	5	90	—	—
Sweden	2	68	—	—
Taiwan	2	58	8	172
United Kingdom	2	52	(1)	6
Other[2]	13	146	8	142
Total[3]	495	5,502	117	2,065

[1]Less than 1/2 unit.
[2]Includes Anguilla, Antigua, Argentina, Belgium, Chile, Colombia, Costa Rica, the Dominican Republic, Guatemala, Hong Kong, Indonesia, Ireland, the Netherland Antilles, Panama, the Philippines, Saudi Arabia, Switzerland, Turks and Caicos Islands, and Venezuela.
[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 CRUDE AND RIFTED MICA IN 1990, 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	—	—	—	—	20	$8	—	—
France	1	$39	(1)	$9	—	—	—	—
India	379	325	1,184	1,321	3,809	856	14	$181
Japan	—	—	—	—	—	—	12	64
Madagascar	—	—	20	88	—	—	—	—
Other[2]	—	—	—	—	—	—	4	23
Total[3]	381	364	1,204	1,419	3,829	864	30	268

[1]Less than 1/2 unit.
[2]Includes Canada and China.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF MICA POWDER AND WASTE IN 1990, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Canada	8,591	$3,594	2	$2
India	64	11	202	108
Japan	146	1,289	1	13
Norway	268	92	—	—
Other[1]	73	147	—	—
Total	9,142	5,133	205	123

[1]Includes China, France, Mexico, Switzerland, and the United Kingdom.

Source: Bureau of the Census.

TABLE 14

U.S. IMPORTS FOR CONSUMPTION OF WORKED MICA IN 1990, BY COUNTRY

Country	Plates, sheets		Other	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Austria	2	$48	18	$462
Belgium	645	4,442	9	46
Brazil	41	160	76	220
China	26	65	—	—
India	28	288	129	842
Korea, Republic of	1	5	25	56
Other[1]	42	358	43	440
Total	785	[2]5,365	300	2,066

[1]Includes Canada, Denmark, France, the Federal Republic of Germany, Hong Kong, Italy, Japan, Madagascar, Mexico, Spain, Suriname, Switzerland, and the United Kingdom.

[2]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

were about 1,600 tons, about the same as in 1988 and 1989, but considerably higher than in previous years. The high level of imports is a result of lower than average sales of mica from the NDS and continued decrease in domestic fabrication of mica parts. Worked mica imports remained at about 1,100 tons. About 9,000 tons of ground mica was imported, mostly from Canada, while about 4,000 tons was exported to 30 countries. The combined value of all mica imports increased 4% to $15.6 million, while the combined value of all mica exports increased 10% to $10.5 million.

World Review

World production of mica decreased 7% to 215,000 tons. The United States continued to lead in the production of flake mica. India continued to lead in the production of sheet mica.

India.—The Engineering Export Promotion Council (EEPC), which monitors and promotes the export of manufactured mica products, asked the Government of India to rescind the 3.5% levy on mica exports. EEPC felt that the tax, in effect since 1946, adversely affects the competitiveness of India's mica exports.[4]

Indonesia.—A deposit, reportedly containing about 90 million tons of mica, was discovered near Wasior in north central Irian Jaya.[5]

TABLE 15

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:								
1986	5,300	$1,758	1,454	$472	44	$196	[e]887	$4,502
1987	4,235	1,275	824	259	77	145	[e]692	4,748
1988	5,202	1,623	1,088	367	63	228	[e]815	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
Imports for consumption:								
1986	5,450	2,324	4,510	1,225	846	653	955	4,859
1987	5,672	2,685	3,916	1,243	1,116	1,230	746	5,125
1988	7,778	4,222	4,345	1,339	1,603	2,083	751	5,679
1989	8,902	4,971	4,185	1,256	1,616	2,054	1,129	6,711
1990	9,142	5,133	4,034	987	1,615	2,051	1,085	7,431

[e]Estimated.

Source: Bureau of the Census.

TABLE 16

MICA: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989	1990[e]
Argentina:					
Sheet	234	340	330	r e400	400
Waste, scrap, etc.	317	451	630	e500	500
Brazil	2,060	r2,415	2,520	r2,579	2,500
Canada[e]	12,000	13,500	12,000	12,000	12,000
France	10,834	r9,300	r e9,000	r e9,000	9,000
India:					
Crude	4,746	4,240	3,839	4,186	4,200
Scrap and waste	2,773	6,307	3,694	3,121	3,100
Total	r7,519	r10,547	r7,533	r7,307	7,300
Iran[3]	r2,450	r1,127	r2,294	r e2,000	2,000
Korea, Republic of (all grades)	41,997	31,938	r18,848	r7,888	8,000
Madagascar (phlogopite)	1,594	402	r618	r1,068	1,000
Mexico (all grades)	1,748	3,419	r6,228	r4,510	5,400
Morocco[e]	1,500	1,500	1,500	1,500	1,500
Mozambique[e]	300	(4)	(4)	—	—
Namibia	—	—	—	r(5)	—
Peru[e]	550	550	550	500	500
South Africa, Republic of (scrap)	2,509	970	1,669	r1,708	6 1,765
Spain	325	r370	e300	r e350	300
Sri Lanka	r895	r1,228	r1,981	r2,510	2,400
Sudan (all grades)[e]	10	r5	r(5)	(5)	—
Taiwan	r774	787	4,387	4,290	4,000
Tanzania (sheet)	(4)	(4)	(4)	(4)	(4)
U.S.S.R. (all grades)[e]	50,000	50,000	50,000	50,000	45,000
United States (scrap and flake)[7]	r134,400	145,650	129,900	119,142	6 108,845
Yugoslavia	r674	1,043	768	e800	750
Zimbabwe	r1,340	800	e800	r1,471	1,400
Total	r274,030	r276,342	r251,856	r229,523	214,560

[e]Estimated. [r]Revised.

[1]Table includes data available through May 24, 1991.

[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]Revised to zero.

[6]Reported figure.

[7]Excludes U.S. production of low-quality sericite and sheet mica, if any.

OUTLOOK

Demand for sheet mica has decreased dramatically during the past 30 years. For block and film mica, the major cause of decreased demand was technological change, specifically the introduction of semiconductor technology in electronics to the detriment of vacuum tube electronics that used large quantities of mica. Although the major impact of the technology change was felt in the 1960's and 1970's, consumption of block and film mica continues to decrease, albeit more slowly. Substitute materials cause part of the decrease, and increased imports of finished electronic gear mean fewer mica parts are fabricated in the United States. Since 1979, consumption block mica has decreased at an average annual rate of about 20%. This decline is expected to continue, and, by 1995, consumption will decrease to 2,500 kilograms. Consumption of mica splittings, the major type of sheet mica consumed in the United States, also decreased sharply through the 1960's and 1970's. During the 1980's, consumption leveled off to between 900 and 1,000 tons per year. Decreases were due to the development of substitute electrical insulating materials, miniaturization of electrical equipment, and increased imports of foreign-built products. Consumption of splittings is expected to decrease very slightly in the near future, remaining between 800 and 1,000 tons through 1995.

Scrap and flake mica enters markets as ground mica, and demand tends to follow construction activity levels. With construction activity somewhat depressed, ground mica consumption has decreased to about 100,000 tons for the past 3 years, down about 15% compared with the 1985-87 levels. Recessionary pressures are expected to ease in the near future, allowing modest increases in construction activity, which will probably bring ground mica consumption to about 120,000 tons by 1995.

The major end use, as a filler in joint compounds, will continue to account for 55% to 60% of the market. Consumption for other uses—in paints, well-drilling muds, and plastics—is expected to increase slightly by 1995.

[1] American Society for Testing and Materials. Standard Specification for Natural Muscovite Block Mica and Thins Based on Visual Quality. D351-7. (1977) in 1984 Annual Book of ASTM Standards: Volume 10.01, Electrical Insulation—Specifications: Solids, Liquids, and Gases; Test Methods: Liquids and Gases; Electrical Protective Equipment for Workers. Philadelphia, PA, 1984, pp. 136-143.

[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.

[4] U.S. Embassy, New Delhi, India. State Dep. Telegram 11672, May 21, 1990, p. 4.

[5] Mining Journal (London). V. 314, No. 8076, June 22, 1990, p. 492.

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MOLYBDENUM

By John W. Blossom

Mr. Blossom, a physical scientist/engineer with 43 years industry and Government experience, has been the commodity specialist for molybdenum since 1982. Survey and trade data were prepared by Sherwood C. Jordan, mineral data assistant; and the world production tables were prepared by Harold D. Willis, international data coordinator.

Molybdenum is a refractory metallic element used principally as an alloying agent in steels, cast irons, and superalloys to enhance hardenability, strength, toughness, and wear and corrosion resistance. Primarily added in the form of molybdic oxide or ferromolybdenum, it is frequently used in combination with chromium, columbium, manganese, nickel, tungsten, or other alloy metals to achieve desired metallurgical properties. The versatility of molybdenum has ensured it a significant role in contemporary technology and industry, which increasingly require materials that are serviceable under higher stresses, greater temperature ranges, and more corrosive environments. Moreover, molybdenum finds significant usage as a refractory metal in numerous chemical applications, including catalysts, lubricants, and pigments. The variety of uses for molybdenum materials, few of which afford acceptable substitutions, has resulted in a demand that is expected to grow at a greater rate than most other ferrous metals.

Distribution of molybdenum reserves and productive capacity is concentrated in a few countries of the world. World mine output was an estimated 112 thousand metric tons (molybdenum contained in concentrate) in 1990, of which Canada, Chile, and the United States provided 80%. An estimated 10% of world output came from the U.S.S.R. These four 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 metric 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 15 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, primarily as an alloy in steels and cast irons, were successful, and by the mid-1920's, demand exceeded that of the war years. Operations resumed at the Climax deposit in 1924. By 1930, world output of molybdenum totaled 4.2 million pounds, of which the United States and the Climax Mine accounted for about 89% and 73%, respectively.

In 1933, the Greene Cananea Copper Co., a Mexican subsidiary of the Anaconda Co., initiated the recovery of molybdenite as a byproduct of copper mining operations. Three years later, Kennecott Corp. began byproduct recovery at its Bingham open pit in Utah. Since that time, molybdenite recovery circuits have been installed at numerous copper concentrating plants, notably in Canada, Chile, and the United States. These sources have supplied 40% to 50% of the world molybdenum output in recent years.

Since the early 1930's, industrial research and marketing programs have considerably expanded the range of metallurgical materials in which molybdenum is a preferred or essential alloy ingredient. The use of molybdenum as a refractory metal and in a variety of chemical applications has also experienced significant growth.

Definitions, Grades, and Specifications

Molybdenum is a silver-white metallic element with an atomic number of 42, atomic weight of 95.95, and a density of 10.2 grams per cubic centimeter. The chemistry of molybdenum is complex; molybdenum exhibits oxidation states from -2 to 6, coordination numbers from 4 to 8, and forms compounds with most inorganic and organic liquids. Molybdenum is a strong carbide-forming element, and much of its alloying effect in steel is imparted through the formation of carbides. It has a melting point of about 2,610° C; among the metallic elements, only osmium, rhenium, tantalum, and tungsten have higher melting points. Other significant physical properties of molybdenum metal are good thermal conductivity (about one-half that of copper), the lowest coefficient of thermal expansion of the pure metals, high strength at elevated temperatures, and resistance to corrosion in a wide variety of mediums. Molybdenum metal is stable in air or water at moderate temperatures, but above 500° C, it oxidizes readily.

Molybdenite is the principal mineral from which molybdenum is obtained. Crude ore containing molybdenite is beneficiated to produce molybdenite concentrate. The concentrate generally contains about 90% molybdenite; the grade may be somewhat lower, particularly if produced at copper byproduct concentrating plants. Technical-grade molybdic oxide is produced by the roasting of molybdenite concentrate. Typically, the oxide has a content of 85% to 90%, or a minimum of 57% contained molybdenum. Other raw materials, including ferromolybdenum, purified molybdic oxide, ammonium, and sodium molybdate, and molybdenum metal powder are produced from technical-grade oxide. The production of these materials is described in the section entitled, "Products for Trade and Industry."

The American Society for Testing and Materials (ASTM) has developed standards for the chemical composition of molybdenum oxide products (Specification A 146-64, reapproved 1979) and ferromolybdenum (Specification A 132-74, reapproved 1979). These standards specify minimums for molybdenum content and maximums for impurity content as an aid to producers and purchasers. Material marketed by the major domestic producers generally meet or exceed ASTM standards.

Products for Trade and Industry

Some commercial-grade molybdenite concentrate is treated in additional grinding and flotation steps to produce lubricant-grade molybdenum disulfide. Oil and water are volatilized by passing an upgraded concentrate through an inert-gas-swept kiln. The oil-free product is about 99% molybdenum disulfide and suitable for use in lubricant applications.

Molybdenite concentrate is converted to technical-grade molybdic oxide, the major form of molybdenum used by industry and the base material for production of ferromolybdenum, chemicals, and molybdenum metal powder. The technical-grade oxide is produced by roasting molybdenite concentrate in the multiple-hearth furnace at temperatures of up to 650° C. Typically, the roasted product contains 90% molybdic oxide and a maximum of 0.1% sulfur. Technical-grade oxide is used to add molybdenum to steels, cast irons, and other alloys.

Ferromolybdenum is typically produced by reduction of technical-grade oxide and iron oxide with a conventional metallothermic process, using silicon and/or aluminum as the reductant. The molybdenum content ranges from 58% to 64%. Ferromolybdenum is used as a alternative additive in producing alloy steels, cast irons, and nonferrous alloys.

Ammonium molybdate is produced by reacting pure molybdic oxide with ammonium hydroxide and crystallizing out the pure molybdate. Sodium and calcium molybdate are made in a similar manner using sodium hydroxide and calcium chloride.

Molybdenum metal powder is manufactured by reducing pure molybdic oxide or ammonium molybdate with hydrogen. The purest metal powder (99.95% molybdenum minimum) is produced from ammonium molybdate. Metal powder is pressed and sintered into small metal ingots, which are converted into rod, wire, or sheet by hot rolling, swaging, or forging. Large ingots are produced by arc-casting powder under a vacuum or inert gas atmosphere.

Industry Structure

Four countries, Canada, Chile, the U.S.S.R., and the United States, mine 90% of world output of molybdenum ore. Plants to convert ore concentrates to technical-grade oxide and other molybdenum products are in Chile, the U.S.S.R, the United States, and Western Europe.

Geology-Resources

Almost all molybdenum is recovered from low-grade deposits of the mineral molybdenite. Deposits mined primarily for molybdenum provide 60% of U.S. output and about 33% of world output. The remainder is obtained mainly as a byproduct from mining of large, low-grade copper porphyry deposits. Primary molybdenum deposits generally grade 0.2% to 0.5% molybdenite; copper ores from which byproduct molybdenum is recovered contain 0.02% to 0.08% molybdenite.

The average crustal abundance of molybdenum is 1 to 2 parts per million (ppm). The molybdenum content of igneous rocks tends to increase with increasing silica content. Molybdenum does not occur in nature in its free or native state, but is found only chemically combined with other elements. Small deposits of molybdenum-bearing minerals occur throughout the world, but the only molybdenum mineral of commercial importance is molybdenite. Wulfenite, powellite, and ferrimolybdite are common but have supplied very little molybdenum.

Molybdenite (MoS_2) is a lead-gray metallic mineral that characteristically occurs in thin, tabular, commonly hexagonal plates and also disseminated as fine specks. It has a specific gravity of 4.6 to 4.7, a hardness of 1 to 1.5, a greasy feel, and it soils the fingers. Superficially, it resembles graphite, for which it commonly has been mistaken.

Molybdenum deposits are of five geological types: (1) porphyry or disseminated deposits, including stockworks and breccia pipes in which metallic sulfides are dispersed through relatively large volumes of altered and fractured rock, (2) contact-metamorphic zones and tactite bodies of silicated limestone adjacent to intrusive granitic rocks, (3) quartz veins, (4) pegmatites and aplite dikes, and (5) bedded deposits in sedimentary rocks.

The first three genetic-type deposits are hydrothermal in origin and as such represent nearly all the known molybdenum resources currently mined in the world. The remaining types do not represent a great volume of molybdenum but are of certain economic importance only when molybdenum is associated with other minerals.

In the hydrothermal deposits, metallic minerals are precipitated from high-temperature aqueous solutions either by changes in temperature and pressure or by evaporation of the liquid. Minerals are deposited in the cavities, cracks, or interstices of the matrix rock.

Most of the porphyry coppers contain small quantities of molybdenite disseminated with the copper minerals through large bodies of granitic rock. The chief minerals are chalcopyrite and chalcocite, with pyrite and small amounts of other sulfides including molybdenite.

Available information on world reserves and reserve base of molybdenum varies widely in reliability. For certain countries such as Canada, Chile, and the United States, company annual reports or other published materials enable inventorying minable ore reserves. For most other countries, reserves must be estimated from fragmentary or preliminary data on ore tonnage and grade of known or anticipated sources. In particular, the reserve figures for China and the U.S.S.R. should be considered order-of-magnitude estimates.

It should be noted that the reserve data refer to molybdenum contained in ore. The recovery of molybdenum after milling approximates 75% to 90% of the in-place ore content at primary molybdenum sources. Recoveries achieved at byproduct sources vary markedly from mine to mine, but average an estimated 55% of the molybdenum in ore processed. Overall, an estimated 65% of the total world molybdenum reserves can be considered as recoverable.

Most of the world reserves of molybdenum occur in the western mountain regions of North and South America, extending from Alaska and British Columbia through the United States and Central America to the Andes Mountains of Chile. These regions, roughly bordering the eastern margin of the Pacific Basin, are also regarded as most promising for future discoveries and additions to reserves.

Technology

Exploration.—Prospecting and exploration for molybdenum is basically the same as that for deposits of other metals. Areas generally considered favorable for molybdenite mineralization are those metallogenic provinces that encompass known occurrences of molybdenum stockworked deposits and copper-molybdenum porphyry deposits. An understanding of regional geology, mineral associations, and known patterns of molybdenite mineralization is essential to identify potential sites for field investigation. Sites for detailed study may be selected on the basis of geologic mapping of rock units and structures, geochemical analyses of sediments and soils, and ground geophysical surveys. An intensive drilling and sampling program is then required to estimate the size, grade, and continuity of the discovery. Exploration drifts may be driven into the ore body to provide more specific geologic information and bulk samples for metallurgical testing.

The evaluation of a deposit may require 2 to 5 years from the time of discovery. During this time, the technical, economic, and environmental aspects of mine development must be evaluated. An additional 3 to 8 years may be required to prepare the deposit for production. Long development times are indicative of the complex planning and considerable capital needed to develop the large, low-grade stockwork and porphyry deposits that are expected to remain the significant sources of molybdenum. As a general rule, development of underground molybdenum deposits would require more time and capital than that of surface deposits.

Mining.—Molybdenum ore is mined by underground and open pit methods, the choice of method determined by the size, configuration, grade, and depth of the ore body. Underground and surface operations accounted for about 40% and 60%, respectively, of the domestic molybdenum output.

Underground deposits of molybdenum ore are mined by block or panel caving methods modified to suit the characteristics of the particular ore body being worked. In these methods, large masses of ore are undercut and blasted at the base to induce the collapse and fragmentation of the ore under its own weight. The broken ore may be drawn off from the caved mass by gravity through finger raises into slusher drifts. The ore is then scraped to draw holes where it falls into ore cars on a haulage level beneath the slusher drifts. Alternatively, the broken ore may be funneled by gravity to crosscut drifts at intervals between production drifts. Ore is moved from the ends of the crosscuts along the production drifts to ore passes where it is dumped and collected in loading pockets on a deeper main haulage level. Ore is then transported from the main haulage level to the site of the initial milling operations. Caving methods are used to mine underground deposits of molybdenum because the low grade of the ore necessitates extraction of large tonnages of rock at a minimum of cost. However, caving of the ore must be carefully controlled to avoid ore dilution and excessive ground stresses to mine openings.

In open pit mining operations, the ore is exposed by removal of waste rock. The cut in the ore takes the form of benches, which vary in height and width from mine to mine. The cycle of open pit extraction consists of drilling, blasting, loading, and haulage. Primary drilling consists of driving a vertical blasting hole into the ore. Secondary drilling and blasting may be required to break large boulders. Ore is loaded by mechanical shovels into rail cars or trucks and hauled by large trucks for short distances or by train for long distances. Skipways and belt conveyors are used at some mines for transporting ore to the mill site.

Beneficiation.—Because of their low molybdenum content, all molybdenum-bearing ores require beneficiation. After crushing and grinding to a suitable size, both primary molybdenite and copper sulfide ore containing molybdenite are beneficiated by flotation. With primary ores, a final concentrate of 90% to 95% molybdenite is produced by subjecting the ore to several stages of grinding and 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). Very little molybdenum-containing obsolete scrap is processed for its molybdenum content. Although some molybdenum is recycled as a minor constituent of scrap alloy steels, the use of such scrap does not generally depend on its molybdenum content. An increasing quantity of molybdenum is being reclaimed from spent catalysts and chemical residues.

Byproducts and Coproducts

Tin, tungsten, and a very minor quantity of pyrite are recovered as byproducts from molybdenum ore at the Climax deposit in Colorado. Rhenium is extracted from flue gases and dust produced during the roasting of molybdenite concentrate that has been produced as a byproduct of copper mining.

Molybdenum is recovered as a byproduct primarily from copper ores. A very small amount is also obtained from tungsten and uranium ores. At the Sierrita Mine in Arizona, copper and molybdenum are considered coproduct values.

Substitutes

Historically, molybdenum has been a relatively inexpensive alloying agent used primarily in specialty steels and alloys, and in the United States, it has been readily available. As a result, metallurgical applications for molybdenum were broadened, and its utility as an alloy ingredient became well recognized. The substitution for molybdenum by other alloy metals has had little impetus.

Several factors mitigate the possible replacement of molybdenum to the degree that its overall demand would be significantly affected. First, there is no acceptable substitute in numerous metallurgical and chemical uses. Second, it is commonly added to steels and alloys to enhance several desired properties (such as hardenability, strength, corrosion resistance, etc.), often in synergistic effect with other alloy metals. In such cases, molybdenum could be replaced for particular effects, but at a sacrifice in overall performance. Moreover, the molybdenum content of alloy and specialty steels ranges from less than 1 to a few percent. Therefore, costs of molybdenum raw materials have to increase substantially to appreciably affect the cost of the finished product, thereby stimulating substitution. Finally, the United States is self-sufficient in molybdenum, a situation unlike that of many other ferrous metals. Significant replacement would entail increases in the imports of substituted metals.

Nevertheless, possible alternatives exist in most applications of molybdenum. Steels and alloys containing less or no molybdenum might be used in place of those with higher molybdenum content. In most cases, such substitution would result in lowered or unacceptable performance. Boron, chromium, and manganese can replace molybdenum in steels where hardenability is the only desired effect. In certain low-alloy steels, columbium, manganese, and vanadium act in similar fashion to molybdenum. Chromium, nickel, and tungsten are possible substitutes in steels and other alloys. Molybdenum has substantially replaced tungsten in high-speed tool steels; a return to tungsten grades is possible, but with a reduction in economy and performance. Nonmetallurgical materials, such as plastics and ceramics, can replace steels and alloys containing molybdenum in certain applications.

Tungsten and tantalum can be substituted for molybdenum in certain refractory metal uses, but as a cost disadvantage. Molybdenum can be replaced by graphite for refractory elements in electric furnaces in the range of 1,000° to 1,600° C, but at the expense of slightly greater difficulty in operation and control. Chrome orange, cadmium red, and organic orange pigments are possible substitutes for molybdenum orange. Acceptable substitutes for molybdenum are not found in most of its major catalytic applications. Graphite and other solid lubricants generally do not perform as well as molybdenum disulfide, especially under high-pressure and high-temperature conditions.

Economic Factors

The prices of molybdenum products are quoted on a contained-molybdenum basis and reflect, at least partially, the cost of conversion. Technical-grade oxide, the major form of molybdenum sold commercially, varies slightly in price depending on purity, type of packaging, and whether it is briquetted.

Price quotations generally fall under two groups, the producer-marketer and the merchant. The producer-marketer mines and concentrates the ore, converts the concentrates into consumer products, and markets these products, while a merchant buys and sells concentrates and may convert concentrates into products that are marketed. The source for the merchant to buy concentrates is the byproduct producer. The byproduct producer prices his byproduct as one that provides extra credit. Therefore, this type of a producer is not likely to hold back concentrates from sale. The producer-marketer tries to keep the market balanced by setting a price-based cost plus profit and varying the output to maintain a balance.

Operating Factors

Environmental Requirements.—The mining of molybdenum ore and disposal of ore tailings disturb land areas. Land reclamation is part of the ongoing mining operation. Development of new mining and milling complexes present local socioeconomic and land-use problems. Because new potentially economic sources are likely to be found in relatively unpopulated regions with little other industry, development of a major mine can have significant impact on established occupational patterns. Interaction between mining firms and local, State, and Federal agencies are required to ensure

that mine development proceeds in as orderly and environmentally sound manner as 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 5 with about the same tonnage of production. This improvement in productivity was due to changes in mining and milling equipment and methodologies.

ANNUAL REVIEW

Domestic and foreign molybdenum markets for concentrates diminished in 1990. Domestic stock levels were unchanged. U.S. mine output of molybdenum was unchanged at 55% of world production. Reported end-use consumption of molybdenum in raw materials increased by 6% from 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 remained about the same as in the previous year. Domestic mine production of molybdenum concentrate decreased to a total of 62,000 metric tons of contained molybdenum compared with 63,000 metric tons in 1989. World mine production of molybdenum concentrate also decreased from a total of 117,000 in 1989 to 112,000 metric tons in 1990. Canada, Chile, the U.S.S.R., and the United States accounted for more than 90% of the molybdenum produced worldwide.

Consumption and Uses

Consumption of molybdenum concentrate decreased 7,000 metric tons in 1990. Domestic mine production of molybdenum concentrate was either roasted, exported for conversion, or purified to lubrication-grade molybdenum disulfide. The quantity of concentrate roasted domestically to produce technical-grade molybdic oxide decreased from that of 1989. 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 20,000 metric tons of molybdenum.

Stocks

Total industry stocks, which include those of producers and consumers, was unchanged at 16,000 metric tons of contained molybdenum. Inventories of molybdenum in concentrate at producer locations increased about 700 metric tons. Producer stocks of molybdenum in consumer products, such as oxide, ferromolybdenum, molybdate, metal powders, and other types, decreased about 1,000 metric tons. Compared with apparent consumption, yearend producer stocks of these materials represented about a 10-month supply. Domestic consumer inventories of about 3,000 metric tons, the same amount as at yearend 1989, represented approximately a 2-month supply as measured by average monthly reported consumption.

Prices

The "Metals Week Dealer" (MWD) price of molybdic oxide (per kilogram of contained molybdenum) increased from $5.78 per pound in January to $7.04 at the end of April, decreasing to $5.35 at the end of December 1990. The average MWD price of oxide was $5.62 or $1.85 less than the average MWD price in 1989.

The posted producer price (AMAX Inc. and Cyprus Minerals Co.) for molybdic oxide was $7.38 during 1989.

Foreign Trade

Exports of molybdenum in concentrate and of oxide decreased compared with those of 1989. Molybdenum concentrate exports were about 67% of domestic mine production. Approximately 95% of reported shipments of concentrate and oxides were made to Belgium, Chile, the Federal Republic of Germany, Japan, Mexico, the Netherlands, and the United Kingdom. The calculated molybdenum content of all exports was about 43,000 metric tons in 1990. Total value of exports decreased from $318 million in 1989 to $209 million in 1990.

Approximately 2,000 metric tons of molybdenum in various forms were imported into the United States, about the same as in 1989. Total value of all forms of molybdenum imported decreased from $30 million in 1989 to $28 million in 1990. In terms of both value and quantity, the major form imported was ferromolybdenum, principally from Chile and China.

World Review

Capacity.—The data in table 11 are rated capacity for mines and mills as of December 31, 1990. 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 12. The United States, with a reserve base of molybdenum estimated at 11.8 million metric tons, has 45% of the world molybdenum reserve base. About 90% of U.S. reserve occurs 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

TABLE 1

SALIENT MOLYBDENUM STATISTICS

(Metric tons of contained molybdenum unless otherwise specified)

		1986	1987	1988	1989	1990
United States:						
Concentrate:						
Production		42,627	34,073	43,051	63,105	61,611
Shipments		43,094	31,692	45,240	61,733	61,580
Value	thousands	$240,484	$179,286	$266,899	$421,427	$346,262
Reported consumption		24,068	16,983	35,690	41,877	35,455
Imports for consumption		508	573	77	—	45
Stocks, December 31: Mine and plant		3,953	6,841	4,732	r6,969	7,672
Primary products:						
Production		18,820	15,721	25,646	27,985	28,764
Shipments		26,243	18,447	20,535	18,277	17,983
Stocks, December 31		9,389	10,055	7,116	6,675	5,918
Reported consumption, by end use		14,469	14,800	17,422	r17,204	18,233
World: Mine production		r93,218	r89,871	r95,172	p116,799	e111,652

eEstimated. pPreliminary. rRevised.

TABLE 2

PRODUCTION, SHIPMENTS, AND STOCKS OF MOLYBDENUM PRODUCTS IN THE UNITED STATES

(Metric tons of contained molybdenum)

	Metal powder		Other[1]		Total	
	1989	1990	1989	1990	1989	1990
Received from other producers	W	W	2,530	3,339	2,530	3,339
Gross production during year	2,035	2,122	25,950	26,642	27,985	28,764
Used to make other products listed here	W	W	11,440	13,038	11,440	13,038
Net production	W	W	16,545	15,727	16,545	15,727
Shipments	920	875	17,357	17,108	18,277	17,983
Producer stocks, December 31	124	254	6,551	5,664	6,675	5,918

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

[1]Includes ferromolybdenum, molydic oxides, phosphomolybdic acid, molybdenum disulfide, molybdic acid, ammonium molybdate, molybdic oxides, calcium molybdate, sodium molybdate, molybdenum metal, pellets, molybdenum pentachloride, molybdenum hexacarbonyl, and data indicated by symbol W.

TABLE 3

MOLYBDENUM: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons of contained molybdenum)

Country[2]	1986	1987	1988	1989p	1990e
Bulgaria[e]	190	200	200	190	180
Canada (shipments)	11,251	14,771	13,535	13,543	[3]13,481
Chile	16,581	16,941	15,527	16,550	[3]13,830
China[e]	2,000	2,000	2,000	2,000	2,000
Iran[e]	r900	r1,200	r1,200	r1,200	1,200
Korea, Republic of	r315	325	144	132	140

See footnotes at end of table.

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 Chuuicamata 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

TABLE 3—Continued

MOLYBDENUM: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons of contained molybdenum)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Mexico	3,350	4,400	4,456	4,189	4,000
Mongolia[e]	1,100	1,100	1,100	1,200	1,200
Niger[e]	20	8	15	r13	10
Peru	3,484	3,353	2,444	3,177	3,000
U.S.S.R.[e]	11,400	11,500	11,500	11,500	11,000
United States	42,627	34,073	43,051	63,105	[3]61,611
Total	r93,218	r89,871	95,172	116,799	111,652

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through May 31, 1991.

[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.

TABLE 4

U.S. REPORTED CONSUMPTION OF MOLYBDENUM, BY END USE

(Hundred kilograms of contained molybdenum)

End use	Molybdic oxides	Ferro-molybde-num[1]	Ammonium and sodium molybdate	Other molybdenum materials[2]	Total[3]
1989					
Steel:					
Carbon	4,607	932	—	245	5,785
Stainless and heat resisting	r30,478	r2,218	—	741	33,438
Full alloy	r28,521	9,596	—	228	38,344
High-strength, low-alloy	4,672	3,360	—	—	8,032
Tool	7,478	W	—	42	7,520
Cast irons	W	r7,819	—	93	7,912
Superalloys	4,929	r617	—	r9,325	14,871
Alloys:					
Welding materials (structural and hard-facing)	—	r1,108	—	49	1,156
Other alloys[4]	1,429	r448	—	862	2,739
Mill products made from metal powder	—	—	—	19,180	19,180
Chemical and ceramic uses:					
Pigments	W	—	W	—	W
Catalysts	9,201	—	W	1,793	10,994
Other	38	9	7	4,908	4,962
Miscellaneous and unspecified	2,635	r2,540	11,606	328	17,109
Total[3]	93,989	28,647	11,613	37,794	172,042
1990					
Steel:					
Carbon	4,614	1,082	—	218	5,913
Stainless and heat resisting	34,376	1,996	—	736	37,107
Full alloy	29,845	11,831	—	315	41,991
High-strength, low-alloy	5,322	3,622	—	—	8,944
Tool	5,567	2,263	—	32	7,863

See footnotes at end of table.

molybdenum have been identified in Central and South America. Many of these deposits are actively being explored and evaluated and could add substantially to reserves in the future.

Reserves of molybdenum in China and the U.S.S.R. are estimated to be substantial, but definitive information about the current sources of supply or prospects for future development in the two countries is lacking. Copper ores are being investigated on the islands of New Guinea and Bougainville in the southwest Pacific, but it is not known whether these contain economically recoverable molybdenum.

OUTLOOK

Capital expenditures are expected to decrease from a relatively high level of the previous year to a more normal level over the next few years. Alloy and stainless steel demand is forecast to decline in 1991. Short-term molybdenum demand is expected to remain a little below that of 1990. Molybdenum production must be adjusted to reduce inventories that have been built up in Western Europe during 1989. The long-term demand depends upon events in Eastern Europe and the U.S.S.R.'s ability to meet the needs of capital expenditures for environmental controls and to expand their manufacturing capacity.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

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TABLE 4—Continued

U.S. REPORTED CONSUMPTION OF MOLYBDENUM, BY END USE

(Hundred kilograms of contained molybdenum)

End use	Molybdic oxides	Ferro-molybde-num[1]	Ammonium and sodium molybdate	Other molybdenum materials[2]	Total[3]
1990—Continued					
Cast irons	W	7,401	—	124	7,524
Superalloys	7,612	623	—	11,297	19,532
Alloys:					
Welding materials (structural and hard-facing)	—	844	—	43	888
Other alloys[4]	W	W	—	833	833
Mill products made from metal powder	—	—	—	20,702	20,702
Chemical and ceramic uses:					
Pigments	W	—	1,320	—	1,320
Catalysts	9,076	—	W	1,793	10,869
Other	36	11	7	4,509	4,564
Miscellaneous and unspecified	3,686	714	9,581	298	14,278
Total[3]	100,133	30,388	10,908	40,900	182,329

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Miscellaneous and unspecified."
[1]Includes calcium molybdate.
[2]Includes purified molybdenum disulfide, molybdenite 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)

	1986	1987	1988	1989	1990
Concentrate: Mine and plant	3,953	6,841	4,732	r6,969	7,672
Producers:					
Molybdic oxides[1]	7,466	W	4,816	W	W
Metal powder	W	207	136	124	254
Other[2]	1,923	9,848	2,164	6,551	5,664
Total[3]	9,389	10,055	7,116	6,675	5,918
Consumers:					
Molybdic oxides[1]	983	1,657	1,581	r1,627	1,570
Ferromolybdenum[4]	280	251	260	r235	222
Ammonium and sodium molybdate	59	34	25	19	21
Other[5]	750	745	752	r703	783
Total[3]	2,072	2,688	2,618	2,584	2,596
Grand total[3]	15,414	19,584	14,466	16,229	16,186

rRevised. W Withheld to avoid disclosing company proprietary data; included with "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]Data may not add to totals shown because of independent rounding.
[4]Includes calcium molybdate.
[5]Includes purified molybdenum disulfide, molybdenite concentrate added directly to steel, molybdenum metal powder, molybdenum metal, pellets, and other molybdenum materials.

TABLE 6

DOMESTIC PRICE LISTINGS FOR MOLYBDENUM

(Per kilogram of contained metal)

	1989	1990
Merchant quotes:[1]		
Concentrate (byproducts)	$6.990	$5.623
Ferromolybdenum-export	9.504	8.502
Oxide	7.475	5.859
Producer quotes:		
Oxide	$7.387 - 8.754	$7.380

[1]Average.

Source: Metals Week.

TABLE 7

U.S. EXPORTS OF MOLYBDENUM ORE AND CONCENTRATES (INCLUDING ROASTED AND OTHER CONCENTRATES), BY COUNTRY

Country	1989		1990	
	Quantity (metric tons of contained molybdenum)	Value (thousand dollars)	Quantity (metric tons of contained molybdenum)	Value (thousand dollars)
Argentina	168	1,247	—	—
Australia	138	r997	141	618
Belgium	7,787	42,944	9,107	39,092
Brazil	198	r1,460	37	159
Canada	1,623	r8,354	259	1,562
Chile	593	2,679	1,298	4,250
France	36	r232	899	2,747
Germany, Federal Republic of	2,621	13,910	2,858	10,410
India	182	1,756	196	816
Japan	3,896	25,380	4,844	22,383
Mexico	587	6,774	2,272	14,806
Netherlands	20,924	110,939	7,941	36,935
Sweden	112	370	372	1,431
United Kingdom	12,015	53,744	10,957	32,956
Other	350	1,550	200	1,723
Total[1]	51,231	272,336	41,380	169,888

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

Source: Bureau of the Census.

TABLE 8

U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

Product and country	HTSUS No.	1989		1990	
		Quantity (metric tons of contained molybdenum)	Value (thousand dollars)	Quantity (metric tons of contained molybdenum)	Value (thousand dollars)
Ferromolybdenum:[1]	7202.70.0000				
Belgium		18	159	—	—
Canada		29	254	82	610
Japan		6	49	144	1,265
Malaysia		3	20	(2)	4
Mexico		2	13	11	93
Singapore		10	56	—	—
Venezuela		5	38	25	168
Other		3	25	38	232
Total[3]		75	615	300	2,372
Molybdenum, unwrought:	8102.91.0000				
Canada		7	119	33	852
France		2	57	(2)	11
Germany, Federal Republic of		6	60	—	—
India		1	14	—	—

See footnotes at end of table.

TABLE 8—Continued

U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

Product and country	HTSUS No.	1989 Quantity (metric tons of contained molybdenum)	1989 Value (thousand dollars)	1990 Quantity (metric tons of contained molybdenum)	1990 Value (thousand dollars)
Molybdenum, unwrought—Continued					
Japan		135	1,709	71	824
Mexico		7	63	5	19
Netherlands		85	1,029	66	644
United Kingdom		1	25	1	20
Other		10	140	4	82
Total[3]		253	r3,215	180	2,453
Wire:	8102.93.0000				
Argentina		1	29	2	75
Belgium		14	444	8	604
Brazil		35	1,034	23	902
Canada		10	309	10	385
France		20	615	42	1,365
Germany, Federal Republic of		95	2,562	166	3,865
India		6	269	6	261
Italy		15	625	31	1,145
Japan		60	1,888	34	1,597
Korea, Republic of		11	617	12	632
Mexico		4	226	8	341
Netherlands		(2)	15	(2)	26
Singapore		(2)	16	—	—
South Africa, Republic of		1	43	2	61
Spain		6	169	14	403
Sweden		14	453	14	451
Taiwan		25	278	3	120
United Kingdom		19	1,033	11	520
Other		4	243	2	110
Total[3]		340	10,867	388	12,863
Powder:	8102.10.0000				
Austria		20	158	—	—
Belgium		1	12	—	—
Brazil		412	416	20	516
Canada		8	151	6	195
China		6	84	4	74
France		48	594	98	661
Germany, Federal Republic of		5	162	25	256
India		11	166	14	215
Italy		6	98	3	66
Japan		5	175	26	961
Mexico		5	73	4	60
Netherlands		13	206	2	45
Sweden		10	143	21	309
Taiwan		44	701	48	888
United Kingdom		32	552	5	132
Other		10	155	18	186
Total[3]		634	3,846	292	4,565

See footnotes at end of table.

TABLE 8—Continued

U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

Product and country	HTSUS No.	1989 Quantity (metric tons of contained molybdenum)	1989 Value (thousand dollars)	1990 Quantity (metric tons of contained molybdenum)	1990 Value (thousand dollars)
Molybdenum, wrought:	8102.92.0000				
Australia		2	64	(2)	5
Austria		107	258	6	122
Brazil		(2)	17	(2)	18
Canada		14	694	7	295
France		10	664	9	688
Germany, Federal Republic of		25	1,113	39	1,804
Japan		49	2,502	25	1,487
Korea, Republic of		72	483	36	194
Mexico		3	78	2	99
Netherlands		8	491	6	462
Singapore		(2)	4	(2)	11
South Africa, Republic of		2	175	1	80
Sweden		1	33	1	22
United Kingdom		26	1,164	52	2,044
Other		17	479	6	264
Total[3]		336	8,219	190	7,595
Oxides and hydroxides:	2825.70.0000				
Argentina		2	67	(2)	3
Australia		2	14	7	45
Belgium		262	1,255	120	530
Canada		62	690	176	1,188
Japan		926	12,977	364	2,576
Korea, Republic of		27	116	43	221
Mexico		7	130	51	354
Netherlands		85	1,288	14	84
Taiwan		—	—	8	54
Other		17	409	4	40
Total[3]		1,391	16,947	787	5,095
Molybdates—all:	2841.70.0000				
Belgium		18	78	—	—
Canada		36	1,171	335	2,102
China		18	78	8	49
Japan		153	796	220	1,155
Korea, Republic of		—	—	55	322
Mexico		11	107	12	95
Singapore		47	38	2	13
Taiwan		6	35	15	91
Other		5	35	35	136
Total[3]		295	2,338	680	3,963

[r]Revised.
[1]Ferromolybdenum contains about 60% to 65% molybdenum.
[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. IMPORTS FOR CONSUMPTION OF MOLYBDENUM

Item	HTSUS No.	1989			1990		
		Gross weight (metric tons)	Contained molyb-denum (metric tons)	Value (thousand dollars)	Gross weight (metric tons)	Contained molyb-denum (metric tons)	Value (thousand dollars)
Molybdenum ore and concentrates, roasted	2613.10.0000	620	238	1,791	913	433	2,874
Molybdenum ore and concentrates, other	2613.90.0000	(1)	(1)	(1)	142	45	310
Molybdenum oxides and hydroxides	2825.70.0000	422	NA	3,298	643	NA	3,569
Molydates of ammonium	2841.70.0000	314	181	2,106	109	61	614
Molybdates—all others	2841.70.5000	58	27	375	4	2	13
Molybdenum orange	3206.20.0020	1,046	NA	2,858	916	NA	2,579
Mixtures of inorganic compounds	3823.90.3400	15	13	202	1	(2)	103
Ferromolybdenum	7202.70.0000	1,410	772	9,062	1,401	871	6,990
Molybdenum powders	8102.10.0000	216	198	2,077	79	71	1,771
Molybdenum, unwrought	8102.91.1000	60	46	2,391	58	39	2,147
Molybdenum, waste and scrap	8102.91.5000	175	168	1,701	214	202	1,866
Molybdenum, wrought (includes bars, rods, profiles, plate, sheets, strips, foil)	8102.92.0000	50	NA	3,311	61	NA	4,217
Molybdenum wire	8102.93.0000	8	NA	553	3	NA	249
Molybdenum, other	8102.99.0000	3	NA	637	2	NA	720
Total[3]		4,397	1,643	30,361	4,545	1,725	28,022

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 10

U.S. IMPORT DUTIES ON MOLYBDENUM

Type trade	HTSUS No.	Commodity description	Unit	Duties on imports	
				Most favored nation (MFN) percent (ad valorem)	Non-MFN percent (ad valorem)
Import/export	2613.10.0000	Molybdenum ore and concentrates, roasted	Content-kilogram	13.02 cents per kilogram + 1.9%	$1.13 per kilogram + 15%
Do.	2613.90.0000	Molybdenum ore and concentrates, other	do.	19.8 cents per kilogram	77.2 cents per kilogram
Molybdenum chemicals:					
Import/export	2825.70.0000	Molybdenum oxides and hydroxides	Gross-kilogram	3.2%	20.5%
Import	2841.70.0000	Molybdates of ammonium	Content-kilogram	4.3%	29%
Export	2841.70.0000	Molybdates—all	do.	—	—
Import	2841.70.5000	Molybdates—all others	do.	3.7%	25%
Molybdenum pigments:					
Import	3206.20.0020	Molybdenum orange	Gross-kilogram	3.7%	25%
Export	3206.20.0000	Pigments based on chromium (molybdenum orange, etc.)	do.	—	—
Miscellaneous chemical products:					
Import	3823.90.3400	Mix of two or more inorganic compounds of molybdenum	do.	2.8%	18%
Export	3823.30.0000	Nonagglomerated metal binders, molybdenum, etc.	do.	—	—

TABLE 10—Continued

U.S. IMPORT DUTIES ON MOLYBDENUM

Type trade	HTSUS No.	Commodity description	Unit	Duties on imports	
				Most favored nation (MFN) percent (ad valorem)	Non-MFN percent (ad valorem)
Ferroalloys:					
Import	7202.70.0000	Ferromolybdenum	Content-kilogram	4.5%	31.5%
Molybdenum metals:					
Import	8102.10.0000	Powders	Content-kilogram	13.9 cents per kilogram + 1.9%	$1.10 per kilogram + 15%
Export	8102.10.0000	do.	Gross-kilogram	—	—
Import	8102.91.1000	Unwrought	Content-kilogram	13.9 cents per kilogram + 1.9%	$1.10 per kilogram + 15%
Export	8102.91.0000	Unwrought, waste and scrap	Gross-kilogram	—	—
Import	8102.91.5000	Waste and scrap	Content-kilogram	Free	Free
Import/export	8102.92.0000	Wrought	Gross-kilogram	6.6%	60%
Do.	8102.93.0000	Wire	do.	6.6%	60%
Do.	8102.99.0000	Other	do.	5.5%	45%

TABLE 11

WORLD MOLYBDENUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990

(Hundred metric tons of contained molybdenum)

Country	Rated capacity[1]
Bulgaria	9
Canada	159
Chile	204
China	45
Iran	18
Korea, Republic of	9
Mexico	68
Mongolia	23
Niger	(2)
Peru	45
U.S.S.R.	159
United States	748
Total	1,487

[1]Includes capacity at operating plants as well as at plants on standby basis.
[2]Less than 1/2 unit.

TABLE 12

MOLYBDENUM RESERVES AND RESERVE BASE

(Thousand metric tons of contained molybdenum)

	Reserves	Reserve base
North America:		
Canada	450	910
Mexico	90	230
United States	2,720	5,350
Other	—	90
South America:		
Chile	1,130	2,450
Peru	140	230
Other	—	90
Europe:		
Bulgaria	(1)	10
U.S.S.R.	450	680
Other	—	270
Asia:		
China	500	1,220
Iran	50	140
Other	—	140
Total	5,530	11,810

[1]Less than 1/2 unit.

NICKEL

By William S. Kirk

Mr. Kirk, a physical scientist with 25 years of Government experience, has been the commodity specialist for nickel since 1987. Domestic survey data were prepared by Barbara J. McNair, mineral data assistant; and international data tables were prepared by William Zajac, Chief, and Audrey Wilkes, Section of International Data.

Nickel is vital to the stainless steel industry and has played a key role in the development of the chemical and aerospace industries. Furthermore, through the use of nickel, the sophisticated industrial complexes that provide our high standard of living and superior military technology and armament are made possible. Nickel's greatest value is in alloys with other elements, where it adds strength and corrosion resistance over a wide range of temperatures.

Domestic and Western World nickel demand increased, the latter for the fifth consecutive year. At 750,000 tons in 1990, Western World nickel demand also reached a record level for the fourth consecutive year. Prices remained at relatively high levels in spite of a general economic downturn. The inaugural meeting of the International Nickel Study Group was held at The Hague, the Netherlands. In another significant development, the United States signed an agreement with the U.S.S.R. that allowed the Soviets to resume exports of nickel and nickel-containing products, such as stainless steel, to the United States.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines canvassed all the known nickel consumers whose annual consumption was greater than 2 tons. Of the 197 annual forms sent, 139 responded, representing 71% of the total canvassed. Estimates for nonrespondents were derived by using their past consumption relationships and consumption trends. Reported primary consumption, based on data from monthly and annual canvass forms and estimates, was 87% of apparent primary consumption. Apparent consumption is defined as primary

TABLE 1

SALIENT NICKEL STATISTICS

(Short tons of contained nickel unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Mine production:	1,175	—	—	—	364
Plant production:	[1]1,651	—	—	382	4,080
Secondary recovery from purchased scrap:[e]					
From ferrous scrap	35,320	27,247	41,537	35,597	30,202
From nonferrous scrap	8,406	8,392	3,700	8,258	6,963
Exports:					
Primary (nickel content)	r3,934	r4,405	r5,127	r5,670	6,652
Secondary (nickel content)	r17,655	r18,691	r24,642	r29,340	31,068
Imports for consumption:					
Primary (nickel content)	129,094	r148,273	154,366	130,725	144,530
Consumption:					
Reported:					
Primary	107,062	130,504	125,520	116,998	122,621
Secondary (purchased scrap)[e]	43,726	35,639	45,237	43,855	37,164
Apparent:					
Primary	r135,984	r153,423	r147,360	r127,577	144,029
Secondary (purchased scrap)[2 e]	r27,704	r17,242	r19,880	r18,706	19,556
Stocks, yearend:					
Government	37,215	37,215	37,214	37,214	37,214
Producer	10,300	6,824	7,672	6,819	5,643
Consumer:					
Primary	16,557	10,478	r11,509	r10,222	9,327
Secondary	4,669	4,375	5,090	5,305	4,669
Employment, yearend:					
Mine	—	—	—	—	12
Smelter	—	—	—	245	300
Refinery	—	—	—	—	—
Price, cash, London Metal Exchange, per pound	r$1.76	r$2.19	$6.25	$6.05	$4.02
World: Mine production	r939,320	r983,887	r1,018,775	r1,066,659	e1,029,405

[e]Estimated. [r]Revised.
[1]Includes byproduct nickel.
[2]Secondary exports were included in apparent consumption for the first time in 1988.

nickel produced from domestic ores plus scrap recovery plus imports minus exports plus adjustments for Government and industry stock changes.

BACKGROUND

Definition, Grades, and Specifications

Primary nickel is marketed in the form of nickel cathodes, powder, briquets, pellets, ingots, and shot and in nickel oxide sinter and ferronickel. Commercial nickel in these forms usually is more than 99.5% pure, except for ferronickel and nickel oxide sinter. The ferronickel produced in the United States contains 48% to 52% nickel and is sold in 28-pound ingots; that produced in other countries contains 20% to 50% nickel. Nickel oxide sinter contains either 77% or 90% nickel.

Industry Structure

At least 27 countries produced nickel in 1990. Nickel-producing countries and companies can be grouped by deposit type; production within a country is generally from laterite or sulfide deposits. Exceptions include Australia, Brazil, and the U.S.S.R. Usually ferronickel is produced from laterite ores because of their high iron content and because these ores are more easily smelted than concentrated and refined hydrometallurgically. Refined metal is most often produced from sulfide ores. From 1985 through 1990, those countries producing from laterite ore accounted for about 34% of world mine production, with the balance coming from sulfide ores. Inco Ltd. of Canada is the largest single producing company. From 1985 through 1990, the six largest producing countries and their share of world mine production were as follows: the U.S.S.R. (29%), Canada (21%), New Caledonia (8%), Australia (8%), Indonesia (6%), and Cuba (4%).

The Sudbury area of Canada has remained one of the principal sources of nickel in the world. This area is mined by Inco and Falconbridge Ltd. Other very important nickel mining districts are the Noril'sk in the U.S.S.R. and the Kambalda district of Western Australia. The only U.S. producer is the Glenbrook Nickel Co., which operates a ferronickel smelter at Riddle, OR. Some nickel is also produced in the United States as a by-product of copper refining and recycling.

Geology-Resources

Nickel is the Earth's fifth most abundant element, but occurs in the Earth's crust only in the range of 0.008% to 0.02% by weight. Nickel deposits generally originate from ultramafic rocks. These are igneous rocks that are low in quartz and feldspar and 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. Moreover, nickel is less likely to be found in any significant degree of concentration than are some less abundant elements, such as copper. To be rich enough to mine, some natural process must have concentrated the nickel. These processes result in the two very different major types of nickel ore.

The first deposit type is nickel laterites and is formed by the weathering of ultramafic rocks. As the rocks weather, nickel and sometimes cobalt are taken into solution by ground water and redeposited at greater depth, producing a zone of enrichment. At the base of the weathered rock, zones of enrichment may form that contain between 0.8% and 4% nickel, although the typical content is closer to 1%.

The second deposit type is nickel sulfides and is formed by the intrusion of molten ultramafic rocks or by replacement of the host rock by hydrothermal solutions. After the emplacement of a magmatic sulfide, the rock cools, and nickel and other metals combine with sulfur to form dense immiscible droplets that settle to the bottom of the magma chamber. These accumulations often form deposits rich in nickel as well as copper, cobalt, and the platinum-group metals. The world's most important and productive nickel deposit, the Sudbury deposit in Ontario, Canada, formed partly by this process. It, however, differs from most other sulfide deposits. Although Sudbury's origin is still somewhat controversial, there appears to be a consensus among geologists that its formation may have been triggered by the impact of a large meteorite.

Substitutes

With few exceptions, substitutes for nickel would result in increased cost or some sacrifice in the economy or performance of the product. Present and potential nickel substitutes include aluminum, coated steels, and plastics in the construction and transportation industries; nickel-free specialty steels in the power generating, petrochemical, and petroleum industries; titanium and plastics in severe corrosive applications; and platinum, cobalt, and copper in catalytic uses.

Economic Factors

Prices.—Table 2 shows the time-price relationship for nickel over a 50-year span. The upward price trend in the 1970's reflected generally strong demand.

TABLE 2

TIME-PRICE RELATIONSHIPS FOR NICKEL

Year	Average annual price, dollars per pound	
	Actual price	Based on constant 1982 dollars[1]
1940	0.35	2.69
1945	0.32	2.01
1950	0.45	1.87
1955	0.66	2.41
1960	0.74	2.39
1965	0.79	2.33
1970	1.29	3.07
1971	1.24	2.78
1972	1.35	2.89
1973	1.49	3.01
1974	2.00	3.70
1975	1.87	3.15
1976	2.08	3.30
1977	2.04	3.02
1978	1.89	2.61
1979	2.96	3.76
1980	2.96	3.45
1981	2.71	2.88
1982	2.18	2.18
1983	2.18	2.10
1984	2.16	2.01
1985	2.26	2.04
1986	1.76	1.55
1987	2.19	1.87
1988	6.25	5.15
1989	6.05	4.73
1990	4.02	3.06

[1]Constant dollar price determined from gross national product implicit price deflator.

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 reached their lowest levels in more than 50 years. During this period, producers were forced to close at least six production facilities; some others were on the verge of failure and lost large amounts of money. Consumption, driven by stainless steel demand, rebounded dramatically in late 1987, reaching record levels for that year and each of the next 3 years. Prices soared along with demand.

Costs.—There are several significant factors that determine the cost of producing nickel. They include the type and nickel content of the ore, mining method, transportation, infrastructure, cost of energy, labor and materials, regulatory compliance, and credits from recoverable byproducts. Generally, nickel can he recovered from sulfide ores at a lower cost. Virtually all nickel laterite ores are mined by surface methods, whereas sulfide deposits are generally mined by more costly underground mining methods.

Energy used in the processing of laterite ores represents the most significant cost of 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 for those operations that are dependent on oil for drying and smelting the ore to ferronickel or matte. Sulfide ores, on the other hand, do not have to be dried, and, unlike laterite ores, are readily amenable to concentration by established mineral dressing methods.

Revenues from byproducts can significantly reduce net production costs. Smelters that process laterite ores to ferronickel produce only iron and sometimes electrical power as byproducts. Smelters that process laterite ores using a chemical leaching method recover cobalt as a byproduct. In contrast, sulfide operations generate revenues from the recovery of byproduct copper, cobalt, and precious metals. Some sulfide facilities also profit from the sale of byproduct liquid sulfur dioxide and sulfuric acid.

The costs associated with compliance 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, reduction of sulfur dioxide emissions from smelters processing nickel-copper sulfide concentrates represents large capital investments. During the past 10 years, Inco Ltd., the Western World's largest nickel producer, has allocated 12% of its total capital expenditures to attain compliance with legislation limiting sulfur dioxide emissions.

ANNUAL REVIEW

Legislation and Government Programs

In an agreement that became effective on June 28, 1990, the U.S.S.R. was allowed to resume exports of its nickel and nickel-containing products, such as stainless steel, to the United States. In 1983, the U.S. Department of the Treasury banned imports of these materials from the U.S.S.R. The measure was taken to enforce the ban of importation of nickel from Cuba, based on the information that almost one-half of the total nickel production of Cuba was exported to the U.S.S.R. Most of that material was concentrate for refining to electrolytic nickel. The new agreement specified that Raznoimport, a Soviet trade organization, had to certify that exports of nickel and nickel-bearing products are exclusively of Soviet origin. Certificates of origin were to be obtained for nickel and nickel-bearing products from the Norilsk Mining and Metallurgical Plant, Norilsk, Krasnoyarsk Region, U.S.S.R., and the Nickel Industrial Amalgamation, Monchegorsk, Murmansk region, U.S.S.R. At yearend, Bureau of the Census data indicated that nickel imports from the U.S.S.R. were 332,600 pounds.

In November, the Congress amended the Clean Air Act (Public Law 101-549) to require, among other things, that nickel compounds be regulated as hazardous air pollutants. As part of the new program, Congress established a list of hazardous air pollutants to be regulated. Nickel compounds, defined as unique chemical substances that contain nickel as part of their infrastructure (composition), were included. Petitions to delete specific chemicals can be submitted to the Environmental Protection Agency (EPA) for consideration. Congress instructed the EPA to regulate hazardous air pollutants by regulating the source of those pollutants. EPA must develop a list of pollution source categories by November 15, 1991. Examples of possible pollution source categories include chemical process plants. Once EPA has listed pollution sources, petitions to delete specific sources can also be submitted to EPA for consideration.

In July, the EPA published proposed drinking water standards for nickel and other materials. The maximum contaminant level goal for nickel was set at 0.1 gram per liter.

Strategic Considerations

Nickel is an essential ingredient in austenitic stainless steel and superalloys. As such, its availability is important to the national security. Domestic production capacity is less than 1% of apparent consumption. Canada, however, a close ally and a geographically secure source, is capable of supplying U.S. needs under normal circumstances.

Issues

The primary environmental problem associated with nickel production is the emission of sulfur dioxide (SO_2) from nickel smelters processing sulfide ore. The SO_2 emitted from smelter smokestacks combines with atmospheric water to form sulfuric acid (H_2SO_5), a major component of acid rain. Inco Ltd., the world's largest nickel producer, must reduce SO_2 emissions by two-thirds to 290,000 short tons per year by 1994 at its Sudbury complex to meet Ontario Provincial Government imposed limits. The company has embarked on a $410 million program to install new technology to meet those limits. The alternative would be to reduce its production by two-thirds from 1989 levels.

Nickel producers who mine sulfide deposits have a particularly high sulfur burden compared with that of other producers of other metals such as copper. In general, in copper smelting, there is 1 ton of sulfur for each ton of copper produced; in smelting nickel, there is 8 tons of sulfur for each ton of nickel. More than 12% of Inco's capital spending during the past 10 years has been for environmental concerns.

Production

The only domestic nickel producer, Glenbrook Nickel Co., Riddle, OR, began using two new sources of feedstock for its smelter: spent catalysts and freshly mined ore. The company used spent hydrogenation catalysts containing 5% to 10% nickel. It also began mining for

the first time. The mine was on Nickel Mountain, the nearby laterite deposit that was first mined in 1955 by Glenbrook's predecessor, the Hannah Nickel Smelting Co. Until Hannah closed the smelter in 1986, Hannah screened the ore, smelting the higher nickel-content finer fraction and stockpiling the coarser fraction. When Glenbrook began smelting in August 1989, the stockpiled material was its sole source of feedstock. To supplement this source, mining was started in November 1990. According to a company spokesperson, the mine was on a section of Nickel Mountain containing ore grading 1.2% nickel; reserves were expected to be sufficient for 3 years of operation. At yearend, negotiations were underway concerning two other sections of the deposit, and plans for importing ore from New Caledonia grading 2.3% nickel were being considered. Glenbrook mined 364 tons of nickel contained in ore and produced 4,080 tons of nickel contained in ferronickel.

Black Hawk Mining Inc., Toronto, Canada, purchased and began developing a nickel-copper sulfide deposit in Warren, ME. Formerly known as the Union or Crawford Pond deposit, its name was changed to the Knox deposit. Metallurgical testing of drill cores indicated an estimated 3 million short tons of probable reserves grading 1.49% nickel, 0.69% copper, and 0.12% cobalt. The company also began a feasibility study on mine and mill design and production costs. At yearend, Maine was drafting legislation affecting mining in the State. Black Hawk was awaiting the outcome of this legislation before beginning the process of obtaining mining permits.

Consumption and Uses

Western World nickel demand increased for the fifth consecutive year and, at 750,000 tons in 1990, reached a record level for the fourth consecutive year. Domestic apparent consumption increased over that of the previous year. Both U.S. and world demand continued to be driven by the stainless steel industry, which accounts for about 45% of nickel demand in the United States and more than 60% in the world as a whole.

A 44% increase in nickel consumption for superalloys was due to a shortage of scrap rather than a significant increase in superalloy production. The superalloy scrap shortage created more demand for primary nickel and was the result of two

TABLE 3

NICKEL RECOVERED FROM PURCHASED SCRAP IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY[e]

(Short tons of contained nickel)

	1988	1989	1990
KIND OF SCRAP			
Aluminum-base	233	231	230
Copper-base	722	3,605	3,400
Ferrous-base	41,537	35,597	30,202
Nickel-base	2,745	4,422	3,333
Total	45,237	43,855	[1]37,164
FORM OF RECOVERY			
Aluminum-base alloys	561	231	230
Copper-base alloys	1,768	5,396	4,891
Ferrous alloys	41,592	35,656	30,253
Nickel-base alloys	1,316	2,572	1,790
Total	45,237	43,855	37,164

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

FIGURE 1

U.S. NICKEL CONSUMPTION IN 1990, BY FORM AND USE

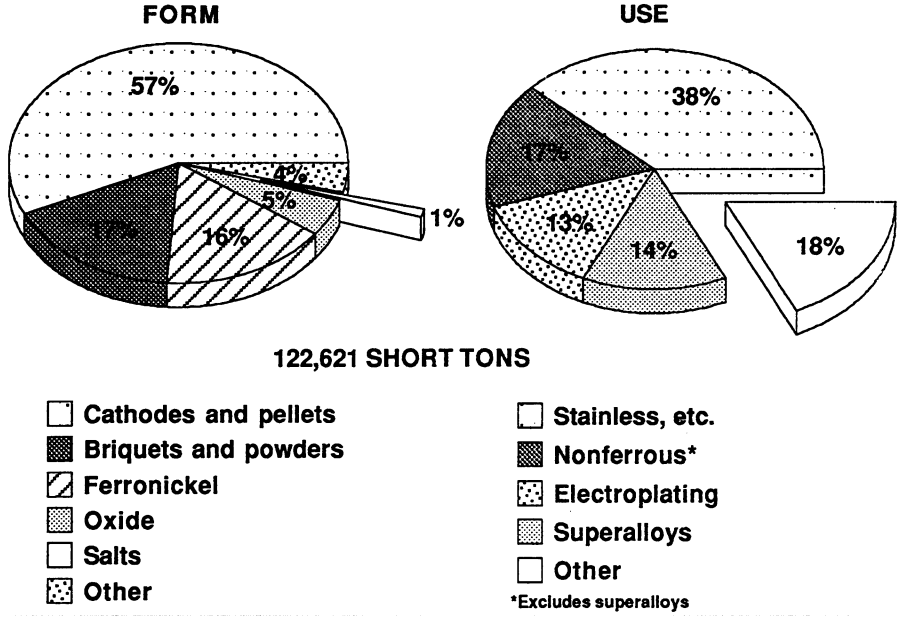

TABLE 4

REPORTED U.S. CONSUMPTION OF NICKEL, BY FORM

(Short tons of contained nickel)

Form	1986	1987	1988	1989	1990
Primary:					
Ferronickel	13,256	17,418	12,936	11,203	19,130
Metal	82,884	98,673	99,398	96,396	91,321
Oxide and oxide sinter	7,357	9,926	7,790	6,485	6,149
Salts[1]	2,416	2,435	2,657	420	1,055
Other	1,149	2,052	2,739	2,494	4,966
Total primary	107,062	130,504	125,520	116,998	122,621
Secondary (scrap)[2]	r43,726	35,639	45,237	43,855	37,164
Grand total	r150,788	166,143	170,757	160,853	159,785

rRevised.
[1]Metallic nickel salts consumed by plating industry are estimated.
[2]Based on gross weight of purchased scrap consumed and estimated average nickel content.

TABLE 5

U.S. CONSUMPTION OF NICKEL, BY USE

(Short tons of contained nickel)

Use	Commercially pure nickel	Ferronickel	Nickel oxide	Nickel salts	Other forms	Total primary	Secondary[e p] (scrap)	1990 grand total	1989 grand total
Cast irons	678	W	4	W	191	873	573	1,446	2,555
Chemicals and chemical uses	1,196	—	49	29	—	1,274	—	1,274	1,283
Electric, magnet, expansion alloys	W	—	W	—	W	W	52	52	193
Electroplating (sales to platers)[1]	15,516	—	—	W	—	15,516	—	15,516	r24,197
Nickel-copper and copper-nickel alloys	4,003	—	W	—	W	4,003	3,823	7,826	10,944
Other nickel and nickel alloys	16,288	W	W	—	97	16,385	2,706	19,091	r21,151
Steel:									
Stainless and heat-resistant	22,751	18,530	5,272	W	W	46,553	29,261	75,814	r76,768
Alloys (excludes stainless)	6,862	179	W	—	27	7,068	369	7,437	6,717
Superalloys	17,272	W	—	—	W	17,272	152	17,424	12,077
Other[2]	6,755	421	824	1,026	4,651	13,677	230	13,907	4,968
Total reported by companies canvassed	91,321	19,130	6,149	1,055	4,966	122,621	37,164	159,785	160,853
Total all companies, apparent	XX	XX	XX	XX	XX	XX	19,556	163,586	r157,436

[e]Estimated. [p]Preliminary. rRevised. W Withheld to avoid disclosing company proprietary data; included with "Other." XX Not applicable.
[1]Based on monthly estimates.
[2]Includes batteries, ceramics, and other alloys containing nickel.

factors. The first factor was relatively high prices; superalloy scrap sells well when nickel prices are high. Nickel prices averaged more than $6.00 per pound in 1988 and 1989, and this caused a depletion in supplies of superalloy scrap. The second factor was that less scrap was being generated because of near net-shape-casting procedures.

Stocks

The combined stocks of primary nickel maintained in the United States by foreign producers with U.S. sales offices and by metal-trading companies with U.S. sales offices decreased 17% during the year. At yearend, these stocks represented 14 days of domestic apparent primary consumption.

Markets and Prices

Nickel prices throughout 1990 were higher than expected by many industry observers. The average London Metal Exchange (LME) cash price for the year was $4.02 per pound. The primary reasons were the higher than expected demand by the stainless steel sector and the decreased availability of stainless

TABLE 6

NICKEL IN CONSUMER STOCKS IN THE UNITED STATES, BY FORM

(Short tons of contained nickel)

Form	1986	1987	1988	1989	1990
Primary:					
Ferronickel	1,028	776	1,520	2,077	1,092
Metal	11,829	8,303	r7,520	r5,959	7,489
Oxide and oxide sinter	3,281	995	r1,979	1,371	317
Salts	175	196	r212	r377	196
Other	244	208	r278	r438	233
Total primary	16,557	10,478	r11,509	r10,222	9,327
Secondary (scrap)	4,669	4,375	5,090	5,305	4,669
Grand total	21,226	14,853	r16,599	r15,527	13,996

rRevised.

steel scrap compounded by primary production shortfalls.

The LME nickel cash price began the year at $3.57 per pound and rapidly fell to the year's lowest level of $2.68 on January 23. From then the price just as quickly rose to $4.66 in late March. LME prices remained close to the $4.00 level from that point until early August, when uncertainty about supplies caused prices to begin rising to what would be their highest level of the year at $5.41 in mid-September. The uncertainty was the result of a furnace explosion at P. T. Inco Indonesia, the closure of a Cuban nickel plant, and the prospect of a strike at the Inco Ltd. facility at Thompson, Manitoba. After the signing of the Inco labor agreement, the LME cash price dropped gradually, ending the year at $3.71.

Domestic stainless steel production, at 2,039,210 tons, was slightly higher than that of 1989, which was 1,926,438 tons. Stainless steel plate shipments, however, at 206,000 tons, greatly exceeded the previous record year of 1988, which was 183,000 tons. Stainless steel plate is a flat product that is three-sixteenths of an inch or more in thickness as opposed to sheet, a flat product that is less than three-sixteenths of an inch in thickness. Together, the two types of products constituted 86% of domestic stainless steel shipments. Stainless steel plate is primarily used in the capital goods sector of the economy by the chemical, paper and pulp, food processing, and other industries, while sheet is used primarily in the manufacture of products in the consumer sector, such as household appliances. Reflecting general economic conditions, shipments of sheet were 712,000 tons, about the same as in 1989. The increase in demand for plate was due to continued spending for new and refurbished plants in the pulp and paper, textile, food and beverage, chemical, and petrochemical industries.

Foreign Trade

The U.S. net import reliance as a percentage of apparent consumption was 75% because of the facts that there was little domestic primary production and virtually all primary nickel consumed in the United States was imported. Canada, as usual, supplied most of the imported nickel, including most of the nickel imported from Norway. This nickel was mined and smelted in Canada before being refined in Norway and shipped to the United States. The high level of demand for primary nickel also meant high demand for nickel-bearing scrap, both domestically and abroad. This accounted for the balance of domestic production. As a result of high prices, U.S. stainless steel scrap exports in 1990 were high. Assuming a nickel content of 7.5%, 19,260 tons of nickel contained in stainless steel scrap was exported in 1990 compared with 21,871 tons in 1989 and an average of about 15,300 tons per year for the 6 years preceding 1989.

World Review

Capacity.—The data in table 9 are rated capacity for mines, smelters, and refineries as of December 31, 1990. 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.

The inaugural meeting of the International Nickel Study Group (INSG) was held on June 25–28 in The Hague, the Netherlands, after a 10-year effort at forming the group. The 12 nations joining the INSG were: Australia, Canada, Cuba, the Federal Republic of Germany, Finland, France, Greece, Indonesia, Japan, the Netherlands, Norway, and Sweden. Countries and organizations attending as observers were: Brazil, China, Italy, The Philippines, the U.S.S.R., the United States, Zimbabwe, the General Agreement on Tariffs and Trade, the European Community, and the Nickel Development Institute. Members of the nickel production industry participated as advisors to government delegations. A special 1-day meeting of industry experts and government officials was held to discuss possible statistical systems for nickel and other work plans and priorities, such as special studies. The INSG had two primary functions; the first function was to provide transparency in the nickel market by gathering, collating, and publishing statistical data on the international nickel market. The second was to provide an intergovernmental forum for discussion of issues of concern to nickel-producing and nickel-consuming countries.

The LME approved Baltimore, MD, and Bridgeport, CT, as U.S. locations for warehouses for its nickel. At yearend, a warehouse in Baltimore had been chosen but was not operational. The LME had not yet chosen a warehouse in Bridgeport. These two locations would serve as delivery points for LME nickel.

Australia.—Outokumpu Metals & Resources Oy and Australian Consolidated Minerals Ltd. (ACM) changed their plans concerning their Mount Keith joint-venture project. The original plans had called for the simultaneous development of the mine and concentrator at the Mount Keith deposit in Western Australia and a ferronickel facility to be built in Finland to process the concentrate. Mount Keith is a sulfide deposit reportedly containing an estimated 300 million short tons of ore grading 0.06% nickel. Although this was considered a low-grade deposit, it was low in pyrrhotite, an undesirable mineral, and tests indicated that

FIGURE 2

MAJOR SOURCES OF U.S. PRIMARY NICKEL IMPORTS, BY COUNTRY

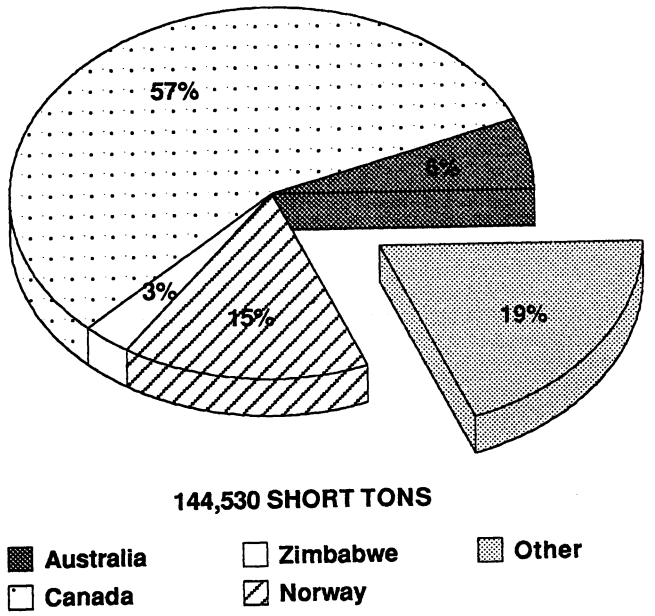

TABLE 7

U.S. EXPORTS OF NICKEL PRODUCTS, BY CLASS

(Contained nickel[1])

Class	1987		1988		1989		1990	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Unwrought:								
Primary:								
Cathodes, pellets, briquets, and shot	1,547	$10,581	1,940	$19,344	975	$10,861	978	$7,913
Electroplating anodes	213	1,864	206	1,618	NA	NA	NA	NA
Ferronickel	71	NA	—	—	666	949	1,902	5,358
Powder and flakes	582	6,720	575	8,184	661	12,111	762	10,684
Chemicals:								
Catalysts	3,984	16,940	4,812	21,745	6,736	34,875	6,020	40,121
Total	r6,397	XX	r7,533	50,891	r9,038	58,796	9,662	64,076
Secondary:								
Stainless steel scrap	12,920	94,025	18,251	239,807	21,871	320,683	19,260	212,368
Waste and scrap	5,771	17,273	6,391	36,079	7,469	45,739	11,808	49,355
Total	r18,691	111,298	r24,642	275,886	r29,340	366,422	31,068	261,723
Grand total	25,088	XX	32,175	326,777	38,378	425,218	40,730	325,799
Wrought:								
Bars, rods, profiles, and wire	NA	NA	NA	NA	282	4,399	144	901
Sheets, strips and foil	NA	NA	NA	NA	243	4,107	247	3,097
Tubes and pipes	NA	NA	NA	NA	67	3,445	66	1,049
Total	NA	NA	NA	NA	592	11,951	457	5,047

NA Not available. XX Not applicable.
[1]The nickel contents are as follows: catalysts, 50%; stainless steel scrap, 7.5%; and waste and scrap, 50%.

Source: Bureau of the Census.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF NICKEL PRODUCTS, BY CLASS

(Contained nickel[1])

Class	1988		1989		1990	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Unwrought:						
Primary:						
Cathodes, pellets, briquets, and shot	112,576	$1,024,106	r102,914	$114,861	115,193	$910,544
Ferronickel	16,066	116,990	12,650	117,630	15,733	116,484
Flakes	730	6,274	62	5,702	9	53
Oxide sinter[2]	2,942	26,009	r247	3,052	962	8,294
Powder	10,254	94,469	11,510	121,416	10,060	91,179
Chemicals:						
Catalysts	NA	NA	NA	NA	993	34,141
Salts	11,798	51,512	r3,342	16,275	1,580	16,917
Total[3]	154,366	1,319,360	130,725	378,936	144,530	1,177,611
Secondary:						
Stainless steel scrap	5,742	8,887	4,406	29,826	8,445	31,284
Waste and scrap	2,306	38,039	r5,666	78,089	4,379	46,764
Total	8,048	46,926	10,072	107,915	12,824	78,048
Grand total[3]	162,414	1,366,286	r140,795	486,851	157,354	1,255,659
Wrought:						
Bars, rods, profiles and wire	NA	NA	425	7,739	661	7,963
Sheets, strip and foil	NA	NA	361	5,973	386	5,228
Tubes and pipes	NA	NA	125	2,799	93	2,304
Total[3]	NA	NA	911	16,511	1,140	15,495

rRevised. NA Not available.

[1]The nickel contents are as follows: oxide sinter from Australia, 90%; elsewhere, 77%. The salts category contains the following: chemical-grade oxide, 77%; chloride, 25%; sulfate, 22%; and compounds, which are assumed to be 50% nickel. Waste and scrap is assumed to be 50% nickel and stainless steel scrap 7.5% nickel.

[2]Includes metallurgical-grade oxide only; chemical-grade oxide is included with salts.

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

Sources: Bureau of the Census and Journal of Commerce.

a high-purity 20% nickel concentrate could be produced. The deposit was also amenable to open pit mining methods. The new plans called for the project to be completed in two stages, the first of which would be the development of the deposit. The development of the ferronickel facility was to be delayed; its completion would constitute stage two. In the meantime, about 18,000 short tons of nickel per year contained in concentrate was to be sent to Finland and processed to matte and refined nickel in existing facilities. An additional 10,000 tons per year of nickel in concentrate was to be sold on the world market until stage two was completed.

Western Mining Corp. (WMC) of Australia announced plans to expand its nickel production and capacity. The company's goal was to produce about 72,000 short tons of nickel contained in concentrate compared with about 51,500 tons produced in 1989. The expansion was expected to begin in 1991 and be completed in 3 years. It was to be achieved by upgrading the Leinster and Kambalda mining complexes while closing the Windarra mining complex, which was nearly depleted. Plans also called for the installation of additional equipment at the Kalgoorlie smelter and an increase in capacity at the Kwinana refinery from 38,500 short tons per year to about 46,300. WMC planned to smelt all the concentrate. Because smelter capacity was to exceed refinery capacity by about 22,000 tons per year of contained nickel, that quantity of nickel in matte would be available for sale on the open market. The excess matte was expected to be purchased by Japanese refineries. The expansion was expected to reduce WMC's production costs.

WMC acquired a 70% interest in the Bulong deposit, a nickel and cobalt laterite prospect in Western Australia. The company planned to build a pilot plant and conduct a feasibility study.

Queensland Nickel Pty. Ltd. sought approval for the construction of a port facility at Halifax Bay, north of the company's refinery at Townsville in Queensland. Queensland Nickel planned to expand the capacity of its refinery by increasing the throughput and treating higher grade ore. To this end, the company signed agreements with P.T. Aneka Tambang of Indonesia and two New Caledonian firms to supply nickel ore for the plant. The port construction was strongly opposed by local environmentalists who were concerned about possible

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF NEW NICKEL PRODUCTS IN 1990, BY COUNTRY

(Short tons of contained nickel[1])

Country	Cathodes, pellets, and briquets (unwrought)	Powder and flakes	Ferronickel	Oxide sinter[2]	Waste and scrap	Stainless steel scrap	Salts and compounds	Wrought nickel[3]	Total 1990[4]	Total 1989
Australia	8,422	1,261	—	462	2	—	—	—	10,148	r7,530
Belgium	—	(5)	—	—	68	—	738	—	806	r821
Canada	70,722	7,937	112	500	2,418	6,850	336	52	88,875	r87,946
Colombia	—	—	2,952	—	—	22	—	—	2,974	1,727
Dominican Republic	239	—	9,396	—	16	1	—	—	9,652	7,558
Finland	1,636	—	—	—	—	—	269	—	1,905	r1,058
France	2,128	(5)	—	—	236	—	141	188	2,505	r2,817
Germany, Federal Republic of	20	24	—	—	547	—	276	645	867	r833
Japan	(5)	2	—	—	64	2	408	15	476	r293
New Caledonia	—	—	3,049	—	—	—	—	—	3,049	4,764
Norway	24,144	—	—	—	28	—	—	—	24,172	16,643
South Africa, Republic of	1,873	428	18	—	—	—	36	—	2,355	1,718
United Kingdom	312	314	—	—	647	63	47	11	1,383	r668
Zimbabwe	3,955	—	—	—	—	—	—	209	3,955	r3,871
Other	1,743	104	204	—	352	1,508	322	20	4,232	r2,548
Total[3]	115,193	10,069	15,733	962	4,379	8,445	2,573	1,140	157,354	r140,795

rRevised.

[1]The nickel contents are as follows: oxide sinter from Australia, 90%, elsewhere; 77%. The salts category contains the following: chemical-grade oxide, 77%; chloride, 25%; sulfate, 22%; and compounds, which are assumed to be 50% nickel. Waste and scrap is assumed to be 50% nickel and stainless steel scrap 7.5% nickel.

[2]Includes metallurgical-grade oxide only; chemical-grade oxide is included with salts and compounds.

[3]Not included in total.

[4]Data may not add to totals shown owing to individual rounding of converted units.

[5]Less than 1/2 unit.

Source: Bureau of the Census.

damage to the Great Barrier Reef. In June, the Great Barrier Reef Marine Park Authority decided not to grant the approval.

Dominion Mining Ltd., a gold producer, was considering developing its 100%-owned Six Mile deposit near Yakabindie, Western Australia. Less than 50 miles south of Australian Consolidated Minerals' Mount Keith deposit, the Six Mile was a large, low-grade sulfide deposit containing an estimated 100 million short tons of reserves at 0.53% nickel. Dominion conducted a study that indicated that a low-impurity, 18% nickel concentrate could be produced from the ore. The concentrate could be sold to smelters and some refineries, or a roasted calcine could be produced, which could be sold to stainless steel mills.

Defiance Mining NL, based in Kalgoorlie, reportedly planned to purchase and reopen the Carr Boyd nickel mine about 50 miles northeast of Kalgoorlie. The mine, owned by WMC, was thought to contain as much as 2 million short tons of ore at a grade of 1.5% nickel and 0.5% copper. Defiance planned to dewater and refurbish the shaft to gain access for underground mapping, sampling, and drilling.

Agip Australia Pty. Ltd. announced its intention to develop the Radio Hill nickel-copper deposit. The deposit, about 18 miles south of Karratha in the Pilbara region of Western Australia, reportedly had estimated proven and probable reserves of 1.2 million short tons of ore grading 2.5% nickel and 1.8% copper. Production at the underground mine was expected to begin in late 1992, with an annual production of about 3,300 tons of nickel contained in matte and an expected life of 7 years. The facility was to use Isamelt technology, developed jointly by MIM Holdings and an Australian Government-owned research organization. This was to be the first time the technology was used for smelting ores other than those of lead and copper.

Canada.—Inco Ltd. announced major investment plans for its nickel production complex in Thompson, Manitoba. The plan called for the company to spend $248 million between 1991 and 1997 to develop a new ore body and expand an existing mine. Most of the development was to focus on the new 1-D ore body. Ore from the 1-D would be transported underground more than 3 miles to an existing shaft at the Thompson Mine; production from the ore body was expected to begin in 1992. By 1997, production was expected to reach an annual rate of 37 million pounds of nickel. The balance of the development was to be a 50% expansion of the Birchtree Mine, which entailed deepening its shaft. By incorporating new mining technologies and equipment, Inco expected that productivity of both the 1-D and Birchtree would be more than double that of existing Thompson mines.

TABLE 10

WORLD MINE AND PLANT PRODUCTION CAPACITY, BY COUNTRY

(Thousand short tons contained nickel)

Country	Mine capacity	Refinery and smelter[1] capacity
North America:		
Canada	220	170
United States	5	55
Total	225	225
South America:		
Brazil	26	21
Colombia	24	25
Total	50	46
Caribbean:		
Cuba	60	33
Dominican Republic	35	35
Total	95	68
Europe:		
Albania	11	5
Finland	12	21
France	—	13
Greece	25	30
Norway	—	59
U.S.S.R.	335	340
United Kingdom	—	50
Other[2]	30	17
Total	413	535
Africa:		
Botswana	22	—
South Africa, Republic of	50	32
Zimbabwe	20	20
Total	92	52
Asia:		
China	40	30
Indonesia	70	6
Japan	—	124
Korea	—	13
Philippines[3]	45	35
Taiwan	—	9
Total	155	217
Oceania:		
Australia	83	59
New Caledonia	100	50
Total	183	109
World total	1,213	1,252

[1]Because matte is an intermediate product that must be refined before the nickel it contains can be used in making alloys or other product, smelter capacity for matte is not listed to avoid double counting.
[2]Includes Austria, Czechoslovakia, the Federal Republic of Germany, Poland, and Yugoslavia.
[3]Standby or partially standby capacity.

TABLE 11

NICKEL: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Short tons of nickel content)

Country	1986	1987	1988	1989[p]	1990[e]
Albania (content of ore)[e]	10,700	9,900	9,900	9,900	9,900
Australia (content of concentrate)	84,590	82,182	68,738	73,900	77,000
Botswana (content of ore milled)[e]	r28,200	r28,500	r28,700	r26,100	27,600
Brazil (content of ore)	23,262	22,215	22,963	r23,108	23,000
Burma (content of speiss)	52	55	115	110	100
Canada[2]	180,381	208,431	r219,077	r215,561	3222,501
China[e]	27,600	27,600	27,600	27,600	27,600
Colombia (content of ferroalloys)	20,975	21,301	r18,374	re18,700	18,700
Cuba (content of oxide, sinter, sulfide)	35,514	37,285	r46,457	r49,257	42,300
Dominican Republic	24,116	35,848	e32,300	e35,300	36,000
Finland (content of concentrate)	13,102	11,637	12,897	r11,552	11,600
Germany, Federal Republic of:					
Eastern states[e]	2,200	2,200	2,200	1,700	1,700
Greece (recoverable content of ore)[e]	15,900	10,100	r15,600	r20,000	20,000
Indonesia (content of ore)	59,171	63,674	63,914	r69,431	64,000
New Caledonia (recoverable content of ore)[e]	68,100	62,700	74,600	r109,000	97,000
Norway (content of concentrate)[e]	3483	440	440	440	440
Philippines	14,099	8,619	e11,900	r14,220	13,200
Poland (content of ore)[e]	2,200	2,200	2,000	2,000	2,000
South Africa, Republic of[e]	34,200	37,800	38,400	39,100	40,000
U.S.S.R. (content of ore)[e]	r285,000	r300,000	r310,000	r310,000	285,000
United States (content of ore shipped)	1,175	—	—	—	3364
Yugoslavia (content of ore)[e]	4,200	4,300	4,300	r880	1,100
Zimbabwe (content of concentrate)[e 4]	4,100	6,900	8,300	8,800	8,300
Total	r939,320	r983,887	r1,018,775	r1,066,659	1,029,405

[e]Estimated. [r]Revised.
[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. Table includes data available through Apr. 4, 1991.
[2]Refined nickel and nickel content of oxides and salts produced, plus recoverable nickel in exported matte and speiss.
[3]Reported figure.
[4]Estimates are based on metal production after deduction for nickel content of matte imported from Botswana for processing.

In addition to mine development, the company would be further delineating ore reserves in the Thompson nickel belt.

The board of directors and chief executive officer of Sherritt Gordon Ltd. were replaced at a meeting called by dissident shareholders, reportedly critical of the way Sherritt had been operating. Representatives of a newly formed private company, Canada SherGor Enterprises Inc. (no relation to Sherritt), called for the meeting, its prerogative as an owner of 5% of Sherritt's stock. At the meeting held in September, shareholders, by a narrow margin, voted to replace Sherritt's board with representatives of SherGor. One of SherGor's criticisms involved the 2-month closure of Sherritt's refinery in Fort Saskatchewan, Alberta, owing to a lack of feed. The primary reason for the shortage of feed was the expiration, at the end of 1989, of Sherritt's 10-year toll refining contract with Inco that had provided the company with 60% of its feedstock.

Cuba.—The Punta Gorda nickel refinery was closed as part of a number of energy-saving measures announced by the Cuban Government. Supplies of oil from the U.S.S.R., which accounted for more than 70% of Cuba's imports, had been falling increasingly behind schedule. Because Cuba reportedly had little foreign currency with which to purchase oil

from Arab countries, its energy problems have been compounded by the rise in oil prices caused by the Persian Gulf crisis. Punta Gorda was one of the country's three nickel production facilities. The other two, the Moa Bay and Nicaro, were not affected by the problem. Plans for a fourth plant at Las Camariocas, which was expected to begin operations in the mid-1990's, could be delayed. The Punta Gorda plant had three production lines, each a separate unit with a nominal capacity of 11,000 short tons per year. The first line had been operating normally, and the second was just coming on-stream after experiencing technical difficulties. The third line was to become operational after the second line.

Finland.—Outokumpu Metals & Resources Oy, a subsidiary of Outokumpu Oy, the Finnish state-owned nickel producer, signed an agreement with the Karelian Autonomous Soviet Socialist Republic to develop the republic's nickel-copper deposits. The agreement involves exploration work on the nickel-copper deposit in the Kivijarvi region of Soviet Karelia northeast of Aanisjarvi. The agreement primarily covered geological and ore-dressing studies. If the work led to mining, Outokumpu officials expected to receive some feed for the company's Harjavalta plant in Finland.

Outokumpu Oy began a significant increase in its production of nickel salts and oxide. This was made possible by the company's decision to continue operating the company's Hitura Mine, which the company had planned to close. Outokumpu expected to expand its annual production of salts and oxide from 2,000 to more than 5,550 short tons of contained nickel over a 3-year period.

Indonesia.—Inco Ltd. sold 20% of the ownership of its subsidiary, P.T. Inco Indonesia, to the Indonesian public, reducing Inco's share in the company to 58%.

Japan.—Sumitomo Metal Mining Co. was planning to purchase a 21% interest in Ballande, a French company, which operated a 550,000-short-ton-per-year nickel mine in New Caledonia. Sumitomo had been purchasing the mine's production of about 11,000 short tons per year of contained nickel for smelting in Japan.

New Caledonia.—Société Metallurgique le Nickel (SLN), the French nickel producer with nickel production facilities in New Caledonia, was twice forced to declare force majeure on ferronickel shipments during the year. The first time was the result of a strike in June. The second occasion was in December after a fire at the company's Doniambo ferronickel smelter destroyed two transformers and badly damaged a third. The transformers had been supplying electrical power to one of the three furnaces. SLN quickly installed a spare transformer in an effort to prevent the melt in the furnace from solidifying and damaging the furnace itself. Damage to the furnace could have meant that it would have to be relined, a process that would put the furnace out of commission for 6 months. At yearend, the company was unsure of the extent of damage.

Philippines.—An agreement on the sale of the Nonoc Mining & Industrial Corp.'s nickel production facility to the Philippine Nickel Co. (Philnico) was signed.

U.S.S.R.—Outokumpu Oy, the Finnish nickel producer, agreed in principle to modernize the Pechenga and Monchegorsk nickel complexes in the Kola Peninsula near the Finnish border. The renovation of both smelters was to begin in 1991 and be completed in 1994. The introduction of Outokumpu flash smelting technology was expected to reduce sulfur dioxide emissions from the Kola Peninsula to a very small proportion of 1990 levels. It was not anticipated that the renovation would have a significant impact on nickel production.

The Norilsk Combine, the U.S.S.R.'s major nickel-producing organization, severed relations with Raznoimport, the Soviet state trading organization that once controlled all or most nickel sales from the country. The Norilsk Combine included the Norilsk nickel production complex in the eastern part of the country as well as the Pechenga and Monchegorsk nickel production complexes. Thus, Norilsk then controlled the sale of close to 90% of Soviet nickel production. Norilsk was also recognized by the LME, which had previously accepted Soviet nickel registered only under the Raznoimport name.

The Soviets sought western help in reclaiming nickel and other metals from slag. There are more than 440 million short tons of slag from which nickel, cobalt, molybdenum, and vanadium could be recovered. Some of these slags had a metal content higher than some of the ores then being mined in the U.S.S.R.

Current Research

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.[1] 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 nickel-exposed individuals in workplace settings. The results showed that, in general, although nickel caused some allergic reaction in some individuals, it was found to be nontoxic. The study was sponsored, among others, by the U.S. EPA.

Researchers at the Department of Energy facility at Oak Ridge, TN, developed a process for recycling chemicals used in electroless nickel plating.[2] As the name implies, electroless nickel plating does not use electrodes or electricity. Instead, parts are placed in a chemical bath, and chemical reactions cause the nickel to he plated onto the surface of the parts. As the plating progresses, however, the bath accumulates impurities that eventually render the bath ineffective. The new process removed these impurities by using a combination of ion exchange and selective chemical precipitation. The advantages of the process were (1) impurities that formerly had to be disposed of as hazardous material could be removed in a way that was environmentally safe (in fact, they could be used as fertilizers), (2) nickel and other valuable constituents could be returned to the bath, and (3) the amount of downtime for the bath was much reduced. The process was expected to be licensed for commercial development. The process had potential to make electroless nickel plating more competitive.

A method for reclaiming the nickel contained in nickel-cadmium batteries was developed by Dutch scientists.[3] The new energy-efficient method involved the use of acid and solvents to recover 60% of the nickel and more than 99% of the cadmium, a toxic metal. Nickel was reported to be recovered as ferronickel suitable for use by the steel industry.

A new stainless steel, developed in Japan for use in lining smokestacks and flues, offered outstanding resistance to sulfuric acid corrosion.[4] Designated as

TABLE 12

NICKEL: WORLD PLANT PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Short tons of nickel content)

Country[2] and product	1986	1987	1988	1989	1990[e]
Albania: Metal[e]	—	—	3,500	5,000	5,000
Australia:					
Oxide	22,540	21,936	[e]20,900	[e]22,000	22,000
Metal	23,864	27,149	[e]25,400	24,250	27,500
Total	46,404	49,085	[e]46,300	[e]46,250	49,500
Brazil:[3]					
Ferronickel	10,559	10,735	10,161	[r]10,411	10,500
Metal	4,284	4,942	4,893	[e]5,000	5,000
Total	14,843	15,677	15,054	[re]15,411	15,500
Canada:					
Oxide	15,341	22,834	43,143	41,900	33,400
Metal	107,323	122,119	126,595	114,600	100,200
Total	122,664	144,953	169,738	156,500	133,600
China: Metal[e]	24,800	24,800	27,600	27,600	27,600
Colombia: Ferronickel	20,975	21,301	[r]18,374	[e]18,700	18,700
Cuba:[4]					
Oxide	9,240	6,509	13,911	[r]15,823	12,000
Oxide sinter	9,137	12,477	12,358	[r]13,069	12,000
Total	18,377	18,986	26,269	[r]28,892	24,000
Czechoslovakia: Metal[e]	[r]4,200	[r]4,200	[r]4,200	[5]4,200	4,200
Dominican Republic: Ferronickel	24,239	32,519	32,347	34,450	33,000
Finland: Metal	19,611	16,967	17,329	[r]14,721	15,400
France:					
Metal	8,630	8,270	9,700	9,480	9,700
Salts	1,070	1,325	[r]1,545	1,543	1,300
Total	9,700	9,595	[r]11,245	11,023	11,000
Germany, Federal Republic of:					
Eastern states, metal[e]	3,500	[r]3,500	3,800	3,300	3,300
Greece: Ferronickel	11,380	10,141	14,474	[r]15,002	14,900
Indonesia: Ferronickel	4,980	1,855	5,407	5,472	5,500
Japan:					
Ferronickel	54,708	54,460	63,445	69,263	[5]62,252
Oxide	[r]20,834	[r]24,774	[r]27,276	[r]24,520	25,200
Metal	[r]27,152	23,586	22,003	[r]24,184	[5]24,553
Total	[r]102,694	[r]102,820	[r]112,724	[r]117,967	112,005
Korea, Republic of: Metal	—	—	—	[e]4,600	6,600
New Caledonia: Ferronickel	36,377	32,552	41,173	[r]39,997	[5]35,580
Norway: Metal	42,118	49,124	[r]57,923	[r]60,501	60,600
Philippines: Metal	2,288	—	—	—	—
Poland: Unspecified[e]	2,100	2,100	1,800	1,800	1,700
South Africa, Republic of:					
Metal[e]	27,600	30,200	30,700	30,800	31,000
Taiwan: Metal	—	9,000	11,500	11,000	11,500
U.S.S.R.:[e]					
Ferronickel	27,500	27,500	27,500	27,500	25,000
Oxide	16,500	16,500	16,500	16,500	15,000

See footnotes at end of table.

TABLE 12—Continued

NICKEL: WORLD PLANT PRODUCTION BY COUNTRY AND PRODUCT[1]

(Short tons of nickel content)

Country[2] and product	1986	1987	1988	1989	1990[e]
U.S.S.R.—Continued					
Metal	r256,000	r271,000	r281,000	r281,000	260,000
Total	r300,000	r315,000	r325,000	r325,000	300,000
United Kingdom: Metal	34,130	32,518	30,534	r28,770	29,800
United States: Ferronickel	1,651	—	—	382	[5]4,080
Yugoslavia:					
Ferronickel[e]	2,750	2,750	r5,800	r1,100	1,600
Metal	—	—	—	1,054	1,100
Total[e]	2,750	2,750	r5,800	r2,154	2,700
Zimbabwe: Metal	10,725	11,457	12,666	r12,823	12,700
Grand total	r888,106	r941,100	1,025,457	r1,022,315	969,465
Of which:					
Ferronickel	195,119	193,813	r218,681	r222,277	211,112
Oxide, sinter and powder	r93,592	r105,030	r134,088	r133,812	119,600
Metal	r596,225	r638,832	669,343	r662,883	635,753
Salts	r1,070	r1,325	r1,545	1,543	1,300
Unspecified	r2,100	r2,100	r1,800	r1,800	1,700

[e]Estimated. [r]Revised.

[1]Table includes data available through Apr. 4, 1991.

[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. 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 short tons of contained nickel: Australia: 1986—54,078; 1987—52,728; 1988—50,000 (estimated); 1989—50,000 (estimated); and 1990—50,000 (estimated); Botswana: 1986—20,915; 1987—18,219; 1988—24,845; 1989—21,781; and 1990—21,500 (estimated); Canada: 1986—63,691; 1987—62,344; 1988—63,607; 1989—48,854; and 1990—47,700 (estimated); Indonesia: 1986—30,837; 1987—29,220; 1988—31,817; 1989—32,000; and 1990—29,873; and New Caledonia: 1986—10,097; 1987—9,130; 1988—11,541; 1989—11,750; and 1990—10,674.

[3]Brazil is believed to also produce nickel oxide, but information is not available on which to base estimates.

[4]Cuba also produces processed nickel sulfide, but it is not included to avoid double counting. Output of processed sulfide was as follows, in short tons: 1986—18,240; 1987—18,300; 1988—20,188 (revised); 1989—20,365; and 1990—18,100 (estimated).

[5]Reported figure.

YUS 260 and jointly developed by Nippon Steel Corp. and Mitsubishi Heavy Industries Ltd., the steel was said to be 10 times more corrosion resistant than conventional materials.

A nickel-metal hydrides (NIMH) rechargeable battery was developed and was expected to be produced in Japan.[5] The battery could be charged in the same charger as that used by conventional nickel-cadmium batteries. The NIMH battery, however, had about twice the energy density of the nickel-cadmium battery. The new battery was expected to be used in portable personal computers, audio and video equipment, and power tools.

A method for joining stainless steel pipe for use in plumbing was developed in Europe.[6] The use of stainless steel pipes for domestic water plumbing was first tried about 25 years ago. Conventional techniques, at the time, failed to provide a suitable joint. The new method uses an electromechanical pressing tool that compresses beaded ends of couplings that contain "O" ring seals. Because the stainless steel pipes are unaffected by chemicals in drinking water, they eliminate contamination.

OUTLOOK

In the short- to mid-term (1991-92), the downturn in the world economy that existed in 1990 and early 1991 will probably result in nickel consumption that is lower than that of 1990. In relative terms, however, demand will still be reasonably strong, as 1990 marked the fourth consecutive year of record consumption. Nickel consumption in stainless steel plate, the bright spot in the 1990 stainless steel picture, is expected to slow as growth in the capital goods sector becomes sluggish. The supply and demand are expected to be in balance for the first time since 1986.

In the long-term (1992-1995), nickel consumption is expected to increase. Stainless steel accounts for more than 60% of total world nickel demand and is of overwhelming importance in determining changes in the level of overall nickel consumption. Western World stainless steel demand grew at an average annual rate of 5.7% between 1960 and 1988. In light of this, a forecast of 3% to 4% average annual growth in the 1990's seems reasonable. Moreover, the austenitic grades' (nickel-bearing) share of stainless steel production during the same period grew from 65% to 75%. There are, then, two long-term trends in the largest end-use sector. One trend is toward greater production of the product, and the other is toward the use of more nickel in the product. Also, world consumption of stainless steel, as seen in terms of intensity of use, has shown a

steady increase. For example, in the United States, intensity of use, defined as consumption divided by gross domestic product, more than doubled from 1950 to 1990.

Another large use of nickel in the United States is in superalloys, which are used in jet turbine engines. There are record numbers of orders for civil aircraft as air traffic steadily increases and aging fleets are replaced. Nickel demand in this application through 1992 may be flat, but should recover afterward. Long-term consumption should grow at an average annual rate of about 2%, primarily as a result of stainless steel demand. U.S. consumption should increase at about the same rate as the result of demand from the stainless steel and superalloy sectors. The fastest growth should be in the Far East. Recent events in Eastern Europe, after which these countries began moving toward market-based economies, could have a profound effect on nickel consumption. Pent-up consumer demand could cause the region to become a major stainless steel consumer. Consumption is expected to rise faster in the Far East and in Eastern Europe than in the rest of the world.

The production of electric cars using some type of nickel battery may have a significant impact on consumption in the future. California mandated that in 1998, 2% of the cars sold in the State have zero tailpipe emissions; that figure would rise to 10% in the year 2003.[7] Only electric vehicles meet this standard. California, with sales of 2 million cars per year, constitutes the largest market in the United States. U.S. and Japanese automakers have been developing electric cars. Two of the types of batteries that could be used in these vehicles are nickel-iron and nickel-cadmium.

[1]The study can be obtained free of charge from the following address:
Nickel Development Institute
15 Toronto Street, Suite 402
Toronto, Ontario
Canada M5C 2E3

[2]Information on the process was available at the following address:
J. R. Palmer
Office of Technology Transfer
Martin Marietta Energy Systems Inc.
FEDC, M/S 8218, P.O. Box 2009
Oak Ridge, TN 37830

[3]American Metal Market. Method Reclaims Rechargeable Batteries, V. 97, No. 171, Aug. 31, 1990, p. 4.
[4]Nickel. New Stainless Reported More Corrosion Resistant. V. 6, No. 1, Sept. 1990, pp. 12-13.
[5]———. High-Energy Density Output and Cleanliness for Small Appliances. V. 6, No. 2, Dec. 1990, p. 5.
[6]———. At Last!-Solderless Stainless Steel Plumbing. Nickel, v. 6, No. 2, Dec. 1990, p. 8.
[7]Newsweek. The Power of a Voltswagon. Apr. 1, 1991, p. 62

OTHER SOURCES OF INFORMATION

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Mineral Industry Surveys, monthly.
Mineral Commodity Summaries, annual.
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American Metal Market.
Company Annual Reports.
Metals Week.
Metals Bulletin.
World Bureau of Metals Statistics (London).
Nickel Development Institute (Toronto).

NITROGEN

By Raymond L. Cantrell

In June 1988, Mr. Cantrell entered public service with the U.S. Bureau of Mines in the capacity of physical scientist, chemical materials specialist. He was previously affiliated with W.R. Grace & Co., Hasbro Industries, and Columbia Nitrogen Corp. Domestic survey data were prepared by Tonya Hardin, mineral data assistant; and international data tables were prepared by Virginia Woodson, international data coordinator.

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 leguminious (nitrogen fixing) plants for human and animal nutrition.

Elemental nitrogen gas and liquid (N_2), together with synthetic anhydrous ammonia (NH_3)—a derivative of atmospheric nitrogen and fossil fuels—form the base for an enormous global agricultural and industrial sector. Elemental nitrogen is used extensively by the electronics, metals, food, and aerospace industries because of its unique inert and cryogenic properties. Nitrogen contained in anhydrous ammonia and its downstream fertilizer derivatives provides more than 50% of the world's essential plant nutrient demand. In the industrial sector, anhydrous ammonia derivatives are important for the production of synthetic fibers, resins and polymers, explosives, animal feeds, and an enormous array of inorganic and organic compounds.

In 1990, U.S. elemental nitrogen sales amounted to an impressive $0.8 billion and were expected to rise to about $1.1 billion (38%) by 1994.[1]

The U.S. agricultural nitrogen and industrial chemical sectors also experienced a good year in 1990. Ammonia producers operated at near capacity (17 million tons), the nitrogen trade deficit declined 20% to 1.3 million tons N, and net cash farm income reached a record $59 billion. Natural gas feedstock for ammonia production was available at reasonable prices. Shipments of U.S. nitrogen fertilizer materials exceeded $4 billion.

Anhydrous ammonia facilities in 66 countries produced approximately 131 million short tons that was valued at about $13 billion. World ammonia production declined by a net 1.3 million tons in 1990 owing to economic pressures accompanying sweeping political reform in the Eastern bloc, together with the Persian Gulf crisis prompted by Iraq's invasion of Kuwait in early August. There was a significant runup in global fertilizer and petroleum prices during the fourth quarter of 1990 as a result of the Gulf crisis.

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

TABLE 1

SALIENT AMMONIA STATISTICS[1]

(Thousand short tons of contained nitrogen unless otherwise specified)

	1986	1987	1988	1989	1990[p]
United States:					
Production	11,909	13,232	13,827	[r]13,449	13,940
Exports	531	848	642	381	531
Imports for consumption	2,048	2,357	3,032	3,154	2,947
Consumption, apparent[2]	13,714	15,193	16,250	[r]16,306	16,413
Stocks, Dec. 31: Producers'	1,507	1,053	1,020	936	879
Price per ton product, yearend, f.o.b. gulf coast[3]	$75	$90	$128	$87	$117
Net import reliance[4] as a percent of apparent consumption	13	13	15	[r]18	15
Natural gas price: Wellhead[5]	$1.94	$1.67	$1.69	[r]$1.69	$1.72
World:					
Production	[r]100,389	[r]103,198	[r]109,448	[r]109,142	[e]108,056
Trade[6]	7,920	9,080	10,210	10,830	[p]10,920

[e]Estimated. [p]Preliminary. [r]Revised.
[1]Synthetic anhydrous ammonia, calendar year data; excludes coke oven byproduct.
[2]Calculated from production plus imports minus exports plus or minus industry stock changes.
[3]Green Markets, Fertilizer Market Intelligence Weekly, McGraw-Hill, Inc.
[4]Defined as imports minus exports plus adjustments 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.

product codes 28731, 28732, and 28742 in Current Industrial Reports (CIR), Fertilizer Materials, M28B. Final monthly data are subsequently published in a companion annual report MA28B. During 1990, the Bureau of the Census surveyed approximately 250 known producers of inorganic fertilizer materials. Production data are shown in table 1.

Statistics covering industrial gases were reported in the Bureau of the Census CIR publications M28C and MA28C, Industrial Gases.

BACKGROUND

Nitrogen chemical matter developed as part of our solar system about 5 billion years ago, according to astrophysics. About 4 billion years ago, volcanic activity was believed to have belched gases from the bowels of primordial Earth, forming the nucleus for the nitrogen-rich atmosphere as we know it today. Nitrogen was discovered independently in 1772 by the Swedish druggist, Carl Scheele, and the Scotch botanist, Daniel Rutherford.[2]

Planet Earth is enveloped by an atmosphere dominated by nitrogen (N_2), oxygen (O_2), and water vapor (H_2O), above which lies a delicately thin layer of protective ozone (O_3) that screens harmful ultraviolet radiation. Trace gases in the atmosphere such as carbon dioxide (CO_2) absorb much more radiant energy than they release, providing the additional warmth necessary for our habitation of the planet.

The air we breathe consists of about 78% N_2 and about 21% O_2 by volume; argon makes up most of the remainder. Trace amounts of helium, hydrogen, krypton, neon, and xenon are natural atmospheric sources, together with the greenhouse gases—global warming gases—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Fossil fuel combustion has been responsible for a significant buildup in atmospheric CO_2 during the 20th century.

At the turn of the 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. Scientific ingenuity prevailed, as 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.

Definitions, Grades, and Specifications[3]

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 minor 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 parts per million for up to 30 minutes or "rapidly fatal" if exposure levels reach 5,000- to 10,000 part per million concentrations for up to 30 minutes. Goggles, respirators, gloves, other protective body gear, and plenty of water—in cases of personal exposure or spills—should be readily available when working with ammonia. Steel is the only acceptable metal allowed in the process of transfer, storage, and transport of anhydrous ammonia.

Technology

Elemental nitrogen is mined from the air by cryogenic separation and membrane technologies. In a typical air separation plant, liquefied air is separated into its individual components by fractional distillation. The resources of nitrogen in the air are virtually unlimited and renewable because of the continuous nitrogen cycle between fixed forms on Earth and atmospheric nitrogen.

Mining.—Mineralized occurrences of sodium nitrate ($NaNO_3$) 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 1990, 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.[4] 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° to 1,800° F and 500 to 3,000 pounds per square inch gauge, respectively. A nickel catalyst is used in the reformer and associated front-end sections of the plant, while an iron-promoted catalyst is used for ammonia synthesis.

Urea is formed when ammonia is reacted with byproduct carbon dioxide (CO_2) generated during ammonia synthesis. The materials are reacted under high pressure in a two-step reaction at about 400° F to first form ammonium carbamate, which then decomposes to urea (NH_2CONH_2).

Nitric acid is formed when ammonia is passed over a platinum-rhodium catalyst at about 1,700° F and 120 pounds per square inch gauge. As ammonia passes over the catalyst gauze, it reacts with oxygen to form nitric oxide (NO), which is converted to nitric acid by mixing with water in a countercurrent absorption tower. Ammonium nitrate, in turn, is formed by the simple acid-base reaction between ammonia and nitric acid.

Economic Factors

The data of table 2 reflect long-term price trends for U.S. ammonia and natural gas over a period of 21 years (1970–90). The ratio of ammonia prices to natural gas feedstock prices provides a measure of ammonia's relative price sensitivity to changing feedstock costs. This relationship, however, does not give an accurate account of the impact of market forces and improvements in production efficiency on indicative profitability in the U.S. ammonia market. Between 1970 and the early-1980's, natural gas prices rose dramatically, and ammonia production costs became much more sensitive to feedstock costs. Feedstock costs as a percentage of total production costs rose precipitiously, from 45% in 1970 to 75% by 1982. Natural gas prices have declined since 1985, and feedstock costs now represent about 70% of total production costs.

The U.S. ammonia industry experienced record profitability during 1974–75 because of a tight global supply 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 significant downturn in global agriculture. In 1990, the U.S. ammonia industry returned to respectable profit margins.

On April 3, 1990, the New York Mercantile Association (NYMEX) established natural gas futures trading in the United States. Natural gas futures trading was designed to allow suppliers, producers, and end users to shift or hedge price risks. NYMEX believed that natural gas futures contracts would provide the same liquidity, unambiguous price reference, and hedge against risk characterized by its successful petroleum contract system. Futures prices reflected price stability in the U.S. natural gas market for the coming year.

TABLE 2

TIME-PRICE RELATIONSHIPS FOR AMMONIA AND NATURAL GAS

(Dollars per ton and dollars per million Btu)

Year	Ammonia		Natural gas		Ammonia-natural gas ratio
	Actual value[1]	Constant 1990 dollars	Actual value[2]	Constant 1990 dollars	Actual value[3]
1970	34	106	0.17	0.53	200
1971	34	101	.18	.53	189
1972	35	99	.19	.54	184
1973	43	114	.22	.58	195
1974	93	226	.30	.73	310
1975	148	328	.44	.98	336
1976	107	223	.58	1.21	184
1977	102	199	.79	1.54	129
1978	102	186	.91	1.66	112
1979	107	179	1.18	1.97	91
1980	130	199	1.59	2.44	82
1981	146	204	1.98	2.77	74
1982	141	185	2.46	3.23	57
1983	139	176	2.59	3.28	54
1984	152	186	2.66	3.25	57
1985	140	166	2.51	2.98	56
1986	102	118	1.94	2.24	53
1987	98	110	1.67	1.87	59
1988	105	114	1.69	1.83	62
1989	104	108	r1.69	1.76	62
1990[p]	106	106	1.72	1.72	62

[p]Preliminary. [r]Revised.
[1]Value of shipments, f.o.b. plant, in dollars per ton.
[2]Value at wellhead, in dollars per million Btu.
[3]Ratio of ammonia value to natural gas value.

Source: Council of Economic Advisors (1990 implicit price deflators for gross national product); 1982 = 100.

ANNUAL REVIEW

Legislation and Government Programs

The Food, Agriculture, Conservation, and Trade Act of 1990, Public Law 101-624, signed on November 28, 1990,[5] and called the "1990 farm bill," extended many of the highly successful program initiatives of the 1985 bill. It created the "triple base flexibility" initiative that gave farmers more freedom to make planting decisions.

Under triple base, farmers lost Government subsidizies 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.[6]

Farmers were also given the opportunity to hedge an additional 10% of program acreage to alternate crops at the risk of lost deficiency payments. Target prices were frozen at 1990 levels. The target price—expected price for the crop—sets the upper limit for deficiency payments—the lower of the two values calculated between target prices and actual market prices or loan rates.

The 1990 farm bill was one of the most environmentally progressive farm bills ever signed. The Environmental Conservation Acreage Reserve Program (ECARP) broadened the 1985 Conservation Reserve Program (CRP) provisions to divert up to 1 million acres of cropland to "wetlands reserve" in adverse water-quality areas. Total ECARP program acreage was required to increase from the current 34 million acres to 40 to 45 million acres by 1995.

Other environmental programs adopted, subject to appropriations, included the Agricultural Water Quality Protection Program (AWQPP)—a 10-million-acre voluntary incentive program designed to promote the efficient use of crop nutrients and pesticides and ensure safe storage, mixing, and handling of agricultural chemicals and animal wastes—and the Environmental Easement Program (EEP)—designed to create easements for long-term protection of environmentally sensitive lands through an approved natural resource management plan.

Forestry provisions in the new farm bill supported the President's "America the Beautiful Initiative" that challenged Americans to plant 1 billion trees annually.

The Clean Air Act of 1990 (Public Law 101-549), signed on November 15, 1990,[7] was the most comprehensive air pollution legislation passed in our Nation's history. The massive clean air bill contained 11 titles that targeted 3 principal forms of pollution: acid rain, smog, and toxic air pollutants. In total, about 30 million tons per year of hazardous chemicals and noxious pollutants was to be removed from the air.

Provisions were also incorporated for Stratospheric Ozone Protection (title VI), "renewable biomass energy and energy conservation incentives" under title VIII, and Clean Air Research (title IX). The National Energy Strategy report was issued by the Department of Energy (DOE) in early 1991 to provide guidance in implementing the new clean air bill, pursuant to the President's directive of mid-1989.[8]

Acid rain is caused primarily by sulfur dioxide (SO_2) and nitrogen oxide (NOx) 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 NOx emissions were to be cut by 2 million tons.

Smog results when motor vehicle tailpipe exhaust gases, NOx and volatile organic compounds (VOC's), react photochemically. According to recent estimates, motor vehicles nationwide are responsible for about 45% of NOx emissions and 34% of nonmethane VOC emissions. Motor vehicle emissions are also reported to cause about 70% of total carbon monoxide (CO) pollution and generate about 18% of the Nation's particulate emissions and 40% of the total lead pollution.[9]

Under title II, reductions in vehicular NOx and VOC emissions of 60% and 35%, respectively, will be required by 1996. CO emissions standards will also be effected at the same time. Tighter emissions standards for trucks and buses and reduced CO emissions during the cold starting of cars are also included.

To meet the objectives of title II, gasolines will be reformulated and oxygenated as prescribed in section 219. The 2%-by-weight minimum oxygen content requirement will likely be met by a methyl tertiary butyl ether (MTBE) additive—a methanol-butane derivative—and to a lesser extent by ethanol, formulated in a 10%-by-volume blend with gasoline to produce "gasohol." Ethyl tertiary butyl ether (ETBE), an ethanol derivative, may also become a significant oxygenated fuel additive. Tax incentives for ethanol production and blending were renewed in the 1990 Budget Reconciliation bill to encourage its use. Between 1994 and the year 2000, MTBE demand was projected to rise 175% to 5.5 billion gallons and ethanol to 2.5 billion gallons (67%).[10]

Under title II, section 241, provisions were made for "clean alternative fuels" motor vehicle fleets that would be designed to run on liquefied natural gas, methanol, ethanol, hydrogen, and electricity.

Toxic air pollutants are released into the air in significant quantities, about 1.3 million tons annually, during chemical manufacture, petroleum refining, mining and processing, and solid waste combustion. 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 toxics. Title III contained provisions that would reduce toxic air emissions by more than 75%.

Several important industrial nitrogen-containing compounds were on the list, including acrylonitrile, aniline, caprolactam, ethyl carbamate (urethane), hydrazine, coke oven byproducts, and cyanides. Ammonia and its downstream fertilizer derivatives were excluded from the list.

Issues

The U.S. Department of Commerce, Bureau of the Census, announced that publication of the strategic fertilizer and industrial chemical reports—CIR series M28A, M28B, and M28C—might be discontinued because of budget restrictions. After receiving a significant public response in favor of preserving the publications, the Bureau of the Census elected to publish the reports on a quarterly basis, effective January 1, 1991.[11]

After years of data gathering and analysis, the Environmental Protection Agency (EPA) released its National Drinking Water Well survey on November 13, 1990. The study, a survey of community and rural drinking water wells for pesticide and nitrate presence, found nitrate in amounts above EPA's 10 parts per million maximum in less than 3% of the wells.

The Fertilizer Institute (TFI) reported that EPA's study might surprise some environmental groups that sought sweeping reforms in farm practices to protect ground water. TFI referenced several States that had already conducted in-depth studies indicating that nitrate occurrence above a natural level was usually due to factors other than fertilizer use, either poorly constructed wells or other point sources.

EPA released the preliminary results of its 1989 Toxics Release Inventory

(TRI), which indicated that 22,650 industrial facilities released about 3 million tons of toxic chemicals into the Nation's environment. The report found that between 1987 and 1989, TRI chemicals decreased by a favorable 18%.

In 1989, a total of approximately 200,000 tons of ammonia was released into the air (61%) and water (6%), injected into underground wells (17%), delivered to municipal waste treatment plants (14%), and disposed of in landfills (2%).

Between 1987 and 1989, ammonia losses to the atmosphere declined by a favorable 18%, and discharges into rivers, lakes, streams, and other bodies of water declined 25%. Ammonia processed through municipal waste treatment plants rose 14%, and underground injection disposal methods increased 17%.

Production

In 1990, the U.S. ammonia industry ran at an impressive 98% of rated capacity. Thirty-three firms in 23 States produced 17 million short tons of anhydrous ammonia (82.2% N) an increase of 4% over that of the prior year. Louisiana, Oklahoma, and Texas, in order of importance, provided about 60% of total U.S. production; the Midwest, South, and Southeast, 30%; and the Western States and Alaska, 10%. Anhydrous ammonia production was buoyed by a good crop year, a reduction in the trade deficit, field inventory drawdowns, and a tight global supply situtation that developed in the fall because of the Persian Gulf crisis and Eastern bloc restructuring. Natural gas feedstock was reasonably priced.

About 90% of U.S. ammonia production was for fertilizer products and about 10% went into industrial products. Major downstream ammonia fertilizer derivatives included urea (46% N), diammonium phosphate (18% N), ammonium nitrate (35% N), and ammonium sulfate (21% N). Important industrial chemical derivatives were urea, ammonium nitrate, nitric acid (22% N), acrylonitrile (26% N), and caprolactam (12% N).

Mississippi Chemical Corp. (MCC) was operating ammonia, nitric acid, ammonium nitrate, urea, and urea-ammonium nitrate (UAN) solutions plants at Yazoo City, MS, that provided nitrogen products to 10 principal States in the South, Southwest, and Midwest. MCC's featured product was AMTRATE, a superior ammonium nitrate prill containing

TABLE 3

FIXED NITROGEN PRODUCTION IN THE UNITED STATES

(Thousand short tons of contained nitrogen)

	1986	1987	1988	1989	1990[p]
Anhydrous ammonia, synthetic:[1]					
Fertilizer	10,852	12,019	12,566	[r]12,183	12,677
Nonfertilizer	1,057	1,213	1,261	[r]1,266	1,263
Total	11,909	13,232	13,827	[r]13,449	13,940
Byproduct ammonia, coke plants:[e 2]					
Ammonium sulfate	50	50	60	60	50
Ammonia liquor	4	5	5	6	5
Total	54	55	65	66	55
Grand total	11,963	13,287	13,892	[r]13,515	13,995

[e]Estimated. [p]Preliminary. [r]Revised.
[1]Current Industrial Reports, MA28B and M28B, Bureau of the Census.
[2]Quarterly Coal Report, U.S. Department of Energy. Production (1985–90) based on reported coke production trend.

TABLE 4

MAJOR DOWNSTREAM NITROGEN COMPOUNDS PRODUCED IN THE UNITED STATES[1]

(Thousand short tons)

Compound	1986	1987	1988	1989[r]	1990[p]
Urea:					
Gross weight	6,264	7,433	7,914	7,963	7,907
Nitrogen content	2,881	3,419	3,640	3,663	3,637
Ammonium phosphates:[2]					
Gross weight	11,001	13,352	15,121	16,341	16,590
Nitrogen content	1,861	2,296	2,591	2,769	2,801
Ammonium nitrate:					
Gross weight	6,091	6,547	7,504	7,871	7,106
Nitrogen content	2,132	2,291	2,626	2,755	2,487
Ammonium sulfate:[3]					
Gross weight	2,080	2,189	2,333	2,347	2,495
Nitrogen content	437	460	490	493	524
Nitric acid, direct use:[4]					
Gross weight	1,939	2,069	2,082	2,151	2,152
Nitrogen content	431	460	463	478	478
Acrylonitrile:					
Gross weight	1,157	1,275	1,288	1,304	1,514
Nitrogen content	305	337	340	344	400
Caprolactam:					
Gross weight	425	580	631	656	690
Nitrogen content	53	72	78	81	86
Total:					
Gross weight	28,957	33,445	36,873	38,633	38,454
Nitrogen content	8,100	9,335	10,228	10,583	10,413

[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.
Sources: Bureau of the Census and International Trade Commission.

34% available nitrogen. AMTRATE prills remain free-flowing even when handled under hot, humid conditions owing to MCC's recently developed proprietary technology. The construction of a new 200,000-ton-per-year nitric acid plant scheduled on-stream in late-1992 will increase AMTRATE output. N-sol 32, a UAN solution containing 32% N, was also a featured product. MCC holds a 50% interest in Triad Chemical, a major urea production complex at Donaldsonville, LA.

In February, Freeport-McMoRan Resource Partners (FRP) sold its Agrico Div. nitrogen fertilizer facilities at Verdigris, OK, and Blytheville, AR, and certain fertilizer terminal facilities for $230 million.[12] Agricultural Minerals Corp. (AMC) was formed to purchase the plants in a leveraged buyout. AMC assumed control of the Verdigris, OK, and Blytheville, AR, plants effective March 1 and planned to establish headquarters in Tulsa, OK.

Ammonia, urea, and UAN solutions are the primary products produced by AMC, along with the highly efficient slow-release Super N fertilizers containing dicyandiamide. AMC ranked second in U.S. UAN capacity, fourth in ammonia capacity, and fifth in terms of urea capacity.

In June, Freeport's Agrico Div. sold its 25% interest in Namhae Chemical, a nitrogen and phosphate fertilizer facility in the Republic of Korea, for $80 million.[13]

In October, the W. R. Grace Agricultural Chemicals Group in Memphis, TN, signed a letter of intent to sell ammonia interests at Point Lisas, Trinidad, to Norsk Hydro a.s. of Norway. Included in the sale were Grace's wholly owned Federation Chemicals Ltd. ammonia plant (255,000 annual tons) and a 49% share in Trinidad Nitrogen Co. Ltd., a joint venture with the Government of Trinidad and Tobago in two ammonia plants (Tringen I & II), having a combined annual capacity of 920,000 tons. The sale was finalized in late December.

Grace also transferred ownership of its U.S.-based marketing operations and shipping interests that were linked to the output of the Trinidad facilities. Hydro Agri Ammonia, Inc. (HAAI), a U.S. affiliate of Norsk Hydro, was established in Tampa, FL, for this purpose. HAAI was staffed by key personnel from the former Grace marketing team in Memphis, TN.

TABLE 5

DOMESTIC PRODUCERS OF ANHYDROUS AMMONIA IN 1990

(Thousand short tons per year of ammonia)

Company	Location	Capacity[1]
Freeport-McMoRan (Agrico)	Donaldsonville, LA	r500
Agricultural Minerals Corp.[2]	Blytheville, AR	r390
Do.	Verdigris, OK	950
Air Products and Chemicals Inc.	New Orleans, LA[3]	290
Do.	Pace Junction, FL	100
Allied Chemical Corp.	Hopewell, VA[3]	r410
American Cyanamid Co.	Fortier, LA[3]	425
Arcadian Corp.[4]	Augusta, GA	545
Do.	Clinton, IA	256
Do.	Geismar, LA	352
Do.	Lake Charles, LA	460
Do.	LaPlatte, NE	190
Do.	Woodstock, TN	340
Nitrogen Products, Inc.[5]	Helena, AR[3]	210
Borden Chemical Co.	Geismar, LA	400
Carbonaire Co. Inc.	Palmerton, PA	35
CF Industries Inc.	Donaldsonville, LA	r1,740
Do.	Terre Haute, IN[6]	—
Chevron Chemical Co.	El Segundo, CA	20
Do.	Pascagoula, MS[7]	—
Do.	St. Helens, OR	80
Do.	Finley, WA	140
Coastal Chem, Inc.[8]	Cheyenne, WY	r170
Cominco American Inc.	Borger, TX[3]	r400
E.I. du Pont de Nemours & Co. Inc.	Beaumont, TX	r490
Farmland Industries Inc.	Beatrice, NE	237
Do.	Dodge City, KS	210
Do.	Enid, OK	840
Do.	Fort Dodge, IA	210
Do.	Hastings, NE	9140
Do.	Lawrence, KS	400
Do.	Pollock, LA[3]	420
First Mississippi Corp. (Ampro)	Donaldsonville, LA[3]	r450
Green Valley Chemical Corp.	Creston, IA	35
IMC Fertilizer Group, Inc.	Sterlington LA	1,050
Jupiter Chemicals	West Lake, LA	30
LaRoche Industries Inc.	Cherokee, AL	175
Mississippi Chemical Corp.	Yazoo City, MS[3]	r500
Monsanto Co.	Luling, LA[5]	460
Occidental Chemical Corp.	Tacoma, WA	28
Pennwalt Chemical Co.	Portland, OR	8
Phoenix Chemical Co.[10]	East Dubuque, IL	238
PPG Industries Inc.	Natrium, WV	50
J. R. Simplot Co.	Pocatello, ID	108
Sohio Chemical Co. (BP Intl Ltd)	Lima, OH[3]	530
Tennessee Valley Authority[11]	Muscle Shoals, AL	—
Terra International, Inc.	Port Neal, IA	230
Do. (Oklahoma Nitrogen)	Woodward, OK	450
Triad Chemical Co.[12]	Donaldsonville, LA[3]	r420

See footnotes at end of table.

TABLE 5—Continued

DOMESTIC PRODUCERS OF ANHYDROUS AMMONIA IN 1990

(Thousand short tons per year of ammonia)

Company	Location	Capacity[1]
Union Chemical Co. (Unocal)	Kenai, AK	1,200
Do.	Brea, CA[11]	—
Wil-Grow Fertilizer Co.[10]	Pryor, OK	94
Total		r17,406

rRevised.
[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 by Fertilizer Industries, holding company for the Sterling Group and Unicorn Venture Funds.
[5]Closed Mar. 1989; operated intermittently in 1990 under new ownership.
[6]Plant dismantled (150,000 annual tons).
[7]Large 530,000-ton-per-year plant idle for more than 3 years will reportedly be dismantled.
[8]Wycon Chemical Co. assumed parent company's name, midyear 1989.
[9]Plant idle.
[10]Former N-Ren Corp. plants acquired by Great American Management and Investment, Aug. 1987.
[11]Plant closed midyear 1989.
[12]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, Jan. 1991, and U.S. Bureau of Mines.

In late 1990, Chevron Chemical Co. announced plans to divest its fertilizer divisions, including active nitrogen production facilities in California, Oregon, and Washington State. Industry sources reported that Chevron's idle ammonia plant at Pascagoula, MS, (530,000 annual tons) would be dismantled and moved to Pakistan. A 400,000-ton-per-year diammonium phosphate (DAP) complex brought on-stream at Rock Springs, WY, in mid-1986 was also for sale.

Cargill Fertilizer of Minneapolis, MN, was building a C$430 million nitrogen fertilizer complex—the Saferco project—in Belle Plaine, Saskatchewan, through a joint venture between its Canadian subsidiary, Cargill Ltd., and the Crown Investments Corp. of the Province of Sasketchewan. Construction was 9% complete by yearend.[14] The plant was scheduled for completion in the fall of 1992 and was designed to produce 560,000 tons per year of ammonia and 750,000 tons per year of urea.

CF Industries was planning to expand urea and nitric acid capacity at its Donaldsonville, LA, nitrogen fertilizer complex. CF's Donaldsonville ammonia plants were capable of operating at 2 million tons per year, 120% of design capacity, because of recent revamp and retrofit initiatives. The planned expansions would lead to further improvements in the cooperative's competitive economics.

Coastal Chem, Inc. planned a 175,000-ton-per-year ammonia expansion by late 1992 at Cheyenne, WY, based on the reconstruction of a plant to be moved from Arcadian's Augusta, GA, complex. Coastal was constructing a 130,000-ton-per-year nitric acid plant at Elko, WY, that would be used to produce ammonium nitrate-base explosives. BP Chemicals announced a $17 million 90,000-ton-per-year nitric acid replacement/expansion at Lima, OH, that was scheduled on-stream in late 1992.

The former Big River ammonia complex at Helena, AR, was purchased by an investment consortium in bankruptcy proceedings during 1989 and renamed Five Rivers. The plant was subsequently closed in mid-1990 owing to a lack of reliable power sources and equipment failures. Ownership was transferred to the original lending institution, the Dutch-owned bank NMB, which contracted with the Royster Co. to operate a new enterprise called Nitrogen Products, Inc. A 210,000-ton-per-year ammonia plant was to be revamped and on-stream by late December 1990.

In August, Diamond Shamrock acquired the Center Plains ammonia facility at Dumas, TX, in bankruptcy proceedings through a repurchase agreement and planned to reactivate one of the two 80,000-ton-per-year plants on-site in early 1991.

Consumption and Uses

Fertilizer materials accounted for about 80% of domestic ammonia conversion disappearance, and about 20% went into industrial applications.

Urea and ammonium nitrate, in solid and liquid form, found extensive use in both the fertilizer and industrial sectors. UAN solution fertilizers that contain 28% to 32% N were growing in popularity because of their safe handling and storage characteristics and ease of application. In the industrial sector, urea was used in the production of synthetic fibers, resins, and polymers and as a protein supplement in 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.

Other uses for ammonia and ammonia-base compounds were for speciality horticultural and lawn and garden fertilizers, home and industial cleaners, and as a propellant in vehicular air bags. Ammonia and urea were also becoming popular low-cost agents that significantly reduced NOx atmospheric emissions when injected into combustion gas streams.[15]

In 1990, ammonia and ammonia derivatives accounted for 54% of the 20.6-million-ton primary fertilizer nutrient market in the United States. The ratio of nitrogen nutrient consumption to phosphate and potash fertilizer nutrient consumption was 2.5:1 and 2.1:1, respectively.

U.S. nitrogen fertilizer consumption reached 11.1 million tons N in 1990, an increase of 5% over that of the prior year. Single-nutrient compounds, led by direct application ammonia, UAN solutions, and ammonium nitrate, in order of importance, provided 80% of the total. Urea and nitrogen solutions were up by more than 10% each, while direct application ammonia remained static.

The six States that comprise the Midwest Corn Belt—Illinois, Indiana, Iowa, Missouri, Nebraska, and Ohio—together with Minnesota, consumed 4.6 million tons N, 41% of the U.S. total. Texas, Kansas, California, and Oklahoma, in order of importance, accounted for 2.2 million tons N, 20% of the total.

U.S. net cash farm income rose 8% to a record $59 million in 1990. Planted crop acreage approximated 327 million

TABLE 6

CONSUMPTION TRENDS FOR MAJOR NITROGEN COMPOUNDS PRODUCED IN THE UNITED STATES[1]

(Thousand short tons of contained nitrogen)

	1986	1987	1988	1989[r]	1990[p]
Fertilizer materials:					
Urea:					
Solid	1,529	1,904	2,028	1,999	2,064
Solution	1,033	1,137	1,201	1,232	1,164
Total	2,562	3,041	3,229	3,231	3,228
Ammonium phosphates[2]	1,861	2,296	2,591	2,769	2,801
Ammonium nitrate:					
Solid	623	626	776	793	767
Solution	963	1,012	1,193	1,231	1,144
Other[3]	43	53	10	46	-68
Total	1,629	1,691	1,979	2,070	1,843
Ammonium sulfate:					
Synthetic and byproduct	437	460	490	493	524
Coke oven byproduct[e]	47	51	59	60	53
Total	484	511	549	553	577
Total fertilizer	6,536	7,539	8,348	8,623	8,449
Nonfertilizer materials:					
Urea:[2]					
Feed	107	142	171	193	81
Industrial	212	237	241	239	328
Total	319	379	412	432	409
Ammonium nitrate[2]	503	600	647	685	645
Nitric acid	431	460	463	478	478
Acrylonitrile	305	337	340	344	400
Caprolactam	53	72	78	81	86
Total nonfertilizer	1,611	1,848	1,940	2,020	2,018
Grand total[4]	8,147	9,386	10,287	10,643	10,466

[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 M28B, Bureau of the Census, and International Trade Commission.

TABLE 7

U.S. NITROGEN FERTILIZER CONSUMPTION, BY PRODUCT TYPE[1]

(Thousand short tons nitrogen)

Product type[2]	1989[r]	1990[p]
Single-nutrient:		
Anhydrous ammonia	3,792	3,800
Nitrogen solutions[3]	2,032	2,267
Urea	1,552	1,715
Ammonium nitrate	644	603
Ammonium sulfate	172	184
Aqua ammonia	100	82
Other[4]	137	177
Total	8,429	8,828
Multiple-nutrient:[5]	2,164	2,248
Grand total	10,593	11,076

[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]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. 1990.

TABLE 8

U.S. PRODUCER STOCKS OF FIXED NITROGEN COMPOUNDS AT YEAREND[1]

(Thousand short tons nitrogen)

Material[2]	1989	1990[p]
Ammonia	936	879
Nitrogen solutions[3]	442	314
Urea	171	201
Ammonium phosphates[4]	138	105
Ammonium sulfate	53	52
Ammonium nitrate	64	49
Total	1,804	1,600

[p]Preliminary.
[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.

Source: Current Industrial Reports, M28B, Bureau of the Census.

acres, and another 60 million acres was idled by crop programs and the CRP.

Stocks

U.S. nitrogen producer stocks declined to a level of 1.6 million tons N and stood 11% below 1989 levels at yearend. Field inventories were also believed to have declined because of favorable domestic nitrogen fertilizer consumption and trade.

Transportation

In late December 1990, the Research and Special Programs Administration (RSPA) of the U.S. Department of Transportation (DOT) ruled that anhydrous ammonia should not be reclassified as a poisionous gas for the purposes of domestic transportation as previously proposed.[16] The RSPA ruled that classifying anhydrous ammonia as a nonflammable gas linked to the requirement of an "inhalation hazard label" would provide adequate hazard communication at substantially less cost and disruption to the agricultural and industrial users of the material. RSPA officially classified anhydrous ammonia a Division 2.2 nonflammable, nonpoisonous compressed gas for domestic shipments. A 5-year period was to be allowed for compliance.

International shipments, however, were classified as a Division 2.3 "poison

gas" consistent with United Nation regulations. International shippers were required to comply under the new regulations by 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 requirements.

Ammonia was transported by refrigerated barge, rail, pipeline, and truck. Mapco Ammonia Pipeline Inc. was operating Mapco Ammonia Pipeline and its sister company, Mid-America Pipeline, along a 1,098-mile corridor that extended in a northeasterly direction from Borger, TX, in northern Texas, to Mankato, MN, in southern Minnesota. Mapco built the first leg of the pipeline in 1968-69 and, by 1978, had added six extensions. About 500,000 tons of ammonia storage capacity was located along the pipeline. Mapco Ammonia Pipeline neither produced nor marketed ammonia independently, but transported ammonia on behalf of five shippers. Competition from the rail and truck transportation sectors was minimized because areas served by Mapco Ammonia Pipeline did not have river access. Mid-America Pipeline had more than 400 shippers and competed with the other transportation sectors.[17]

Koch Industries was operating the Gulf Central Pipeline built in 1969 that extended about 1,900 miles from the Gulf of Mexico into the Midwest, as far north as Iowa. Koch Nitrogen, a subsidiary, purchased four Midwest ammonia terminals from ConAgra Fertilizer in 1990 having a combined capacity of 150,000 tons.

In October, the Interstate Commerce Commission (ICC) replaced the Federal Energy Regulatory Commission (FERC) as the Federal agency responsible for ammonia pipeline regulation. FERC had been responsible for ammonia pipeline regulation since 1977, when ICC transferred power of control under the Department of Energy Act. Actions on complaints that had been previously filed with FERC against ammonia pipelines for alleged excessive rate charges were delayed because of the transfer after the U.S. Court of Appeals ruled in favor of ICC control.

Markets and Prices

Anhydrous ammonia prices continued an upward trend that had developed in the fall of 1989 because of strong domestic fertilizer movement and averaged $93 per ton, f.o.b. barge, New Orleans, for the first quarter. Urea followed a similiar trend, with granular product averaging $122 per ton, f.o.b. U.S. gulf coast. Anhydrous ammonia and urea prices fell during the second quarter and into the third quarter.

A dramatic rise in nitrogen fertilizer prices was precipitated following Iraq's invasion of Kuwait in early August. Anhydrous ammonia prices, f.o.b. barge, New Orleans, jumped 44% between July and December and sold for $117 per ton at yearend. Granular urea prices on the U.S. gulf coast rose about 26% and closed the year at $156 per ton. At yearend, prices for all major nitrogen fertilizers were up substantially relative to those of the prior year.

Foreign Trade

Effective January 1, 1990, the Bureau of the Census reinstated anhydrous ammonia export and import tonnage data that had been suppressed in total during calendar year 1989. U.S.S.R. anhydrous ammonia import tonnage data, however, continued to be withheld from the public domain because of a previous ruling that determined Occidental Petroleum to be the proprietary U.S. agent.

In 1990, the U.S. ammonia trade deficit was 2.9 million product tons, about 13% favorable to the record 3.4 million ton deficit established in 1989. The average c.i.f. price of ammonia landed in the U.S. in 1990 was about $100 per ton. Canada, Trinidad and Tobago, the U.S.S.R., and Mexico, in order of importance, accounted for 97% of total U.S. anhydrous ammonia imports.

The total U.S. converted nitrogen trade deficit was 1.3 million tons N in 1990, 0.3 million tons (19%) favorable to the 1.6-million-ton deficit of 1989. Anhydrous ammonia (2.4 million ton N deficit) and urea (0.5 million ton N deficit) were the predominate trade deficit materials. In contrast, diammonium phosphate generated 1.5 million tons of positive N net trade.

The United States imported 2.1 million product tons of urea from 20 countries in 1990 that was valued at $251 million ($122 per ton c.i.f.). Canada provided 65% of the total, while Mexico, Trinidad, and Venezuela—in aggregrate—accounted for another 18%. Bulgaria, the Federal Republic of Germany, and Yugoslavia shipped an aggregrate total of 8% (157,000 tons), but International Trade Commission (ITC) antidumping provisions sheltered the domestic industry from U.S.S.R., the Federal Republic of

TABLE 9

PRICE QUOTATIONS FOR MAJOR NITROGEN COMPOUNDS AT YEAREND

(Per short ton product)

Compound	1989	1990
Ammonium nitrate: f.o.b. Corn Belt[1]	$105-$115	$120-$125
Ammonium sulfate: f.o.b. Corn Belt[1]	100- 120	120- 130
Anhydrous ammonia:		
F.o.b Corn Belt	110- 115	140- 145
F.o.b. gulf coast[2]	86- 88	115- 118
Diammonium phosphate: F.o.b. central Florida	125- 126	145- 148
Nitrogen solutions (28% to 32%):		
F.o.b. South Central[3]	84- 98	95- 99
Urea:		
F.o.b. Corn Belt, prilled	110- 120	155- 165
F.o.b. gulf coast, granular[2]	115- 117	155- 156
F.o.b. gulf coast, prilled[2]	98- 105	142- 145

[1]Illinois, Indiana, Iowa, Missouri, Nebraska, and Ohio.
[2]Barge, New Orleans.
[3]Alabama, Arkansas, Louisiana, Mississippi, Kentucky, Tennessee, and Texas.

Source: Green Markets, Fertilizer Market Intelligence Weekly, Dec. 25, 1989, and Dec. 24, 1990.

TABLE 10

U.S. EXPORTS OF ANHYDROUS AMMONIA, BY COUNTRY

(Thousand short tons ammonia)[1]

Country[2]	1989	1990[P]
Korea, Republic of	171	300
South Africa, Republic of	160	178
Belgium	29	101
Denmark	23	—
France	22	9
Netherlands	—	16
Norway	—	22
Japan	23	—
Canada	8	14
Other[3]	27	6
Total	463	646

[P]Preliminary.
[1]Value data suppressed by Bureau of the Census.
[2]Ranked in relative order of importance.
[3]Twenty-seven countries; principally Brazil, Costa Rica, El Salvador, Mauritius, Morocco, Trinidad, Spain, Taiwan, Tunisia, and Venezuela.

Sources: Bureau of the Census, The Fertilizer Institute (1989); Bureau of the Census (1990).

Germany (Eastern states), and Romanian shipments that had previously been landed at prices below fair market value. A small shipment of U.S.S.R. urea reported by the Bureau of the Census in November was in error.

World Review

Geopolitical events in Eastern Europe and the Persian Gulf dominated the global nitrogen fertilizer scene in 1990.

In Eastern Europe, the drive toward democratization was accompanied by sweeping political reforms that placed downward pressure on Eastern bloc economies. Fossil fuel energy essential to ammonia production was in short supply and portended significant shortfalls in nitrogen fertilizers critical to domestic consumption and trade. In early 1990, Romania declared force majeure on urea exports as did Poland and Hungary later in the year; shipments of ammonia and urea from the U.S.S.R. and other Eastern European nations were cut back. It is estimated that Eastern European ammonia supply capability declined by more than 2 million tons (5%) in 1990.

Iraq's invasion of Kuwait in early August played havoc with the export-oriented ammonia and urea fertilizer industries on the Persian Gulf. Iraq and Kuwait in combination represented about

TABLE 11

U.S. IMPORTS OF ANHYDROUS AMMONIA BY COUNTRY

(Thousand short tons ammonia)[1]

Country	1989		1990[e p]	
	Gross weight	Value[2] (thousands)	Gross weight	Value[2] (thousands)
Canada[3]	[3]1,428	[3 4]$136,308	1,220	$122,525
Trinidad and Tobago	795- 980	92,270	882	88,841
U.S.S.R.	886- 898	84,028	[5]875	84,123
Mexico	253- 268	22,830	505	52,242
Venezuela	31- 57	3,578	61	5,786
Kuwait	99- 133	14,644	34	2,868
Saudi Arabia	61- 75	7,166	—	—
Bahrain	32	4,230	—	—
Other[6]	26- 69	[7]22,498	9	801
Total	[8]3,714-[9]3,837	387,552	3,586	357,186

[e]Estimated. [P]Preliminary.
[1]Tonnage data suppressed by Bureau of Census effective Jan. 1, 1989; alternate sources as described. Reinstated Jan. 1, 1990, excluding U.S.S.R. Ranked in relative order of importance by country.
[2]Bureau of Census c.i.f. data, excluding Canadian value for 1989 (see footnote 3). Grand totals as reported by Bureau of Census.
[3]Canadian tonnage and value data for 1989 as published by Statistics Canada, courtesy Canadian Fertilizer Institute. Value of Canadian shipments converted to U.S. dollars.
[4]Canadian ammonia imports in 1989 valued at $151,706,746 c.i.f. by Bureau of Census.
[5]U.S. Bureau of Mines data.
[6]Fifteen countries; principally Colombia in 1990.
[7]Determined by difference; includes discrepancy between Canadian import value as reported by Bureau of Census (c.i.f.) and Statistics Canada (see footnotes 3 and 4).
[8]Sum of data reported by The Fertilizer Institute.
[9]Sum of data reported by U.S. Bureau of Mines.

Sources: Bureau of the Census, The Fertilizer Institute, U.S. Bureau of Mines, Canada (1989); Bureau of the Census and U.S. Bureau of Mines (1990).

TABLE 12

U.S. EXPORTS AND IMPORTS OF MAJOR NITROGEN COMPOUNDS IN 1990

(Thousand short tons)

Compound	Gross weight	Nitrogen content	Value[1] (thousands)
EXPORTS			
Fertilizer materials:			
Ammonium nitrate[2]	46	15	NA
Ammonium sulfate[2]	1,123	236	NA
Anhydrous ammonia	646	531	NA
Diammonium phosphate	8,550	1,539	NA
Monoammonium phosphate	812	89	NA
Nitrogen solutions	514	154	NA
Sodium nitrate	5	1	NA
Urea	941	433	NA
Mixed chemical fertilizers[3]	215	34	NA
Other ammonium phosphates[4]	61	10	NA
Other nitrogenous fertilizers[5]	120	5	NA
Total	13,032	3,046	NA

See footnotes at end of table.

TABLE 12—Continued

U.S. EXPORTS AND IMPORTS OF MAJOR NITROGEN COMPOUNDS IN 1990

(Thousand short tons)

Compound	Gross weight	Nitrogen content	Value[1] (thousands)
EXPORTS—Continued			
Industrial chemicals:			
Ammonia, aqua (ammonia content)	31	26	$2,183
Ammonium compounds[6]	3	1	4,949
Ammonium phosphate (ortho)	(7)	(7)	82
Potassium cyanide	1	(7)	2,064
Sodium cyanide	7	2	61,270
Other cyanides and cyanates	1	(7)	4,893
Hydrazine, hydroxylamine and related inorganic salts	15	7	24,972
Bismuth-silver nitrates	(7)	(7)	9,939
Potassium nitrate	9	1	3,338
Other nitrates	4	1	6,350
Nitric and/or sulfonitric acids	14	2	3,980
Nitrites	4	1	2,637
Total[8]	89	41	126,658
Grand total[8]	13,122	3,087	NA
IMPORTS			
Fertilizer materials:			
Ammonium nitrate[2]	448	150	$48,954
Ammonium nitrate-limestone mixtures	1	(7)	99
Ammonium sulfate[2]	398	84	34,403
Anhydrous ammonia[9]	3,586	2,947	357,186
Calcium nitrate	e86	e13	10,254
Diammonium phosphate	12	2	3,271
Monoammonium phosphate	56	6	13,467
Nitrogen solutions	443	133	31,429
Potassium nitrate	40	5	11,422
Potassium nitrate-sodium nitrate mixtures	53	8	6,277
Sodium nitrate	157	25	20,015
Urea	2,050	943	250,507
Mixed chemical fertilizers[3]	177	21	24,380
Other ammonium phosphates[4]	66	11	10,095
Other nitrogenous fertilizers[5]	146	27	25,544
Total[8]	7,719	4,375	847,304
Industrial chemicals:			
Ammonia, aqua (ammonia content)	e15	e5	601
Ammonium compounds[6]	16	4	21,825
Calcium cyanamide	(7)	(7)	267
Potassium cyanide	1	(7)	1,749
Sodium cyanide	14	4	18,544
Other cyanides and cyanates[10]	4	1	4,392
Hydrazine, hydroxylamine and related salts	4	2	6,644
Bismuth and silver nitrates	(7)	(7)	4,989

See footnotes at end of table.

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. War would reportedly result in the damage and destruction of nitrogen production facilities in both Iraq and Kuwait that could require approximately 5 to 6 years to repair and replace.

The outbreak of War in the Persian Gulf could cut off or throttle back nitrogen fertilizer production in Bahrain, Qatar, Saudi Arabia, and the United Arab Emirates, resulting in the potential loss of up to another 10% of world N trade in the form of ammonia and urea. In 1990, it was estimated that ammonia production in the Mideast would decline by a net of 400,000 tons (8%) because of the Persian Gulf crisis.

Industry Structure.—Approximately 108 million short tons of anhydrous ammonia N was produced in 66 countries during 1990, of which about 11 million tons N (10%) was directly traded. Ammonia was converted into about 39 million tons of urea N in 55 countries, of which about 10 million tons (26%) was traded. Total world nitrogen fertilizer consumption was about 87 million tons N, of which trade accounted for about 22 million tons N (25%).

Global ammonia was produced in the developed and developing countries that have access to fossil fuel feedstocks, principally natural gas, naptha, petroleum refinery offgases and condensates, and coal and coke gases. The supply pattern, in general, followed the world population trend, with Asia and Eastern Europe—including the U.S.S.R.—accounting for more than 60% of the global ammonia supply. The developed regions—North America (United States and Canada), Western Europe, and Oceania—produced ammonia primarily for domestic use and accounted for about 25% of the world total. The energy-rich countries of the Middle East accounted for about 5% of the world supply and exported significant quantities of ammonia and urea to the global community.

Capacity.—The data in table 14 are rated capacity for ammonia plants as of December 31, 1990. 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

TABLE 12—Continued

U.S. EXPORTS AND IMPORTS OF MAJOR NITROGEN COMPOUNDS IN 1990

(Thousand short tons)

Compound	Gross weight	Nitrogen content	Value[1] (thousands)
IMPORTS—Continued			
Industrial chemicals—Continued			
Strontium and/or other nitrates	3	(7)	3,071
Nitric and/or sulfonitric acids	11	2	1,753
Sodium and other nitrites	4	1	2,017
Total[8]	71	19	65,852
Grand total[8]	7,791	4,395	913,156

[e]Estimated. NA Not available.
[1]Export values f.o.b.; import values c.i.f.
[2]Includes industrial chemical products.
[3]Harmonized codes 3105.10.0000 and 3105.20.0000.
[4]Codes 3105.51.0000, 3105.59.00 (exports and imports); 3102.70.0000 (exports); 3105.40.0050 (imports).
[5]Codes 3101.00.0000, 3102.29.0000, 3102.60.0000, 3102.90.0000 (exports and imports); and 3105.90.0050 (imports).
[6]Carbonates, chloride, fluorides, and tungstate (exports and imports); bromide, molybdate, orthophosphate, and perrhenate (imports).
[7]Less than 1/2 unit.
[8]Data may not add to totals shown because of independent rounding.
[9]Anhydrous ammonia tonnage data as reported by U.S. Bureau of Mines in 1989 and for U.S.S.R. in 1990; includes industrial ammonia. Value data, Bureau of Census.
[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).

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 1990, about 2 million annual tons of new ammonia capacity was brought on-stream, and about 1 million annual tons was permanently closed. Another 5.5 million annual tons was under construction and scheduled to come on-stream during 1991 and 1992.

The major ammonia capacity that was scheduled on-stream during 1990-92 was as follows: China—1.8 million annual tons in Sichuan, Henan, and Liaoning Provinces, together with small plants at various locations; U.S.S.R.—1.5 million annual tons in the Ukraine and at various locations; India—0.8 million annual tons in Kakinada and Rajasthan; Belgium—0.7 million annual tons at Antwerp; Bangladesh—0.5 million annual tons at Jamalpur and Ghorasal; Egypt—0.5 million tons at Suez and Abu Qir; Indonesia—0.5 million tons at Sumatra; and Turkey—0.4 million annual tons at Gemlik.

Current Research

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.

In late 1990, the Department of Agriculture (USDA) and the Department of Energy (DOE) signed a "memorandum of understanding" for accelerating the development of ethanol and other alternative fuels and fuel additives from agricultural and forestry products.[18] The agreement promised significant new markets for U.S. farmers and supported the President's National Energy Strategy that focused on a reduction in foreign energy dependency and a cleaner environment.

Research and development activities were to focus on four key areas related to production of fuels from agricultural and forestry products: (1) improving the conversion efficiency of biomass products to fuel products, (2) assessing economic effects of alternative fuel production, (3) assessing environmental effects of production and use of alternative fuels, and (4) enhancing economic competitiveness of such fuels.

Exxon Research and Engineering Co. of Florham Park, NJ, developed the THERMAL DeNox Process that significantly reduced NOx emissions by injecting ammonia into flue gas streams emanating from stationary combustion sources. THERMAL DeNOx is a noncatalytic process for NOx reduction based on the gas phase homogeneous reaction between NOx in flue gas and ammonia that produces nitrogen and water. The patented process was offered for license by Exxon Research and Engineering Co.[19]

The Electric Power Research Institute in Palo Alto, CA, developed NOxOUT proprietary technology that injected urea and other commodity chemicals into coal-fired boilers to reduce NOx emissions. Nalco Chemical of Naperville, IL, and Fuel-Tech of Stamford, CT, formed a joint-venture firm NalcoFuel-Tech to market NOxOUT technology.[20]

OUTLOOK

Global ammonia operating rates declined in 1990 owing to a significant downturn in Eastern bloc demand and supply disruptions precipitated by the Persian Gulf crisis. Per capita nitrogen consumption dropped below 41 pounds for the first time since the dismal global agricultural crisis of 1986.

The data of table 15 suggest that soft market conditions will prevail between 1990 and 1994, principally because of significant new additions to world capacity

TABLE 13

WORLD ANHYDROUS AMMONIA ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990

(Thousand short tons per year of ammonia)

	Rated capacity[1]
North America:	
Canada	r4,000
United States	r17,406
Total[2]	r21,410
Latin America:	
Argentina	r120
Brazil	r1,370
Colombia	r180
Cuba	440
Mexico	3,290
Peru	180
Trinidad and Tobago	1,950
Venezuela	900
Total[2]	r8,430
Western Europe:	
Austria	570
Belgium	530
Finland	90
France	2,470
Germany, Federal Republic of:	
Eastern states	2,070
Western states	2,450
Greece	470
Iceland	10
Ireland	510
Italy	r1,950
Netherlands	4,250
Norway	610
Portugal	r340
Spain	r1,010
Switzerland	60
United Kingdom	r1,900
Total	r19,290
Eastern Europe:	
Albania	100
Bulgaria	1,830
Czechoslovakia	r1,100
Hungary	1,090
Poland	3,020
Romania	5,120
U.S.S.R.	r34,450
Yugoslavia	1,630
Total	r48,340
Africa:	
Algeria	1,130
Egypt	r1,230
Libya	380
Nigeria	380
South Africa, Republic of	830
Zambia	60
Zimbabwe	70
Total	r4,080
Asia:	
Afghanistan	80
Bangladesh	1,100
Burma	280
China	r25,970
India	11,630
Indonesia	3,840
Japan	r2,260
Korea, North	1,200
Korea, Republic of	r950
Malaysia	380
Pakistan	1,680
Taiwan	340
Vietnam	70
Total	r49,780
Middle East:	
Abu Dhabi	380
Bahrain	450
Iran	r1,250
Iraq	810
Israel	90
Kuwait	1,120
Qatar	670
Saudi Arabia	1,170
Syria	380
Turkey	r920
Total	r7,240
Oceania:	
Australia	r750
New Zealand	100
Total	r850
Total world	r159,420

rRevised.
[1]Includes capacity at operating plants as well as plants on standby basis. Rated capacity based on 340-day-per-year effective operation.
[2]Data do not add to total shown because of independent rounding.

Sources: Branch of Industrial Minerals, U.S. Bureau of Mines, and International Fertilizer Industry Association Ltd. (IFA).

and a protracted period of economic recovery in the Eastern bloc. A renewal of hostilities in the Persian Gulf would again negatively impact ammonia and urea trade and could stress the global economy through the mechanism of yet another oil shock. By 1995, there appears to be a reasonably favorable probability that ammonia supply and demand will return to balance.

The U.S. Bureau of Mines ammonia nitrogen demand forecast was developed from world population projections of the United Nations, together with historic per capita consumption trends, taking into consideration geopolitical factors in Eastern Europe and the Mideast. Steady-state conditions were assumed for weather. World ammonia capacity projections were provided by the International Fertilizer Industry Association Ltd., Paris, France.

Turning to the U.S. outlook, a continuation of favorable trends in the nitrogen fertilizer and agricultural sectors would appear to be a distinct possibility. U.S. ammonia capacity expansion plans are minimal, and agronomic fundamentals that were improved by the 1985 farm bill should be further perpetuated by the new 1990 farm bill.

The mechanisms of the new ECARP, together with regular program acreage reductions, should hold U.S. crop acreage at about the current 330 million acres. This, together with the Export Enhancement Initiative, should control crop inventories and provide favorable crop prices for the U.S. farmer.

Issues critical to a favorable U.S. nitrogen fertilizer scenario include (1) a continuation of reasonably priced natural gas for U.S. ammonia production, (2) new industrial outlets for U.S. corn-based ethanol in reformulated motor fuels under the provisions of the Clean Air Act of 1990, (3) new markets for the Saferco ammonia and urea nitrogen complex under construction in Sasketchewan that would not result in the significant closure of U.S. nitrogen capacity, (4) a favorable resolution of the ongoing Uruguay round of General Agreement of Tariffs and Trade negotiations that would liberalize global agricultural trade and provide the United States with freerer access to global markets, (5) favorable U.S. implications for the proposed Free-Trade Agreement with Mexico and for the proposed granting of most favored nation (MFN) status to the U.S.S.R. and other Eastern European countries, (6) a smooth transition in democratic reforms in Eastern Europe, and (7) resolution of the MFN status debate with China.

TABLE 14

AMMONIA: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons of contained nitrogen)

Country	1986	1987	1988	1989	1990[e]
Afghanistan[e]	44	44	44	44	44
Albania[e]	r100	r105	r110	r120	110
Algeria	e165	192	217	145	150
Argentina	69	79	86	82	2 77
Australia	375	456	425	r379	2 425
Austria	e495	e495	r450	r452	452
Bahrain	318	304	340	r327	2 352
Bangladesh	430	480	742	r854	870
Belgium	337	296	402	r322	330
Brazil	972	1,049	1,031	1,079	2 1,034
Bulgaria	1,203	1,180	r1,480	r e1,430	1,320
Burma	147	130	r136	r108	2 86
Canada	3,208	3,182	r3,626	r3,681	2 3,267
China[e]	17,100	16,000	17,900	18,700	19,800
Colombia	103	98	93	101	2 108
Cuba	180	164	149	r147	165
Czechoslovakia	838	855	850	r878	2 874
Egypt	r748	r870	r869	r802	810
Finland	74	55	47	r46	2 26
France	2,229	2,237	e2,020	e1,630	2 1,748
Germany, Federal Republic of:					
Eastern states	1,315	1,296	1,274	e1,270	1,100
Western states	1,731	2,129	r2,011	r1,928	2 1,801
Greece	266	280	290	r267	2 283
Hungary	840	867	r763	r742	570
Iceland	9	10	10	e9	9
India[3]	5,438	5,842	6,840	r7,342	2 7,741
Indonesia	2,534	2,606	2,609	2,785	2,900
Iran	73	131	160	370	2 463
Iraq[e]	66	66	345	2 522	440
Ireland	391	440	460	r425	435
Israel	63	68	63	r e63	63
Italy	1,712	1,582	r1,721	1,594	1,320
Japan	1,662	1,715	1,680	r1,696	2 1,688
Korea, North[e]	500	500	r550	r550	550
Korea, Republic of	470	523	558	529	500
Kuwait	497	637	530	733	2 322
Libya	388	386	r239	r234	234
Malaysia	276	354	331	307	2 252
Mexico	1,766	1,922	2,279	r2,315	2 2,385
Netherlands	r2,409	r2,521	3,258	3,308	3,490
New Zealand	80	80	80	r77	2 77
Nigeria	—	142	342	r330	2 367
Norway	330	383	467	421	2 475
Pakistan	1,273	1,300	r1,293	r e1,295	1,300
Peru[e]	110	88	105	r65	65
Poland	2,341	2,400	r2,577	r e2,535	2,150
Portugal	130	171	210	r167	2 218

See footnotes at end of table.

TABLE 14—Continued

AMMONIA: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons of contained nitrogen)

Country	1986	1987	1988	1989	1990[e]
Qatar	600	618	657	[r]647	[2]639
Romania	3,352	3,073	[e]3,090	[e]2,870	2,100
Saudi Arabia	514	702	956	[r]952	[2]1,039
Somalia[e]	17	8	—	—	—
South Africa, Republic of	[e]640	[r]603	520	502	[2]503
Spain	512	495	525	608	[2]533
Sweden	51	37	—	—	—
Switzerland[e]	33	43	[r]35	[r]35	35
Syria	151	102	87	135	[2]114
Taiwan	292	268	307	[r]245	240
Trinidad and Tobago	1,258	1,243	1,528	[e]1,700	[2]1,676
Turkey	[r]210	[r]364	[re]340	[re]340	445
U.S.S.R.	21,605	22,050	[r]22,270	[r]21,495	20,400
United Arab Emirates	321	[r]343	330	357	[2]322
United Kingdom	1,530	1,560	1,218	1,143	1,270
United States[4]	11,909	13,232	13,827	[r]13,449	[2]13,940
Venezuela	[r]571	[r]578	[r]621	[r]587	[2]691
Vietnam	40	40	40	[e]40	40
Yugoslavia	897	1,033	946	750	740
Zambia	27	37	18	[r]13	[2]7
Zimbabwe	54	59	71	68	[2]76
Total	[r]100,389	[r]103,198	[r]109,448	[r]109,142	108,056

[e]Estimated. [r]Revised.
[1]Table includes data available through May 31, 1991.
[2]Reported figure.
[3]Data are for years beginning Apr. 1 of that stated.
[4]Synthetic anhydrous ammonia; excludes coke oven byproduct ammonia.

TABLE 15

WORLD ANHYDROUS AMMONIA SUPPLY-DEMND RELATIONSHIPS[1]

(Million short tons nitrogen)

	1985	1986	1987	1988	1989	1990[e p]	1991[2]	1992[2]	1993[2]	1994[2]	1995[2]
Capacity[3]	122.9	125.8	126.4	129.9	131.4	132.2	134.6	136.7	140.1	142.0	143.5
Demand:[4]											
Fertilizer[r]	88.7	89.2	91.7	97.8	97.4	96.4	97.8	100.5	103.2	105.8	108.5
Industrial[r]	11.6	11.2	11.5	11.6	11.7	11.7	11.8	12.0	12.2	12.5	12.7
Total[r]	100.3	100.4	103.2	109.4	109.1	108.1	109.6	112.5	115.4	118.3	121.2
Operating rate[5]	82%	80%	82%	84%	83%	82%	81%	82%	82%	83%	84%
Consumption:[r]											
Pounds per capita[6]	41.8	41.0	41.3	42.9	42.0	40.8	40.6	40.9	41.2	41.5	41.8
Population:											
Billion[7]	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8

[e]Estimated. [p]Preliminary. [r]Revised.
[1]Calendar years.
[2]Forecast.
[3]Design capacity, 340-day-per-year effective operation.
[4]Ammonia consumed in the production of fertilizer and industrial products, including process losses.
[5]Total demand as a percentage of design capacity.
[6]Ammonia demand expressed in pounds per person.
[7]Statistical Abstract of the United States 1990; Bureau of the Census.

Source: U.S. Bureau of Mines. Division of Mineral Commodities, Branch of Industrial Minerals.

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ORGANIC MATERIALS

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By Ronald J. Hurdelbrink and Michele R. Simmons

Organic materials obtained from nonrenewable resources comprise a wide range of nonfuel applications of natural gas-, coal-, and petroleum-derived feedstocks into both durable and nondurable goods. Plastics, synthetic fibers, and synthetic rubber are important products made from organic feedstocks that traditionally are used primarily as fuels. In addition, lubricants, asphalt, road oil, waxes, and numerous other petrochemicals, also derived from organic feedstocks, fulfill many important nonfuel uses. Products made from these organic materials include such varied items as household goods, eyewear, textiles, tires, engine grease, paving materials, pharmaceuticals, medical devices, and other items vital to society's well-being.

In 1990, there was expansion in nearly all categories of organic materials use from a year ago. Plastics, synthetic fibers, and synthetic rubber use grew 3% in 1990 to 30.5 million metric tons. This was due mostly to solid growth in plastics; in the thermoplastic resin category, for example, there was an 8% increase in polypropylene use and a 12% increase in polyethylene use for the year. Both synthetic fibers use and synthetic rubber use were down slightly in 1990 from a year ago. Nonfuel use of lubricants, petroleum coke, and coal grew 16% in 1990 to 14.8 million metric tons. Asphalt and road oil use increased 6% in 1990 to 30.9 million metric tons, and use of petrochemicals (solvents being the largest volume) grew 2% to 37.4 million metric tons.

Much of the news in the organic materials markets revolved around two specific issues: growing environmental concerns and concerns surrounding the invasion of Kuwait by Iraq and its impact on the markets for these nonfuel uses of fossil fuels. In the environmental arena, there were a number of legislative actions at the Federal, state, and local levels attempting to influence materials choices in ways perceived as reducing environmental damages, facilitating recycling, or alleviating the landfill crisis. One of the big moves in the private sector was McDonald's Corporation's decision to quit using polystyrene in packaging and substitute other materials, principally paper, a move it describes as source reduction.

The Iraqi-Kuwaiti war was another major event of 1990, although the predominant impact after the invasion of Kuwait in August seemed to be on price, not availability, of feedstocks for the materials organic industries. Though crude oil prices jumped very quickly after the invasion, prices for downstream products were slower to rise, and the increases were much smaller. Prices for plastics resins, for example, rose only by about 10% while crude oil prices doubled, and the price increases for resins lagged crude oil price increases by 6 to 8 weeks.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines collects no original data on organic materials use from company surveys. All of the statistical information included in this report was obtained from outside sources. Much of it relies on data collection efforts of other Government agencies and on surveys conducted by various industry publications and materials industry trade associations. The intent of the Bureau is not to duplicate the efforts of those organizations, but to augment those efforts with both data analysis and collection where adequate coverage is not currently available.

The data were obtained from a variety of sources, including the Annual Energy Review 1990 from the Energy Information Administration, U.S. Department of Energy; the Department of Commerce; and a wide variety of industry contacts. In addition, data were obtained from the Society of the Plastics Industry, Inc.; several industry trade associations; other Government data publications; and many industry trade journals, especially Chemical & Engineering News, Plastics News, and Modern Plastics. The focus of the discussion is primarily on plastics, synthetic fibers, and synthetic rubber. The synthetic fiber data were based on the efforts of Chemical & Engineering News, on surveys conducted by the Fiber Economics Bureau, Inc. and by various industry publications, and materials from the American Fiber Manufacturers Association, Inc. Data for synthetic rubber were based on reports in the Chemical & Engineering News, Chemical Week, the International Institute of Synthetic Rubber Producers, and the Rubber Manufacturers Association. Other categories of organic materials use are covered as well, but the same level of detailed information is not generally available for them; therefore, little additional detail was provided.

BACKGROUND

At the beginning of the 20th century, the United States satisfied about 75% of its material needs from renewable resources. The remaining 25% was met by minerals. The traditional primary renewable resources are agricultural (cotton, oils, etc.), forest (lumber, etc.), and wildlife (furs, etc.) products. Primary nonrenewable resources are inorganic minerals and organic materials such as coal, petroleum, and natural gas. This pattern of use held relatively constant until the Second World War when the first of two major shifts in feedstock reliance

started to occur. The first shift was the start of a continuous decline in the percentage share of material needs obtained from renewable sources. The second major change was the increased use of nonrenewable organic feedstocks in the production of asphalt, plastics, synthetic rubber, synthetic fibers, and petrochemicals. This trend is shown in figure 1, which displays the relative market shares for competing material feedstocks. (This figure is an update based on work by Spencer, et al.[1])

While the value of all components of the nonrenewable sector had increased over this period, the organic segment had outpaced the metallic minerals segment to the extent that by the mid-1980's, about 32% of the Nation's nonrenewable raw materials came from organic sources, double the share from metallic sources. The impact on the industrial minerals segment is unclear. As the use of asphalt and plastics (organics) grew, there was a concurrent requirement for increased aggregate and assorted mineral fillers and additives, thereby creating an expanded market for industrial minerals in conjunction with organic materials. Simultaneously, substitution for renewable resources was also taking place as synthetic fibers displaced agricultural fibers and plastic packaging displaced paper products.

Organic feedstocks obtained from petroleum, natural gas, and coal were used to produce material that had an average value of $15.4 billion during 1984-87 at the unprocessed stage. These feedstocks were used to make a variety of products such as asphalt, plastics, textiles, and petrochemicals. The average percentage used for each major application category from 1984 to 1987 is shown in figure 2.

Products for Trade and Industry

Nonrenewable organic resources are used primarily for fuels. Only a small percentage of the total U.S. consumption of oil, gas, and coal goes to nonfuel uses, but chemicals and plastics comprise a large part of the nonfuel materials sector. The portion of total U.S. consumption of fossil fuels that goes into nonfuel uses is often reported in terms of British thermal units (Btu's) or value. Measured in Btu's, it has been approximately 6% for the past several years,[2] but when measured in value terms, the proportion is higher. Fraser[3] calculates that, in value terms, the portion of organic materials consumed in nonfuel uses during the 1980's has been between 8.5% and 10%. He points out that because nonfuel uses consume higher priced petroleum and natural gas instead of lower valued coal, the value of organic materials going into nonfuel uses is understated when measured in Btu's.

Total petroleum products supplied for domestic use was 6.2 billion barrels in 1990; 815 million barrels was for nonfuel purposes, of which 299 million barrels was used for such purposes as asphalt and road oil, lubricants, petroleum coke, waxes, and miscellaneous products.[4] The remainder, 516 million barrels, included liquefied refinery gases (LRG's), natural gas liquids (NGL's), petrochemical feedstocks, and naphthas used by the chemical industry. U.S. consumption of natural gas was 18.8 trillion cubic feet in 1990.[5] A total of 624 billion cubic feet of natural gas, primarily methane, went into nonfuel end uses.[6]

A simplified overview of organic materials from well to feedstocks is shown in figure 3.[7] Among the many products of the petroleum refining process are naphthas and LRG's. These are the sources for petrochemical feedstocks, but both are primarily consumed as fuels. Naphthas are a primary constituent of gasoline, and LRG's have a variety of fuel uses.

During the processing of natural gas, NGL's are extracted from wet gas, producing dry gas, or methane. Methane and NGL's are also primarily consumed as fuels. In addition to their fuel uses, however, they are also the principal sources of petrochemical feedstocks used to make resins, fibers, elastomers, adhesives, paints, and pharmaceuticals.

Petroleum products, including NGL's, accounted for approximately 86% of the Btu's from fossil fuels consumed for nonfuel uses in 1990. Natural gas, principally methane, accounted for approximately 13% of the Btu's from the fossil fuels consumed, and coal accounted for the remainder. Asphalt and road oil, lubricants, petroleum coke, wax, and miscellaneous products comprised approximately 46% of nonfuel uses of petroleum products.[8] The array of products produced at a petroleum refinery is dependent upon a number of factors, including the design of the plant facilities, the characteristics of the petroleum refined, economics, and Government regulations. Crude petroleum varies from source to source and thus the range of products that can be produced economically also varies. The cost differential to produce one product instead of another and the prices received for the products dictate the economically efficient array of products. Governments can also influence the product array through specifying defense needs or by rationing resources during shortages. The plastics industry had limited access to feedstock materials during the oil crisis of the early 1970's, for example.

Table 1 reports the amounts of selected feedstocks, and the relative percentage of total consumption of each feedstock, consumed in the production of plastics. Ethylene dominates plastics feedstock consumption, with 22.4 billion pounds consumed. More than two-thirds of ethylene and benzene consumption, 60% of naphthalene (derived from coal tars), 50% of propylene, and 27% of xylene were consumed in the production of plastics in 1986. While plastics are the primary use for some feedstocks, they are only a minor use for others. Only small percentages of toluene, butadiene, and methane were used in the production of plastics.

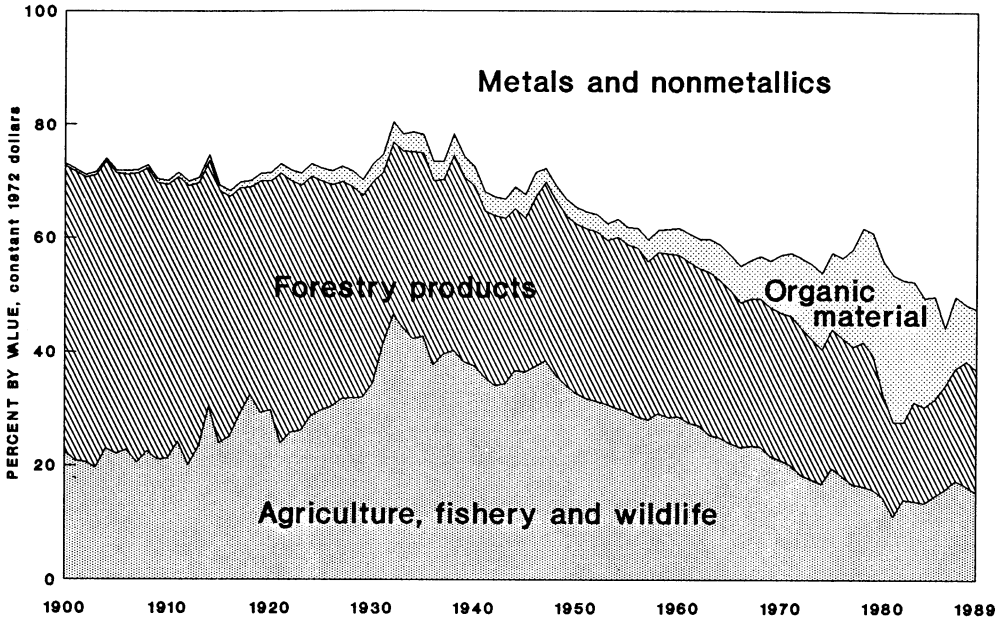
Methane is used to produce fluorocarbons and produces methanol that, in turn, is used in the production of phenolics. Ethane and propane can each be used to produce ethylene or propylene. Ethylene is used in the production of numerous resins, including polyethylene, fluorocarbons, polyesters, and ABS. Propylene is used in the production of resins such as polypropylene, polyesters, acrylics, and polyurethane. Butane is used in the production of ABS and some vinyls. Naphtha is the source of benzene, toluene, and xylene. Benzene is used in the production of unsaturated polyesters (nylon), polysulfone, styrene, and phenolics. Toluene and xylene are used in the production of polyurethanes and polyesters.

Lubricating oils are a combination of a small number of crude oil-base stocks blended with a large number of additives. The additives are used to give specific properties to a wide variety of lubricating oils. These properties include viscosity, viscosity change with temperature, oxidation resistance, acidity, boiling temperature, and pour point.

Petroleum coke comes in three forms. Sponge coke varies from a hard, porous, irregular-shaped lump to a fine powder. It is used in production of pure carbon or artificial graphite used for motor brushes, structural graphite, and dry cells. Needle coke, with its name derived from its shape, is the preferred material for graphite electrodes because of its lower electrical resistivity and lower coefficient of thermal expansion. Shot coke, which is generally produced unintentionally and comes only from residuals of California crude oils, has

FIGURE 1

U.S. CONSUMPTION OF RAW MATERIALS IN NONFOOD AND NONFUEL USES



U.S. Bureau of Mines
Department of Commerce

FIGURE 2

U.S. CONSUMPTION OF ORGANIC MATERIALS (AVERAGE 1984-87)

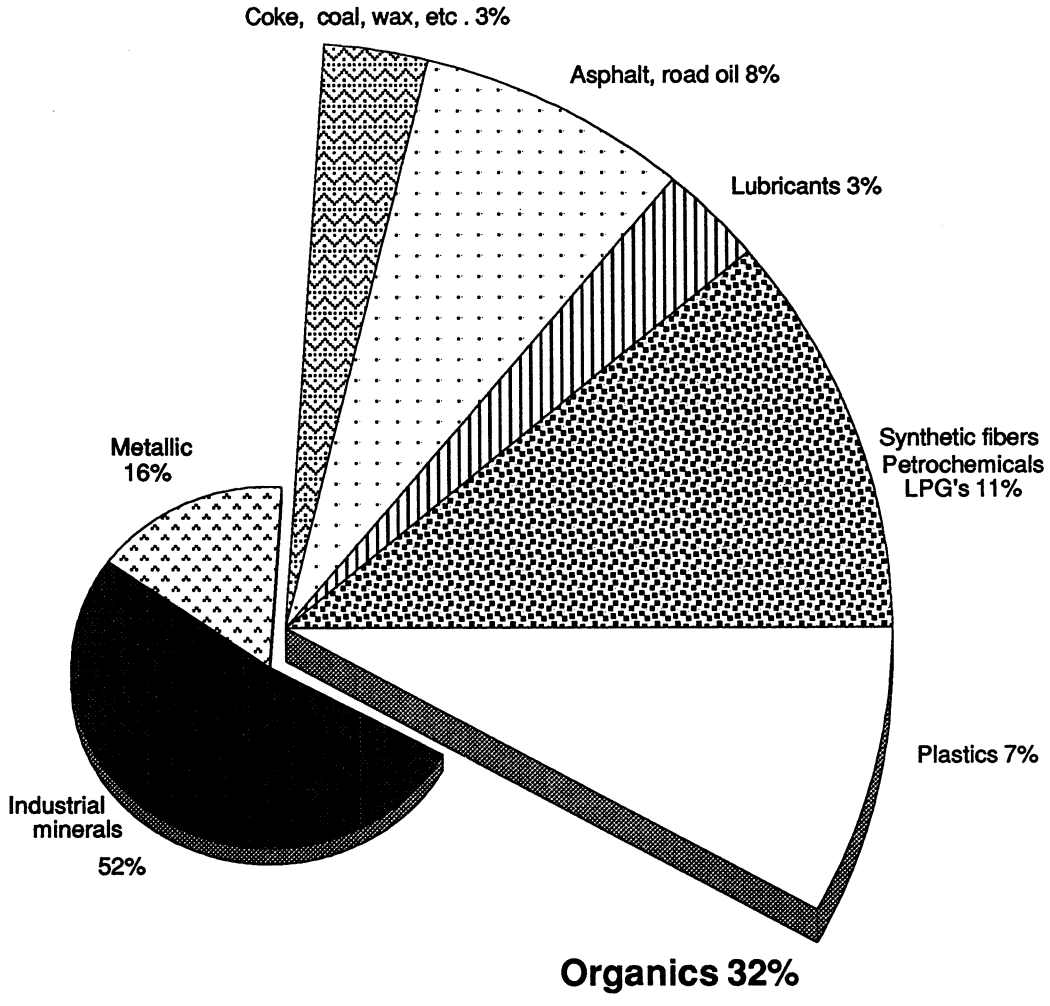
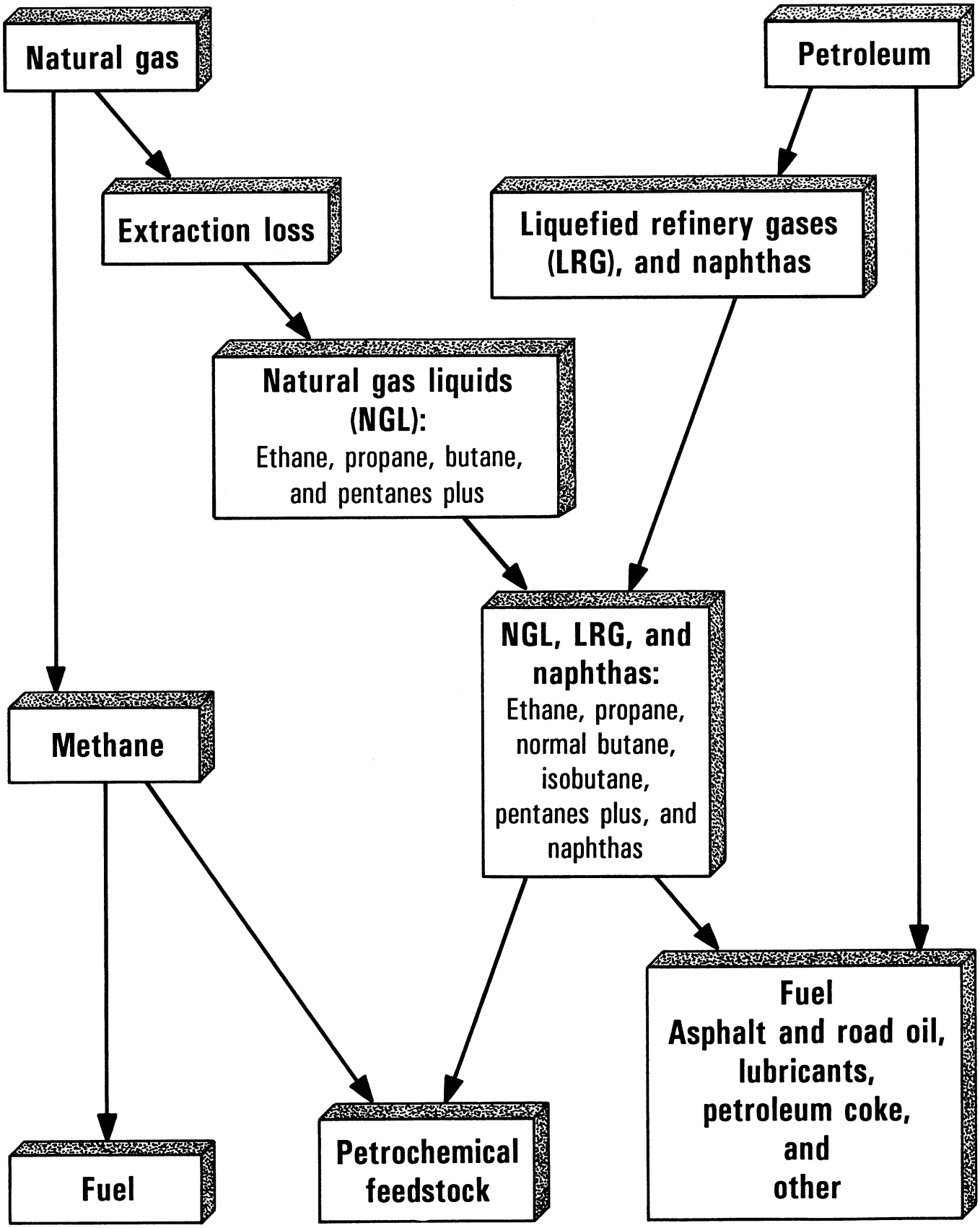


FIGURE 3

MATERIALS FLOW FROM WELL TO FEEDSTOCK



U.S. Bureau of Mines

a variety of uses as carbon or graphite. The nonfuel uses of coal are mainly for its carbon content; it is used as a filter material for boiler water, for example, where it takes out organic contaminants. Coal is also used in the production of cyclic intermediates that feed into the petrochemical feedstocks area.

Asphalt, a product of petroleum refining, is generally the bottom product left after all other products have been taken out. It is always blended with cutter stock, similar to kerosene but with a lower flash point, into three grades: fast cure (less of the kerosenelike material added so it sets up faster), medium cure, and slow cure, for use as road base at different ambient temperatures.

Not all refinery operations produce asphalt. Many refineries are set up to handle light crude oils, and the bottom product is a fuel oil. Asphalt is a natural product only from heavy crude oils, and the amount of asphalt produced will be in rough proportion to the gravity of the crude oil. Further processing is necessary to make the asphaltic material suitable for roofing applications.

Waxes, also a natural product of the refining processes, are derived from the gas oil fraction in the distillation process. Waxes come out of all crude oils. If the crude oil contains a large proportion of wax, then the final "pull" becomes unsuitable for asphalt production, even if it is a heavy crude oil.

Petrochemical feedstocks are divided into three major classes: aromatics, unsaturates, and saturated paraffins. Many of these feedstocks are the raw materials from which plastics, synthetic fibers, and synthetic rubber are produced. Other significant uses for petrochemical feedstocks are for solvents, paint thinners, and cyclic intermediates that are further processed into dyes, medicinal chemicals, and pesticides.

Technology

Approximately 16.2 million tons of plastics was disposed of in the United States in 1990. At present, postconsumer plastics are recycled at a rate of slightly more than 1% of total U.S. virgin production. The largest part of this recycling seems to be in response to the bottle deposit laws enacted in 10 States. Polyethylene terephthalate (PET) beverage containers are recycled into polyester fiberfill used for clothing and camping gear insulation and packing strap. The removal during 1990 of the Food and Drug Administration's proscription on reuse of recycled plastics for food containers has allowed several chemical companies working with the Coca Cola Co. and Pepsi Cola Co. to explore the chemical processes that break PET down into its original chemical components and reform the resin in a closed loop form of recycling back into beverage containers.

Some other examples of thermoplastics recycling are as follows: high-density polyethylene (HDPE) is recycled into cleaning products containers and carpet backing, low-density polyethylene (LDPE) into grocery sacks, polyvinyl chloride (PVC) into garden hose and containers, and reaction injection molding (RIM) scrap regrind back into its original products such as autobody panels and truck beds. Thermoset recycling occurs less often, but phenolics and epoxies have been used as regrind for filler material in the production of their original products such as epoxy circuit boards or pyrolyzed into asphalt or concrete reinforcement.

Textile fiber waste is incorporated into furniture stuffing, mattress felts, carpet and rug underlayments, and filler for rolled roofing goods. If a specific material can be reclaimed in relatively pure form at the source of origin, it may be blended or reintroduced into the virgin production stream. Where there are other nonrecoverable components, including chemical or mechanical binders, waste fiber is usually sent to a landfill.

Tires are the only reported form of synthetic rubber that is being recycled. Of the 234 million tires discarded every year in the United States, 82% is placed in a landfill, 9% is used for energy recovery primarily in cement kilns where their use has reportedly reduced energy costs by 50%,[9] 4% is used as an additive to asphalt, and 2% is recycled into products such as floor mats, buckets, carpet backings, and hoses.[10] Tires can also be used directly as the primary fuel in a waste-to-energy plant. The profitability depends on the price paid for energy in the region and the cost of the tires because the capital costs are higher than for conventional energy-producing plants.

Solvent and paint recovery in the United States is increasing and opening up to newer technologies to supplement the traditional methods of batch distillation and activated-carbon adsorption. The motivation for this was passage of the Clean Air Act Amendments of 1990 with revised National Emission Standards for Hazardous Air Pollutants, which are especially applicable to volatile organic compound emissions. New adsorbents such as Sorbathene and continuous activated-carbon stripping methods using vacuum instead of steam are allowing more solvent recovery with less energy input.

There are currently about 100 fuel blending plants in the Nation. These facilities collect, blend, and ship for incineration turpentine and paint wastes that otherwise might be thrown in a landfill or down a drain.

A controversial use for solvent recovery is their inclusion in the fuel used to fire cement kilns. The controversy centers around the potential release of dioxins and heavy metals into the environment and the perception that this practice is an avoidance of the Resource Conservation and Recovery Act handling and storage requirements that are avoided by mixing the solvent into the fuel oil and not classifying the mixture as hazardous waste.[11]

Some motor oils and turbine oils that are collected in an uncontaminated manner (free of solvents and paints) are recycled by reintroducing these products into the refining process.

Economic Factors

Crude oil and natural gas liquids are the major sources of petrochemical feedstocks. Throughout the world, naphtha, a crude oil fraction, is the main source of ethylene and propylene, the primary olefins involved in plastic resin production. There has been a long-term trend to use less naphtha and more natural gas liquids as sources of these olefins in nations that are gas rich. In the United States, natural gas liquids are the major sources of these primary olefins. Naphtha remains the major worldwide source of benzene. World crude oil production in-

TABLE 1

CONSUMPTION OF MAJOR FEEDSTOCKS FOR PLASTICS, 1986

Feedstock	Consumed in plastic	
	Million pounds	Percent of total
Benzene	6,400	67
Butadiene	200	6
Ethylene	22,400	70
Methane	2,500	[1]—
Naphthalene	250	60
Propylene	7,500	50
Toluene	350	7
Xylene	1,500	27

[1]Less than 0.5%.

Source: Rauch Associates, Inc.

creased by 1.4% in 1990 despite the embargo of oil exports from Iraq and Kuwait and a sharp drop in Soviet output.[12] The increased production was a response to the uncertainty of future supplies caused by the Middle East crisis and the resultant stock building of the market economies.

Consumption in the market economies slumped in the fourth quarter of 1990 because of the higher oil prices after the invasion of Kuwait by Iraq. In the United States, the average price of imported crude oil rose about 50% from $15 to $22 per barrel in the week immediately after the invasion. Import prices rose by early October to a peak of about $30 per barrel and then fell to about $25 per barrel by year's end.

The Middle East crisis increased supply problems in Eastern Europe already aggravated by the collapse of Comecon and diminished production in the U.S.S.R. The U.S.S.R.'s biggest 1990 oil production losses occurred in western Siberia's Province of Tyumen because of well shutdowns forced by pipe and equipment shortages. This province accounts for 63% of the nation's normal crude production. The shortage of Soviet oil production in early 1990 forced several Eastern European nations to look for new sources of crude oil in the Middle East. Oil contracts were signed with Iraq by Bulgaria, Hungary, and Poland, and Iraq was already an established supplier to Romania and Yugoslavia. The shortage of Eastern European hard currency reserves was to have been lessened by Iraq purchasing market goods from these countries through barter deals.[13] This hard currency shortage was compounded by the U.S.S.R.'s insistence on payment in hard currency for its crude exports.

The response of the U.S. petroleum market to the invasion of Kuwait by Iraq was to lessen its reliance on imports of crude oil. The high import level of 6.9 million barrels per day in July 1990 declined to a low of 4.6 million barrels per day in December 1990. The increases in the price of oil slowed the monthly decline of U.S. production during this period, but the 5-year decline in U.S. oil production continued, averaging 7.4 million barrels per day for 1990. U.S. petroleum demand was met by stock drawdowns, including the first sale ever from the Strategic Petroleum Reserve.[14]

Fourth quarter earnings in the petrochemical industry were mixed owing to the rise in feedstock costs, as shown in table 2. World ethane prices increased to as much as $2 per gallon during the crisis, up from $1.43 per gallon in July 1990, an increase of 40%, yet ethylene prices only increased 23.7% to $0.29 per gallon. As the feedstock prices leveled late in the quarter, petrochemical producers were able to maintain precrisis costs for some derivatives, although there was a general increase in prices for all basic petrochemicals.[15]

In the United States, demand for liquefied petroleum gases decreased by 6.7% in 1990 from the 1989 level. This drop in demand was accompanied by an increase in inventories and exports. Heavy petrochemical feedstocks demand rose, while naphtha petrochemical feedstocks demand remained unchanged from the 1989 level. Demand for petroleum coke rose 10% in 1990 while asphalt demand increased 7%.[16]

Operating Factors

Employment.—There was little change in the level of total industrial employment in the organic materials sector in 1990, as shown in table 3. Total industrial employment in the plastics, synthetic fibers, and synthetic rubber category was up slightly, while the number of production workers declined slightly. The number of women employees went up, both in absolute terms and as a percentage of the total. The average workweek declined by 0.6 hours. Average hourly earnings were up 4.3%, slightly more than the increase shown for all manufacturing.

No separate accounting of the total number of employees producing feedstocks for organic materials is possible. Nonfuel uses of fossil fuels account for only 6% to 8% of the total on an energy content basis. Employment in the overall oil and gas sectors, the industries that are the source for most organic materials feedstocks, was up slightly in 1990. Oil and gas extraction showed a 3.5% increase in employment, while petroleum refining, gas production and distribution, and asphalt paving and roofing materials all had employment increases of less than 1%.

Energy Requirements.—In the production of organic materials, energy resources are inherent in the feedstock and consumed in processing. The total amount of energy required for the production of plastic materials, for example, is in about a 1:1 ratio as fuel and feedstock. Figure 4 shows the energy requirements for a variety of plastics on a volume basis. Between 2,000 and 4,000 Btu's are needed to produce 1 cubic inch of

TABLE 2

FEEDSTOCKS (CONTRACT PRICES)

		January 1990	July 1990	December 1990
Benzene	dollars per gallon	1.50	1.30	1.40
Ethylene	cents per pound	24	23	29-30
Propylene	do.	15	16	24.50
Styrene	cents per pound	36.50	40.50	42-43

Source: Plastics World.

TABLE 3

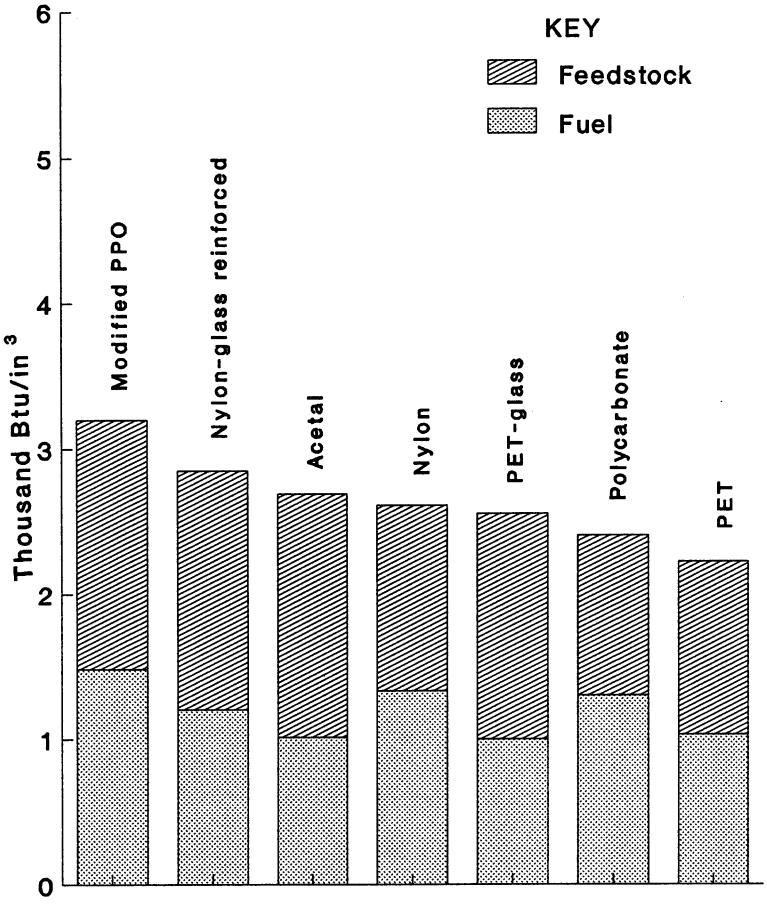
U.S. PLASTICS, FIBERS, AND RUBBER WORK FORCE CHARACTERISTICS

	1989	1990	1991
Industrial employment, thousands:	177	184	185
Women employed	38.2	40.34	41.4
Men employed	138.8	144.7	143.6
Production workers, thousands	116	120	119
Average workweek, hours	43.4	43.1	42.5
Average hourly earnings, dollars:			
Plastics, fibers, and rubber	13.06	13.44	14.02
All manufacturing	10.18	10.47	10.84

Sources: Chemical & Engineering News and U.S. Bureau of Labor Statistics.

FIGURE 4

COMPARISON OF PETROLEUM CONSUMPTION AS FUEL AND FEEDSTOCK IN THE PRODUCTION OF PLASTICS



most plastics. This level is below what is required to produce an equivalent volume of virgin metallic materials; however, it is higher than the energy requirement for metal production when the comparison is made on a weight basis. Only the lightest metals, like magnesium and aluminum, consume an equivalent or greater level of energy for the same weight of material.

Since the energy requirements for materials production show no clear advantage or disadvantage for organic materials, the increasing reliance on petroleum and natural gas as materials feedstocks has only limited strategic importance. Additionally, reliance on fuels for materials purposes is growing but still small in relation to total use, about 6% to 8% on an energy content basis. Of more concern to the organic materials industries is whether in times of shortages, allocation mechanisms would be used to divert available supplies of feedstocks away from the industry and toward its use as fuel for electricity generation and transportation. Plastic resin manufacturers felt this occurred during the oil market disruptions of the 1970's. Should resin manufacturers be forced to rely on alternative feedstock materials, the energy costs of producing plastics, synthetic fibers, and synthetic rubber would be much higher than those shown.

ANNUAL REVIEW

Economic forces, coupled with pressures from the Middle East crisis, affected market activities of the U.S. chemical industry in 1990. Chemical producers faced stalled economic growth, depressed chemical demand in key markets, and, shortly after midyear, increased raw material prices resulting from the Middle East crisis.

Overall production of chemicals and synthetic materials, except for plastics, declined modestly owing to weak demand in 1990. Chemical prices also drifted down until August, when prices rebounded as oil prices significantly increased in the wake of the Middle East crisis and producers tried to pass on their price increases for feedstocks to their customers.

One positive factor is that U.S. chemical producers, in general, were less affected by the higher oil prices stemming from the Middle East crisis than their foreign counterparts because they rely more heavily on natural gas-derived feedstocks rather than petroleum-derived feedstocks. Consequently, U.S. chemical producers were able to manufacture chemicals and plastics more inexpensively than many foreign chemical producers..

In addition, U.S. chemical producers benefited from increased foreign trade in 1990. With the U.S. dollar depressed relative to other currencies in the industry's key markets abroad, the cost of U.S.-produced chemicals were highly competitive during the year. Strong foreign demand for U.S. chemical exports helped trim the U.S. deficit despite higher priced oil imports.

Production of materials from nonrenewable organic resources during 1990 increased in all categories shown in table 4. For the petrochemical industries category, total feedstocks production increased over 3% to more than 61.6 million metric tons. Production of resins (i.e., plastics, synthetic fibers, and synthetic rubber) increased about 4% to 33.7 million metric tons in 1990, representing the eighth consecutive year that production of these materials has increased. Imports increased from 9.3 million metric tons in 1989 to 9.8 million metric tons in 1990. Exports continued their upward trend, growing from 2.3 million metric tons in 1989 to 2.5 million metric tons in 1990. Apparent primary consumption increased just over 2% to 68.7 million metric tons in 1990. ("Apparent primary consumption," as used here, measures supply and disposition of organic materials from primary sources and equals production plus imports minus exports plus stock changes. Recycled materials are not accounted for in this calculation.) The price for feedstocks shown in the table represents the price of the organic material that is used to make these products and not the price of the products themselves. It reflects changes in the price of energy and, consequently, fluctuates with energy markets.

Production of lubricants, petroleum coke, and coal increased to 20.3 million metric tons in 1990 after small declines during the previous 2 years. Imports of lubricants and petroleum coke in 1990 were 630,000 metric tons, the same level as that in 1986. Imports reached 770,000 metric tons in 1987, then fell to 580,000 metric tons in 1988 and remained near that level in 1989. Exports of lubricants and petroleum coke increased just over 2% to about 3.5 million metric tons in 1990, after declining 13% between 1988 and 1989. Yearend stocks of lubricants and petroleum coke were just under 2.1 million metric tons, down from almost 2.3 million metric tons in 1989. Apparent primary consumption of lubricants, petroleum coke, and coal increased 13% to 17.6 million metric tons. It should be noted that data for coal were included in production, but not in imports, exports, or stocks because of lack of detailed information on coal not used as a fuel.

Production of asphalt and road oil increased 6% to 26.9 million metric tons in 1990. It has fluctuated between 24 million metric tons and 27 million metric tons since 1986. Imports of asphalt increased 3% to 1.91 million metric tons in 1990. Exports were 20,000 metric tons in 1990, unchanged from the 1989 level and down from earlier years shown. Yearend stocks of asphalt declined almost 9% to 3.1 million metric tons. Apparent consumption of asphalt increased almost 7% to 29 million metric tons in 1990. Apparent consumption of asphalt and road oil has fluctuated between 27 million metric tons and 29.1 million metric tons since 1986.

World Review

Faced with slower economic growth, currency fluctuations, higher raw material prices, and growing tensions from the Middle East crisis, the chemical industry in 1990 experienced downturns in a number of market activities.

By midyear, many countries were either well into a recession or just coming into one. The chemical industry found the demand for chemicals down in several principal markets. With demand down, chemical production soon declined in response. As a result, chemical producers saw their revenues and profits reduced. Adding further to the squeeze on chemical producers' earnings were the additional supplies and capacity made available from a number of new petrochemical plants that had come on-stream during the year.

Currency fluctuations and increases in raw material prices were other complicating factors to the chemical industry. Throughout 1990, worldwide chemical trade remained strong, but the volume traded was down for many regions. Also, as increases in raw material prices took effect during the year, chemical producers experienced some difficulty in passing along those increases to their customers.

The chemical industry also remained focused on the General Agreement on Tariffs and Trade (GATT) negotiations during the latter part of 1990. The results of a new agreement, once implemented, are expected to have a major impact on the volume of chemicals traded worldwide due to imposed tariff and nontariff barriers.

TABLE 4

SALIENT U.S. ORGANIC MATERIALS STATISTICS

(Million metric tons, unless otherwise specified)

	1986	1987	1988	1989	1990
Petrochemical industries:					
Production, total feedstocks[1]	56.27	59.60	60.11	59.68	61.58
Production, resins[2]	27.92	30.75	32.45	32.50	33.67
Production, others[3]	28.35	28.85	27.66	27.18	27.91
Imports for consumption[4]	7.42	7.04	9.80	9.30	9.84
Exports[4]	1.58	1.59	2.08	2.34	2.54
Consumption, apparent primary[5]	60.94	64.63	67.85	67.29	68.68
Price, dollars per metric ton[6]	74.62	110.80	91.50	114.10	136.15
Stocks, yearend[4]	4.61	5.03	5.01	4.36	4.56
Lubricants, petroleum coke, and coal:					
Production	14.61	19.05	18.93	18.43	20.26
Imports for consumption[7]	.63	.77	.58	.59	.63
Exports[7]	2.98	3.68	3.91	3.40	3.48
Consumption, apparent primary[5]	12.15	16.05	15.62	15.55	17.63
Price, dollars per metric ton[6]	81.37	96.28	81.29	99.68	116.87
Stocks, yearend[7]	2.14	2.23	2.21	2.28	2.06
Asphalt and road oil:					
Production	24.77	26.09	26.72	25.35	26.85
Imports for consumption	1.75	2.19	1.90	1.85	1.91
Exports	.04	.05	.06	.02	.02
Consumption, apparent primary[5]	27.06	28.05	28.22	27.23	29.04
Price, dollars per metric ton[6]	86.88	106.95	87.63	110.43	139.12
Stocks, yearend	2.92	3.10	3.44	3.39	3.09

[1]Total feedstocks are composed of liquefied petroleum gases, petrochemical feedstocks, special naphtha, dry natural gas, and other as defined in table 12 of the Annual Energy Review 1990.

[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]Apparent primary consumption measures supply and disposition of organic materials from primary sources and equals production plus imports minus exports plus stock changes. Recycled materials are not accounted for in this calculation.

[6]Price is based on Btu value as close to the point of production as possible.

[7]Coal is not included.

Sources: Chemical & Engineering News, European Plastics News, Annual Energy Review 1990, Petroleum Supply Annual 1990, and Modern Plastics.

On August 2, 1990, Iraq invaded Kuwait. Within days, Iraq shut down Kuwaiti oil production capacity, and the United Nations imposed an international trade embargo against Iraq. As oil supplies from these regions began to fall, a portion of the world oil supply was effectively removed from the market. The price of crude oil rose quickly and remained high for several weeks before declining owing to increased production from other major oil-producing nations. Because crude oil is an important raw material used to make resins and other nonfuel materials, uncertainties surrounding its availability spawned concerns over future feedstock supplies to the chemical industry. These unfolding events led to higher feedstock prices worldwide and, in turn, to higher resin prices that effected a lower resin demand and contributed to a buildup of resin inventories.

In 1990, production of synthetic fibers, synthetic rubber, and plastics decreased in most countries. Those downward trends led to overall declines in world production of these commodities, except plastics, which rose mainly owing to production increases in Canada and Japan. Among the major producing regions for plastics were Canada, Japan, the United States, and Western Europe. For synthetic fibers, the major producing regions were China, the Federal Republic of Germany, Taiwan, and the United States. For synthetic rubber, the major producing regions were the United States and Western Europe.

Canada.—As Canada's economy moved into a recession at the beginning of the second quarter of 1990, the chemical industry saw sales and profits weakened by high interest rates, a strong Canadian dollar, lackluster domestic demand, and rising energy and raw material costs. However, higher chemical exports during the last months of 1990, despite the strong Canadian dollar, helped to offset demand, prompting an increase in production of some chemicals, especially the major polymer resins.

Japan.—Japan enjoyed economic expansion during 1990. Even so, higher feedstock prices, along with inflationary pressures and high interest rates, threatened the nation's growing economy.

The Japanese chemical industry, like the economy overall, exhibited strong growth through the third quarter of 1990. By yearend, however, higher naphtha feedstock prices arising from Middle East tensions caused supply concerns for chemical producers, as well as lowered their profit margins. In Japan, the chemical industry relies heavily on imported petroleum-derived naphthas for its feedstocks to help meet domestic chemical demand; the lack of those supplies could prove damaging to this thriving industry. Despite this economic climate, chemical demand remained strong throughout the year, especially for petrochemicals and plastics. Consequently, production for most chemicals was up in 1990.

Production of synthetic fibers, synthetic rubber, and plastics continued upward in 1990, with plastics leading in growth.

Western Europe.—In Western Europe, a softening economy, rising raw materials costs, and declining demand curbed activities of the chemical industry in 1990. Chemical industry activities were less profitable for most chemical producers in 1990 compared with those of a year ago. Rising costs of raw materials, especially petroleum-derived naphthas, scaled back chemical producers' earnings as feedstock prices more than doubled in response to petroleum price hikes stemming from the Middle East situation; producers found difficulty in passing along cost increases to their customers. Chemical producers' earnings were further threatened as new plants came on-line and began providing additional chemical supplies. Less affected by rising feedstock costs, however, were producers whose activities occurred farther downstream from the production of basic chemicals. Even so, many chemical producers' earnings were dampened by unfavorable currency exchange rates.

Production of synthetic rubber and plastics increased modestly in 1990, while production of synthetic fibers decreased.

OUTLOOK

The basic olefins, ethylene and propylene, aromatics of which benzene is the major component, and methanol are considered the upstream or elementary building blocks of the petrochemical industry. The main building block of the petrochemical industry is ethylene. Propylene is a byproduct of ethylene production. Propylene is produced in a higher ratio when naphtha steam cracking is the process used for ethylene production and in a lesser proportion when natural gas is the source for ethylene production. The major worldwide source for ethylene has been naphtha from which ethylene is obtained through a steam cracking process and natural gas liquids. However, in the natural gas-rich nations such as the United States and Mexico, natural gas liquids are the preferred source of ethylene through the chemical conversion of ethane. Some substitution of gas oil and fuel oil as sources has been occurring in the petroleum-rich nations spurred on by the introduction of crude residuals into the fluid catalytic conversion process that occurred in the early 1980's. This allowed more economical production of the ethane and propane necessary for conversion to ethylene and propylene.[17]

Worldwide ethylene production capacity continued to grow throughout 1990, with major gains occurring in the United States, Latin America, the Middle East, and the Asia Pacific region. The United States gained 1.59 million metric tons per year as the result of a capacity increase at the Occidental Chemical Corp. plant in Lake Charles, LA. Venezuela increased its production capacity to 660,000 metric tons over a 1989 level of only 150,000 metric tons. Saudi Arabia increased production capacity by 359,000 metric tons equally spread over its three major petrochemical plants. The Asia Pacific region increase occurred only in Japan with a production capacity gain of 553,000 metric tons occurring at five of its petrochemical plants. Eastern Europe production capacity increased in Czechoslovakia at the Zavody CSSP plant, which reported an increase of 370,000 metric tons. Even Western Europe showed a production capacity increase in 1990 despite the significant downpricing that occurred in the 1980's because of ethylene overproduction. France gained 140,000 metric tons in production capacity. The Netherlands increased production capacity by 90,000 metric tons per year, and West Germany increased its production capacity by 25,000 metric tons per year.[18]

The production capacity increases that occurred in 1990 are expected to continue throughout the 1990's, with world ethylene production projected to increase by almost 22 million metric tons per year through 1995. These production capacity increases have created concerns of overcapacity, which could be intensified if the current economic downturn continues. Exxon Chemical Corp. projects that, in 1995, only 85% of world production capacity for ethylene production will be used.[19]

The ethylene producers in the United States could be affected because of this worldwide overcapacity. It is expected that ethylene exports could decline to less than 1 billion pounds per year by the end of the 1990's from a high of about 3 billion pounds per year in 1989.[20]

Worldwide propylene demand is expected to grow to 38.3 million metric tons by 1995 from a production rate of 28.9 million metric tons in 1989. This could cause some shifting of sources for ethylene production in the gas-rich nations because propylene production is a byproduct of ethylene production and its ratio of production is tied to the feedstock source. Demand is expected to increase worldwide, with the Far East and Latin America leading the way with expected increases of approximately 50%. New propane dehydrogenation plants expected to come on-line in the early 1990's in Antwerp, South Korea, Mexico, and Malaysia, and new naphtha cracking plants in Saudi Arabia and South Korea will add about 750,000 metric tons of production capacity by 1995. The U.S. and Western European market shares will drop to 28% and 23%, respectively, by 1995 because of these expected worldwide production capacity increases.[21] World benzene production is expected to increase by 3.6% per year to the year 2000. World production capacity is expected to increase to 36.8 million metric tons by the year 2000 from 29.5 million metric tons of installed capacity in 1990. This could lead to a utilization of only 76% of installed capacity in the year 2000. The United States and Western Europe are leading the way in this production capacity increase. Benzene is produced as one of the products in the catalytic reforming process used to reform naphtha into high octane gasoline. World benzene production capacity from reformers is expected to increase to 11 million metric tons per year by 1996 from a 1990 production capacity of 8.4 million metric tons per year.[22]

The Clean Air Act Amendments of 1990, enacted on November 15, 1990, in the United States, will require benzene content in catalytic reformate to drop to 1% by volume from the previous 2% by volume. This will require a shifting in the processes used to produce benzene. The alternative methods of disproportionation and hydroalkylation are presently being used for benzene production, and their use is expected to increase.

Methanol is used for the production of acetic acid and formaldehyde, as a solvent, and as a raw material for gasoline synthesis. Its nonfuel uses are not expected to increase much in the next decade, but its use in methyl tertiary-butyl ether (MTBE) is expected to increase, leading to a projected rise of 3.5% per year for the next 10 years.[23]

PLASTICS

World sales of plastic resins increased by 4.7% in 1990. All of the increase can be accounted for by three regions, North America, Western Europe, and Japan, which showed sales increases of 5.7%, 5.8%, and 8.0%, respectively. Sales in all other regions of the world combined actually declined.

The Iraqi-Kuwaiti conflict resulted in price increases of plastic resins, although those increases tended to be somewhat less pronounced and slower to become effective than price increases in crude oil and for many other oil-derived products.

Polymeric materials continued to be substituted for traditional materials in many applications. In October 1990, the Saturn was introduced as the newest "polymer-intensive" car. The Saturn is the first car to feature all injection molded thermoplastic body panels and other large exterior components. The "hang-on" panels go over a space frame of stamped double-galvanized steel. Saturn uses a variety of resins to meet different flexibility requirements front and rear, and the method of hanging the panels allows for differing rates of thermal expansion between the panels and the steel frame. The choice of thermoplastics was partly dictated by the ability to recycle and reuse scrap and partly by cost savings. Cost savings claims include reduced tooling costs and tooling lead time, improved surface finish, easier styling changes, and weight savings over that of steel.

There were a number of legislative actions by governments at various levels aimed at reducing environmental damages, facilitating recycling, or alleviating the landfill crisis. One of the big moves in the private sector was McDonald's decision to quit using polystyrene in packaging and substitute other materials, principally paper, as a means of source reduction.

Background

Early beginnings of the plastics industry can be traced back to natural compounds such as horn and hoof, tortoise shell, bone, ivory, gutta-percha, shellac, and glue. Forming useful items with these and other compounds necessitated the development of extrudes, presses, molds, calenders, and so on, that were later used for synthetic materials as they were developed. In 1929, a generic name for the developing industry was selected by a contest. Synthoid was the winner, but it was shunned by the industry in favor of the word "plastic." Plastic was favored because the word means that the substance can be molded or formed into any shape, opposed to nonplastic substances that must be cut or chiselled.[24]

Significant dates in the development of synthetic polymers start with Alexander Parkes' introduction of the cellulose nitrate, Parkesine™, at the Great Exhibition in London, England, in 1862 (see table 5). In the United States, John W. Hyatt independently developed a form of cellulose nitrate and the injection molding machine in 1868. A patent for Celluloid™ was granted to Hyatt and his brother Isaiah in 1870. It was not until 1877 that A. Kekule postulated that natural products are long-chain molecules. E. Ficher finally verified that the structure of cellulose was indeed a macromolecule in 1893.

Hendrik Baekeland was responsible for the introduction of the first synthetic thermosetting resin in 1909. The phenolic was known as Bakelite™. Commercial development of a number of thermoplastics occurred during the 1930's. W. H. Carothers first synthesized nylon 6/6 in 1935, polyurethanes were invented by O. Bayer in 1937, and R. J. Plunkett discovered the polymerization of tetrafluoro-ethylene (PTFE) in 1938. PTFE was developed rapidly to the manufacturing stage under a crash program for use in World War II.[25] However, it was not until 1950 that PTFE came into wide commercial production under the trade name Teflon™.

Production of PVC and formaldehyde laminates (Formica™) began in 1940. Fi-

TABLE 5

HISTORICAL DEVELOPMENT OF POLYMERS

Date	Event
1862	Alexander Parkes introduced the cellulose nitrate, Parkesine™.
1868	J. S. Hyatt discovered a cellulose nitrate and the injection molding machine.
1870	Celluloid™ patent granted to J. S. Hyatt in the United States.
1877	A. Kekule postulated that natural products are long-chain molecules.
1893	E. Ficher verified that the structure of cellulose is indeed a macromolecule.
1909	L. H. Baekeland discovered phenol formaldehyde resins (Bakelite™).
1919	Cellulose acetate available as molding material.
1924	H. Staudinger proposed the linear chain structure for polystyrene.
1927	Introduction of polyvinyl chloride.
1928	O. Rohm commercialized polymethyl methacrylate (PMMA).
1929	Introduction of urea-formaldehyde resins.
1930	First production of polystyrene (PS).
1933	Discovery of polyethylene (LDPE).
1934	Production of polymethyl methacrylate sheet.
1935	W. H. Carothers first synthesized nylon 6/6.
1936	Introduction of polyacrylonitrile, styrene-acrylonitrile copolymers, and polyvinyl acetate.
1937	O. Bayer discovered polyurethanes.
1938	P. Schlack discovered nylon-6 and epoxy resins. R. J. Plunkett discovered the polymerization of tetrafluoroethylene (PTFE). High-pressure polymerization of ethylene was introduced.
1939	Commercial production of LDPE, development of epoxide resins.
1940	Production of PVC, melamine formaldehyde laminates (Formica). G. E. Rochow discovered the direct process for the manufacture of chlorosi lanes, the raw material for silicone resins.
1941	Development of fiber-forming polyesters. J. R. Whinfield and J. T. Dickenson discovered polyethylene terephthalate (PET).
1942	Commercial introduction of PAN fibers (Orlon™).
1948	Introduction of acrylonitrile-butadiene-styrene, used to manufacture luggage.
1950	Commercial production of PTFE (Teflon™).
1952	K. Ziegler developed catalysts for the low-pressure polymerization of ethylene.
1953	G. Natta used Ziegler catalysts to synthesize stereoregular polypropylene (PP). H. Schnell discovered polycarbonate. First PET (Dacron™) plant began production.
1955	Development of HDPE and PP.
1956	A. S. Hay discovered polyphenylene oxide (PPO).
1958	Commercial introduction of polyacetal.
1959	Production of acetal (Delrin™) and polycarbonate (Makrolon™).
1960's	Development of lyotropic LCP films and spun fibers (aramid fibers).
1960's	Introduction of aromatic polyester (Ekonol™) for plasma coating.
1963	Introduction of polyimides (Polymer SP™).
1964	Production of PPO components for appliances, electrical connectors.
1965	Commercial use of polysulfone (Udel™) for electrical components.
1966	Modified PPO introduced as Noryl™, cheaper and easier to process than PPO.
1967	Polyarylsulfone introduced as Astrel 360™.
1968	Polyphenylene sulfide (PPS) introduced as Ryton™.
1972	Polyethersulfone (Victrex™) used in aerospace and automotive applications.
1973	Introduction of Kevlar™ aramid fibers.
1970's	Introduction of Rynite™, a very rigid PET. Blow molding of PET bottles became popular.
1977	Commercial production of linear low-density polyethylene (LLDPE). Polyphenylsulfone (Radel™).
1978	ICI first markets PEEK, a high-temperature resistant material used in aerospace and computer applications.
1982	Modified polyimide (polyether-imide) introduced (Ultem™) for use in high-performance fiber-optic components, coextruded food packaging, and advanced composites.
1984	Thermotropic (melt-processible) liquid crystal polymers (LCP) introduced (Xydar™) consumed mainly by Tupperware.

ber-forming polyesters were developed in 1941, as was polyethylene terephthalate (PET). The 1950's saw the first commercial production of PET as Dacron™, development of polypropylene, polycarbonate, high-density polyethylene (HDPE), and polyphenylene oxide (PPO). During the 1960's, aromatic polyesters were introduced and the first spun fibers or aramid fibers were developed. Polyimides were introduced, and from them, a whole family of polymers emerged. Several new polymers were introduced during the 1970's. Kevlar, an aromatic polyamide (aramid fiber), became available in 1973, and a modification to PET in the late 1970's made it a popular choice for the blow-molding of beverage bottles. Polyetheretherketone (PEEK), first marketed in 1978, is one example of the newer, high-performance, high-cost polymers that have found applications in the aerospace and computer industries, where high cost is less of a consideration.

The 1980's have seen the introduction of a new melt-processible liquid crystal polymer known as Xydar™ (Dartco Manufacturing Co., 1984) and the development of new technologies for alloying and blending old polymers to meet specific engineering criteria. Recent developments and trends suggest that many of the "new" polymers will result from future research efforts into the areas of processing and fabrication technologies rather than into the discovery of additional "new" polymers.

As can be seen from table 5, there is often a significant time lag from discovery of a polymer to commercial production of a product. The 12-year lag from discovery in 1938 to wide-scale commercial production of Teflon™ (PTFE) in 1950, for example, brings up a very important point in the historic development of the polymers industry. Discovering a new polymer does not necessarily lead to its development or commercialization.

Although the science of polymerization has come a long way in defining how molecules can be engineered to meet specific criteria, development of new polymers into commercially acceptable products can be a lengthy process. Aside from finding new uses for a new polymer, there are patents to consider, processes to be worked out for the large-scale manufacture of the polymer, and cost-effective fabrication methods to be developed. In addition, safety factors and standards have to be met, and in some cases, licenses may need to be issued (such as the Food and Drug Administration's approval for medical uses) before a new product can be introduced into the market. The whole process involves a number of disciplines working together and can take years, even decades, to accomplish. It also costs large sums of money, and that limits the number of participants interested in actively developing new polymers.

Definitions, Grades, and Specifications.—Polymers can be classified according to the structural shape of the polymer molecules. They can be either linear, branched, or cross-linked. Linear polymers have repeating units linked together in a continuous length. When branches protrude from the main polymer chain at irregular intervals, the polymer is termed a branched polymer. Both linear and branched polymers are thermoplastics. They can be softened and hardened by heating and cooling. Fabricating processes like injection molding, casting, and blowing take advantage of this feature to shape thermoplastic resins. The rigidity of thermoplastic resins at low temperatures is attributed to the existence of secondary bond forces between the polymer chains. These bonds lose strength or are destroyed at higher temperatures, thereby causing fluidity of the resin.

Polymers used as textile fibers are linear. However, they must be of high molecular weight and have a permanent orientation of the molecules parallel to the fiber axis. The chain orientation necessary to develop sufficient strength by crystallization is achieved in the melt during spinning and then by a process known as cold drawing, in which the initially formed filaments are drawn (stretched and further oriented) at a temperature above the glass transition temperature, Tg. (Tg is the temperature at which sufficient energy is available to the molecular segments to cause them to begin to rotate and materials become soft and rubbery.)

Elastomeric materials, like thermoplastic resins and fibers, are essentially linear polymers. Certain distinctive features in their molecular structures make them rubbery. Because their Tg's are below room temperature, they can be stretched to twice their original length and then can return essentially to their original shape when tension is relaxed.

Polymers or resins that are transformed into a cross-linked product, and thus take on a "set" on heating, are said to be thermosets. Cold flow between molecules can be prevented by cross-links between polymer chains. The structure of polymer chains present in the cross-linked polymers is similar to the wire structure in a bedspring, so chain mobility, which permits one chain to slip by another (cold flow), is prevented. Natural rubber, for example, is a sticky product with no cross linking, and its polymer chains undergo unrestricted slippage. The product has limited use. However, when natural rubber is heated with sulfur, cross linking takes place. Cross linking by sulfur at about 5% of the possible sites gives rubber enough mechanical stability to be used in automobile tires but still enables it to retain flexibility. Introducing more sulfur introduces more cross-links and makes rubber inflexible and hard.

Cross linking is an important process in polymer technology. A high degree of cross linking gives rise to three-dimensional or space network polymers in which all polymer chains are linked to form one giant molecule. Thus, instead of being composed of discrete molecules, a piece of highly cross-linked polymer constitutes just one molecule. At high degrees of cross linking, polymers acquire rigidity, dimensional stability, and resistance to heat and chemicals. Because of their network structure, such polymers cannot be dissolved in solvents and cannot be softened by heat. Strong heating only causes decomposition. Quite commonly, these materials are prepared, by intent, in only partially polymerized states (prepolymers), so that they may be deformed in the heated mold and then hardened by curing (cross linking).

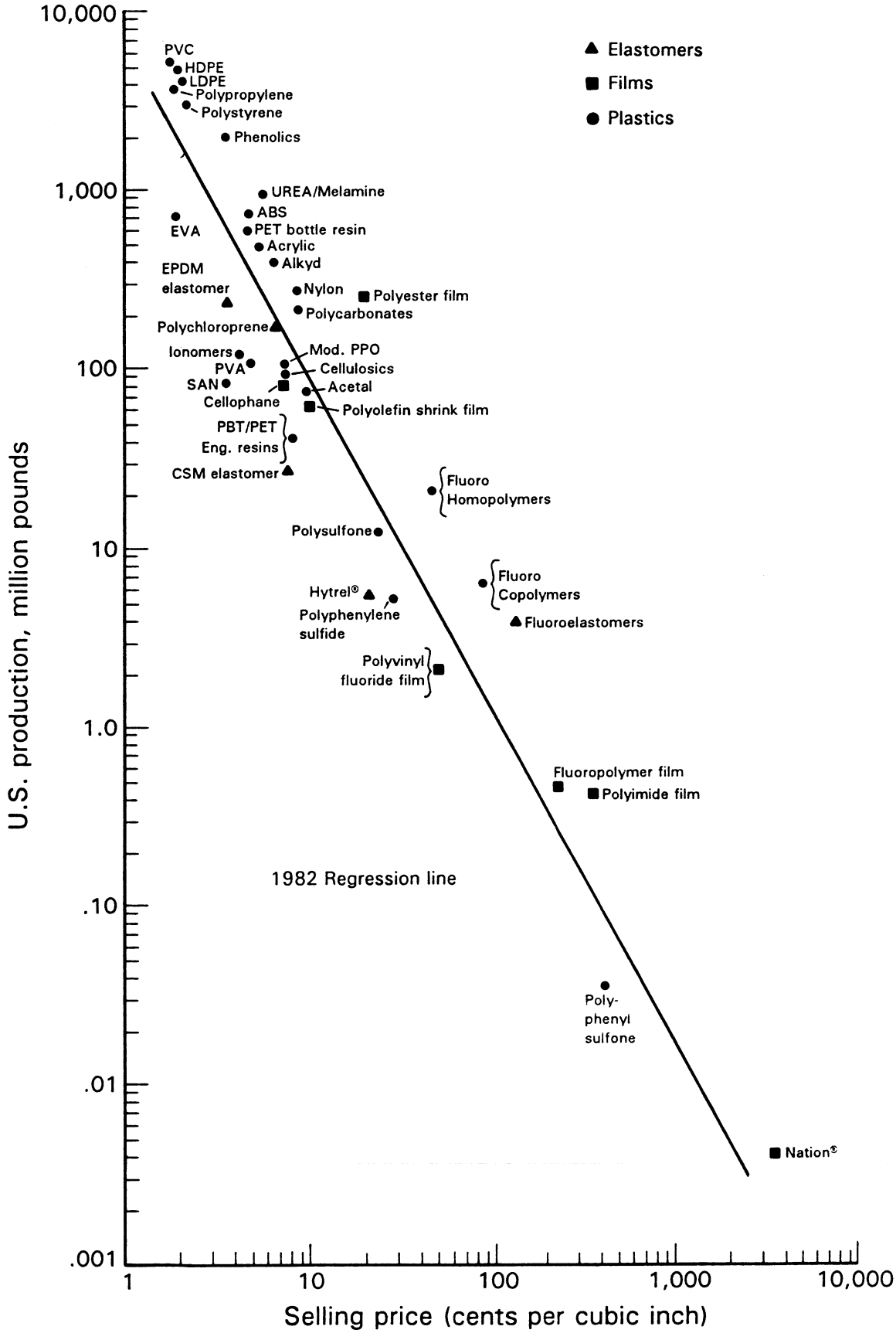
Polymers generally fall into three major categories: commodity, engineering, and high-performance materials, based on price, volume, and usage of the product. Figure 5 plots 1982 U.S. production versus selling price (October 1982) for a wide range of polymeric materials. The grouping of materials in these categories can be recognized fairly easily in this illustration. As production levels decrease, prices increase along the regression line provided.

Commodity materials are the high-volume, low-cost materials that are easily processible. Examples include polyvinyl chloride (PVC), low-density polyethylene (LDPE), HDPE, and polypropylene (PP). Some classifiers place ABS in the commodity grouping, but it also finds usage in engineering applications.

Included in the engineering group are polyamides (nylons), polyacetals, polycarbonates (PC), modified PPO, PET, and polybutylene terephthalate (PBT). These materials are the intermediate grouping in terms of production volume, material costs,

FIGURE 5

PLOT OF U.S. POLYMER PRODUCTION IN 1982 VERSUS THE SELLING PRICE IN OCTOBER 1982



D. R. Rea, Du Pont Company, 1987

and processibility. Engineering polymers have inherent characteristics that make them suitable in areas replacing metals or glass-ceramics. Properties of engineering polymers include good heat resistance, strength, durability, resistance to chemicals and weathering, and good electrical properties (either conductive or insulating).

High-performance materials include polymeric resins and reinforced resins and composites used in more specialized or demanding environments. These materials have a very low production volume relative to the other polymers and a high to very high price, with prices in the hundreds or even thousands of dollars per pound. The polymerization process for high-performance materials is complex, and fabrication is difficult because of their high melting point or even lack of a true melting point. These materials have exceptional resistance to heat, hostile environments, and chemicals; outstanding strength; and good optical, lubricity, and electrical properties. Polymers included in this classification are polyphenylene sulfide (PPS), polysulfones, polyether-imides (PEI), polyamide-imide (PAI), polyimides, polyetheretherketone (PEEK), fluoroplastics, liquid crystal polymers (LCP), and the aromatic polyamides, polyesters and copolymers.

Products for Trade and Industry.—Plastics were initially produced from natural renewable organic materials (such as wood or cotton) or from coal products. Today, petroleum and natural gas are the principal feedstocks used to make a large variety of resins that can be further processed into many different kinds of finished products.

The transportation industry is a continually changing arena of material choices, where lighter, stronger, and less expensive materials are always being sought. The growing importance of plastics in the automobile industry reflects the broadened scope of the material selection process and the desire to make cars lighter and more fuel efficient. In 1988, roughly 11 1/2 million automobiles and light trucks were produced in the United States and Canada. At approximately 210 pounds of plastics per car and 170 pounds per truck, plastics as applied to automobiles and light trucks in 1988 accounted for 2 billion pounds or 3% to 4% of the total plastics produced. Approximately 20% of the plastics used in transportation are enginering polymers. The range for future growth opportunities is shown by experimental applications like the prototype plastic engine, which has been tested in a series of sanctioned road races.[26]

Another area in which plastics play a major role is packaging. Nearly everything is packaged in some manner prior to delivery. Packaging improves product handling and shipping, offers protection, reduces waste, and aids in identification and inventory. The variety of materials used in packaging has remained fairly constant; however, the proportion of each material used has changed dramatically within the past decade. Currently, these materials include wood, glass, steel, aluminum, paper, and plastic. Plastic is now the predominant material in some sectors of the packaging market and a strong competitor in other sectors. From its inception in the 1950's, plastic packaging has now become the largest single market for plastic use, consuming about 25% of all U.S. plastic production in 1988 and accounting for annual revenues of about $70 billion. Approximately 50% of all current packaging applications did not exist 10 years ago. This growth is the result of penetration into existing markets at the expense of other materials and the development of new applications not achievable by other materials. Sales growth in packaging lagged overall growth in plastics slightly; however, the recent introduction of plastic grocery bags is a highly visible illustration that the penetration of plastics into this market is not over.

Plastic products have also made significant inroads in the building and construction industry. Plastics made their first substantial penetration into the building and construction industry in pipe applications but are also advancing into other areas with products such as flooring, siding, window profiles, lighting fixtures, insulation, and many others. Since 1970, construction has been the strongest growth market for plastics. New application studies like General Electric's prototype all-plastic house[27] indicate that a wide variety of opportunities exist for future sales growth.

Highlights of U.S. resin sales in the construction, transportation, packaging (including nonpackaging film), and other markets are shown in figure 6.[28]

Construction increased its share from 11% of the total in 1970 to 18% in 1990. The primary growth areas within this market are in pipe, fittings, and conduit, which used more plastic (37% in 1990) than any other construction application.

Packaging and nonpackaging film decreased its share from 32% of the total in 1970 to 30% in 1990. The primary growth areas within this market are in containers (about one-half of all packaging applications), t-shirt bags (grocery bags), and trash bags.

Transportation increased its share from 2.7% of the total in 1970 to about 3.0% in 1990.

The "other" category encompasses a myriad of other applications and decreased its share from 54% of the total in 1970 to 49% in 1990.

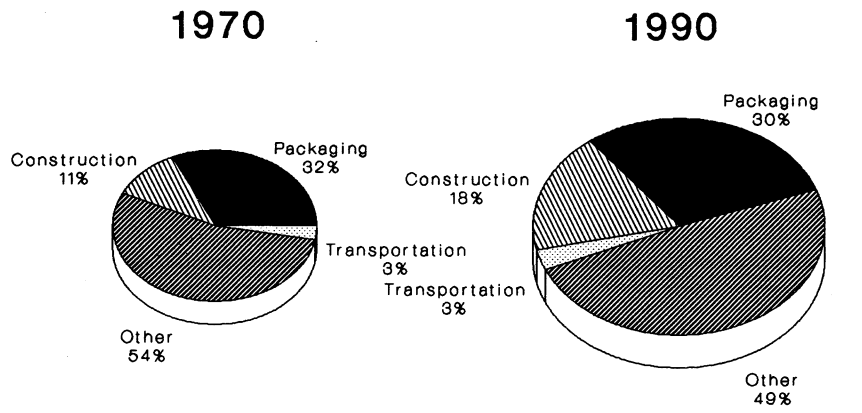
Industry Structure.—Most of the domestically produced resins are produced by a relatively small number of large companies. For example, PE, the largest resin category, has 18 producers, but the top four companies have more than 50% of nameplate capacity. ABS has only three domestic producers. PVC has 12 domestic producers, but the top 4 account for 66% of capacity. PP has 14 domestic producers, and the top 4 account for 59% of total capacity. PS has 14, 63% from the top 4. Table 6 lists the domestic production capacity of polyethylene, polypropylene, polystyrene, and polyvinyl chloride, along with the capacity utilization rates for each of the past 5 years.

In contrast to the relatively high degree of concentration among resin producers, there are a very large number of companies that consume plastic resins. A survey taken by Plastics News at midyear 1990 profiled the injection molding industry, the most widely used plastics fabrication technology.[29] (The extrusion process accounts for more resin usage, but has far fewer facilities.) This survey confirmed some long-held rules of thumb about plastics use in general. That is, a large part of the resin usage is accounted for by a small number of the firms. The survey identified the top 50 injection molders in the United States. Together they account for almost 1 billion pounds of injection molded resin products, valued at about $4 billion. Another survey[30] taken in 1986 identified almost 8,000 businesses engaged in injection molding, and recent data show more than 5 billion pounds of resins processed by injection molding methods. That is, 15% to 20% of all injection molding business is performed by less than 1% of the firms engaged in that business.

The top 5, and 14 of the top 20, injection molders were engaged exclusively or in large part in supplying the automotive industry. All of them had more than one plant and injection molding-related employment levels between 500 and 2,300 persons. Most

FIGURE 6

U.S. RESIN SALES, BY END-USE MARKET



Sources: Society of the Plastics Industry, Inc. and Modern Plastics.

of the businesses supplied plastic products to more than 1 industry, but 14 of the 50 were engaged in a single industry; 9 to automotive, 3 to packaging, and 1 each to electronics and construction.

Table 7 gives information on the number of U.S. plants engaged in fabrication of plastics using one or more primary processes. This information indicates that injection molding is the most prevalent method of fabrication, followed by extrusion. As seen by this and figure 7, the structure of the plastics processing sector is such that more than 50% of fabrication is performed by captive plants.

When the plastics industry is looked at from a perspective of how much resin is processed using each of the major technologies, a somewhat different pattern emerges. Table 8 shows that even though injection molding accounts for the largest number of operations (see table 7), extrusion is the dominant technology in terms of the amount of resin processed. More than 40% of all resins are extruded, about four times the amount processed with injection molding machinery. Blow molding is the third largest technology used, accounting for more than 8% of total resins. A principal reason for this division is that extrusion machinery can create simple shapes, such as pipes and profiles, at a very high throughput rate and very low costs. Injection molding is a very versatile processing technique, but is not a continuous process. Parts can be molded singly or even in multiple numbers relatively cheaply, but each cycle requires a mold fill, cooling, and ejection of the part before the next cycle can begin.

Table 8 also shows that the resin quantities processed by injection molding, extrusion, and blow molding has increased over the past 20 years. For all of these methods, the machinery has improved steadily over that period, becoming more automated, more highly controlled for quality, and the final products less costly to fabricate relative to other processing methods. In combination, these three low-cost fabrication technologies have grown in importance steadily over the period shown.

There are a large number of planned new U.S. facilities for the major resins. In polyethylene, Quantum Chemical Corp. is planning startup of a 200-million-pound facility at Deer Park, TX, in late 1991; Chevron Chemical Co. is planning a new 300-million-pound facility at Orange, TX; and Eastman Chemical Products, Inc. is adding 220 million pounds of new capacity at Longview, TX. Formosa Plastics is con-

TABLE 6

U.S. PRODUCTION CAPACITY, SELECTED RESINS

(Thousand metric tons)

Resin	1986	1987	1988	1989	1990
Polyethylene:					
Capacity	7,887	8,486	9,076	9,534	10,880
Percent utilization	92.5	95.1	94.0	84.7	80.4
Polypropylene:					
Capacity	2,795	3,114	3,622	4,021	4,191
Utilization rate	94.3	96.9	91.1	81.6	88.0
Polystyrene:					
Capacity	2,351	2,368	2,587	2,740	2,903
Utilization rate	86.3	91.6	91.0	84.5	80.2
Polyvinyl chloride:					
Capacity	3,645	3,780	4,040	4,213	4,760
Utilization rate	90.3	95.6	93.8	91.3	88.6

Sources: Society of the Plastics Industry, Inc., Facts & Figures 1990, and Modern Plastics.

TABLE 7

PLASTICS FABRICATION BY PROCESS AND TYPE OF PROCESSOR

Process	Total[1]	Percent of total		
		Captive	Custom	Supplier
Blow molding	1,503	52	43	5
Calendering	491	66	23	11
Compression-transfer molding	1,518	67	28	5
Extrusion	4,893	54	37	9
Foam processing	3,356	57	38	5
Injection molding	7,817	52	45	3
Reinforced processing	2,819	63	33	4
RIM	385	61	29	10
Rotational molding	553	55	39	6
Thermoforming	2,273	57	40	3
Total	25,588	NA	NA	NA

NA Not applicable.
[1]Plants engaged in one or more primary processes.
Source: Rauch Associates, Inc.

TABLE 8

PROCESSING OF PLASTICS, BY PRINCIPAL METHODS

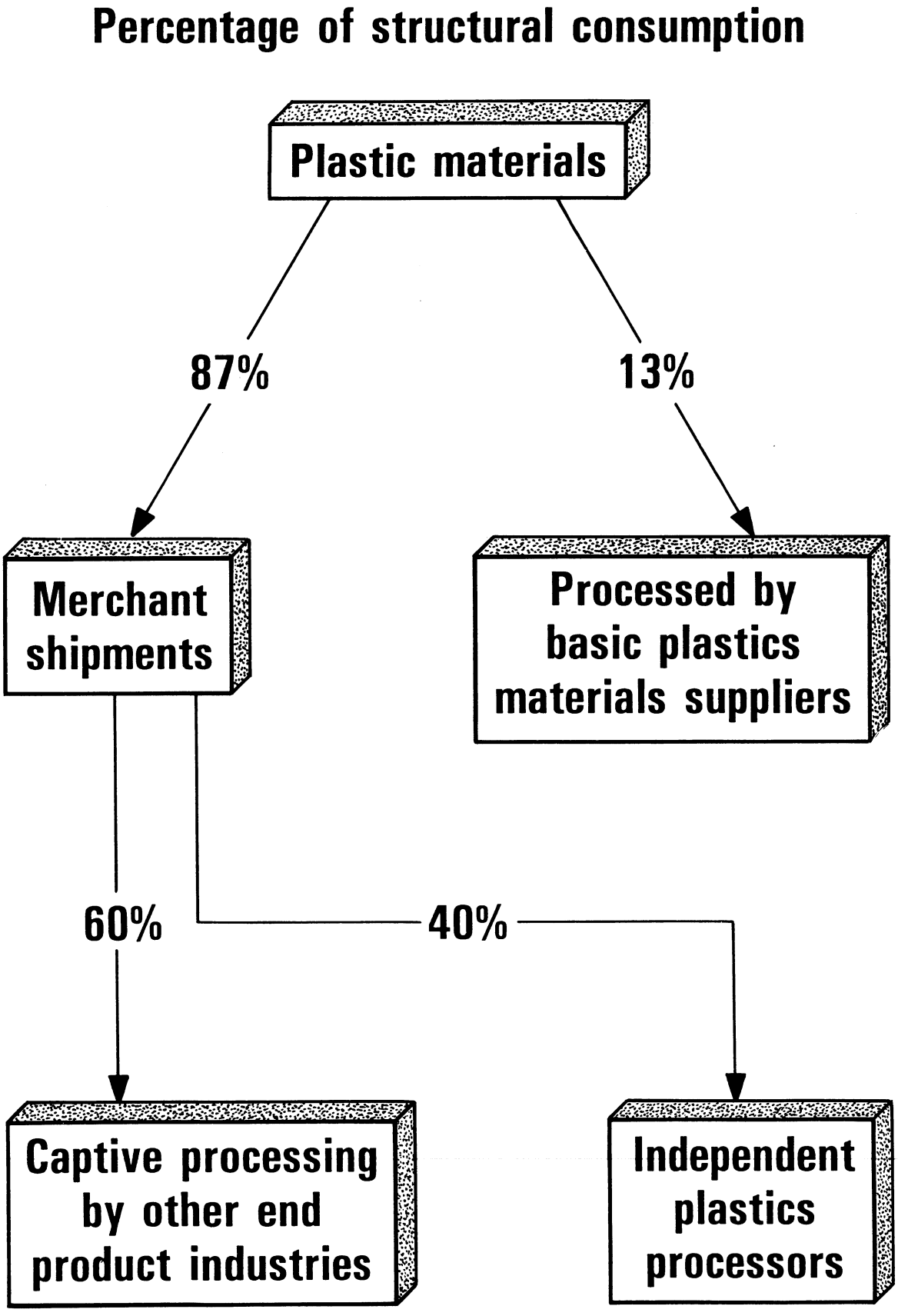
(Thousand metric tons)

Year	Extrusion		Blow molding		Injection molding		Total sales
	Weight	Percent	Weight	Percent	Weight	Percent	Weight
1970	2,337	27.7	400	4.7	645	7.7	8,434
1975	2,985	28.0	470	4.4	817	7.7	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

Source: Modern Plastics.

FIGURE 7

STRUCTURE OF THE PLASTICS PROCESSING SECTOR



Rauch Associates, Inc.

structing a 1.5-billion-pound olefins plant at Point Comfort, TX, and expects new capacity for both HDPE and LDPE in 1992. Debottlenecking could add another 400-million-pound capacity in 1991 and 1992 at facilities owned by Union Carbide Corp., Dow Chemical U.S.A., Chevron Chemical Co., Eastman Chemical Co., and E. I. du Pont de Nemours & Co. In addition, capacity to replace the 1.6-billion-pound Phillips 66 Co. plant in Pasadena, TX, which was destroyed in late 1989, is being added in three 600-million-pound installments, the first due early in 1991, the second in mid-1991, and the last in mid-1992.

New polypropylene capacity additions are planned in 1991 by Himont U.S.A. (175 million pounds at Bayport, TX), Eastman Chemical Products, Inc. (220 million pounds at Longview, TX), and Epsilon (265 million pounds at Marcus Hook, PA). New polystyrene capacity is planned by Mobil Chemical Co. (120 million pounds at Joliet, IL), and Kama (15 million pounds at Hazelton, PA). New polyvinyl chloride capacity is planned by Formosa Plastics (800 million pounds at Baton Rouge, LA) and Vista Chemicals (50 million pounds at Aberdeen, MA).

***Technology.*—Processing.**—Products with good performance characteristics can often be produced at low cost with flexible, high-volume, automated methods such as extrusion, blow molding, and injection molding. Those resins that are best suited to these high-volume methods are likely to continue to grow in importance.

Fabrication processes for the thermoplastic and thermoset classifications of plastics take advantage of the chemical differences between the two, although progress in technology has lessened the effective, if not chemical, distinction between them. Thermoplastic resins may be processed hot, cooled, and then reheated and reprocessed, while thermosetting resins cross link in processing and cannot be reheated and used again.

Common thermoplastics include ABS, PVC, SAN, acetals, acrylics, cellulosics, polyethylenes, polypropylenes, polystyrenes, polycarbonates, polyesters, nylons, and fluoropolymers. The most important processing techniques for thermoplastics are injection molding, extrusion, and blow molding. Other processes include thermoforming, casting, rotational molding, calendering, and spinning.

The common thermoset resins include phenolics, ureas, melamines, epoxies, alkyds, unsaturated polyesters, silicones, and urethanes. The most common processing methods are compression and transfer molding, but thermosetting resins are also processed using reaction injection molding (RIM) techniques, pultrusion, casting, and foaming processes.

The machinery used to process plastics comes from suppliers in a large number of countries. In Western Europe, the Federal Republic of Germany, Italy, and the United Kingdom have large machinery sectors and export a large percentage of what they produce. In Asia, Japan is by far the leading producer of plastics processing machinery. In North America, the United States produces the largest number of machines, but Canada has a surprisingly robust machinery industry. Table 9 shows the numbers of plastic fabrication machines sold into the U.S. market.

Domestic machinery manufacturers felt the effects of the economic slowdown, the injection molding sector much stronger than the extrusion sector. Domestic shipments decreased by 19% from the 1989 level. The biggest fall occurred in the large markets for medium-sized machines, those with clamping forces of 100 to 400 tons. The market for domestically produced machines with clamping force more than 600 tons actually increased slightly. The number of imported injection molding machines dropped from 1989 levels as well, but only by about 8%. The largest part of this decline was for machines built in Europe, imports from which declined 17%. The percentage of the total market was, therefore, more heavily weighted toward imports.

The total number of extrusion machines sold in the United States in 1990 actually went up slightly, although all of the gain was accounted for by increased imports. Domestic shipments of machinery dropped for the second year in a row. The sharpest drop was in the 5.5- to 7.5-inch category, while the largest gain was in the 1.25- to 2-inch range. The Federal Republic of Germany is the largest supplier of machinery to the United States, more so for extrusion machinery. Japan is the second largest supplier, and actually accounts for the largest share of injection molding machinery. Canada also accounts for a significant proportion of machinery imports in both categories.

Recycling.—The present concern with solid waste disposal due to the lack of landfill space coupled with plastics high volume-to-weight ratio and low degradability has caused State and local legislatures to consider plastics banning laws or "use tax" legislation. The industry has reacted to this pressure by forming organizations such as The Council For Solid Waste Solutions and The Vinyl Institute to promote solutions to the plastics disposal problem.

Recycling is one viable alternative for a portion of the waste currently being lost to landfills. Several major companies, such as B.F. Goodrich and GE Plastics, have initiated buyback programs for their materials. Others, like Du Pont and Goodyear, have set up purchasing policies that favor the use of recycled materials in the industrial products they buy, such as pallets or industrial strapping.

TABLE 9

U.S. PLASTICS PROCESSING MACHINERY SALES

(Number of units)

	1989		1990	
	Quantity	Percent	Quantity	Percent
Injection molding machines:				
U.S. made	2,197	45	1,770	42
Imported	2,696	55	2,467	58
Total	4,893	100	4,237	100
Extrusion machines:				
U.S. made	1,021	58	1,007	57
Imported	731	42	775	43
Total	1,752	100	1,782	100

Sources: U.S. Department of Commerce, Society of the Plastics Industry, Inc., and European Plastics News.

Recycling can be primary, secondary, tertiary, or quaternary in form. In primary recycling, materials can be reprocessed into products with chemical and physical characteristics similar to the original product. In secondary recycling, materials can be processed into products with less demanding characteristics than the original product. In tertiary recycling, materials can be processed into fuels or basic chemicals; and in quaternary recycling, materials can be incinerated for heat-power recovery. Each of these options has its proponents and opponents and perhaps each has its own value within any given set of circumstances. Not all resins can fit all the options, and even when a form of recycling is possible, it may not be economically feasible.

In the area of reprocessing plastics, there are five basic types of technologies in use for recycling. These include separation, mixed-plastics, PET recycling, washing-upgrading, and other technologies. Separation technologies mechanically segregate distinct resins from a mixed plastic source, while mixed-plastic technologies use the mixed-plastic stream as is. PET recycling technologies are used for soft-drink bottles only, washing-upgrading technologies for previously sorted plastics such as HDPE dairy bottles, and other technologies now under development.

One separation technology currently in use for a mixed stream of plastics uses the different densities to separate the lighter polyolefins (PE and PP) from heavier resins to form pellets that can be marketed to molders. The pellets run about 95% PE and 5% PP. The heavy fraction that is screened out by polyolefin separation (PET, PVC, PS, and ABS) can become part of the feedstock for mixed-plastic technologies that take various mixtures of material and form them into plastic lumber and other products. The mixed plastic method requires a high percentage of polyolefins, which can include plastic bags. It softens the material by internal friction, then forces it into molds where the heavier and most incompatible plastics tend to settle at the center of the piece.[31]

Because plastics have a high susceptibility to heat, the high temperatures needed to fully sterilize the material may either degrade it or burn it. Therefore, recycled food-contact plastic packages cannot be guaranteed to meet FDA safety standards and are not made back into food packages. While this removes a considerable market for recycled materials, there is a large market for containers for nonfood items like antifreeze, laundry detergent, and motor oil.

As an alternative to recycling plastics, various technologies are being developed to make plastics degradable, thereby reducing their impact on the waste stream. However, additives that facilitate degradability tend to reduce engineering characteristics and to reduce the reliability and adaptability of products. There is also some concern with the chemicals that form when plastics degrade and whether they might contribute to ground water contamination or methane production in landfills.

Several companies are developing additives that combine cornstarch and an oxidizing agent to be mixed with plastic resins. The oxidizing agents react with metal salts in the soil, and the links between polymers are destroyed. At the same time, bacteria can feed on the cornstarch. Over about 15 years, the polymers eventually break down into fragments that are small enough to be eaten by micro-organisms. However, the guarantee of direct soil contact may be elusive due to the nonideal implementation of landfills in actual practice. Another degradable material is being tested by Exxon Chemical.[32] In its process, iron and nickel compounds are added to the polymer and aid in its degradation.

Another area of degradability is photodegradable plastics. Dow is a big producer of photodegradable connector rings for beverage six-packs. Here is an instance where degradability rapidly realizes its potential for injury to animals and birds who may become entangled in or grow into one of the rings much as a tree grows into a piece of wire wrapped around the tree. Other companies are producing bags and other packaging materials that are photodegradable also. Depending on the amount of ultraviolet light needed to initiate degradation, a major problem with photodegradable materials is that once they are landfilled, they cannot be further exposed, and degradation may be limited.

Degradable plastics are of major interest in agriculture, where they are used as mulch films to retain moisture on arable land.[33] Nondegradable films were difficult to collect at the end of a growing season and could not be used again because it was too difficult to separate out the plant stubble. Photodegradable films break into flakes and can easily be plowed back into the soil.

Research is ongoing in uses for plastics that dissolve in special alkalies or acids.[34] Dissolved plastics can be precipitated and reused. Uses for this type of materials include adhesives for bottle labels, tie layers in a multilayer structure, and lost-core cavity moldings.

Imperial Chemical is testing a natural plastic produced by a type of bacteria found in the soil.[35] The plastic is produced by the bacteria much in the same way humans store fat as a future source of energy. The plastic is similar in appearance and texture to petroleum-base polymers and it decomposes into water and carbon dioxide. Decomposition is precipitated by certain enzymes found in the soil. The cost of manufacturing this material is prohibitive at this time. Costs are estimated at $15 per pound compared with $0.65 per pound for conventional plastics.[36]

The plastic component of the waste stream is steadily growing. Current estimates suggest that between 5% and 9%, by weight, of municipal solid waste is made up of plastic. According to information cited in the Plastics Recycling Action Plan for Massachusetts, estimated national plastic discards are about 7.9% for 1988 and projected to be 9.8% by the year 2000.[37]

An even bigger issue in the disposal of plastics is that the volume taken up by plastics is much greater than its weight. Estimates from various sources indicate that while 5% to 9% of the solid waste stream is plastic by weight, those same plastics may be taking up to 25% to 30% of the space by volume.[38] Plastics are light, and in the case of formed shapes, bottles, etc., they take up a certain amount of air space also. Plastics tend to return to their original shape after crushing and thus would need to be shredded to make the most effective use of space.

Waste-to-energy incineration involves segregating plastics from other solid wastes and converting them to pellets prior to burning as a primary fuel. These types of facilities are generally operating on a small scale presently, such as on college campuses, hospitals, municipal buildings, and office and industrial parks.

Plastics have four times the fuel value of the average mix of municipal solid waste and the same value as residual fuel oil. According to Mobil Chemical Co., which is analyzing the industry and its potential, plastic fuel pellets have twice the fuel value of Wyoming coal.[39] Problems with incineration include the potential for production of dioxin as a byproduct of incinerated PVC, other air and water pollution issues concerned with the burning of plastics, and disposal of the resulting ash.

Substitutes.—Intermaterial competition is ongoing all the time, with attempts to

bring to the market new materials with superior properties at low prices. Traditional metal markets have often borne the brunt of attacks from newer materials such as polymers, but just as intense is competition between resins. Much of the blending, alloying, and reinforcing activity in the polymers industry is an approach to minimizing the cost of bringing a new resin to market. A Du Pont executive was quoted as saying his company's approach is to "extend the envelope of nylons, acetals, and polyesters," all workhorse resins for this company.

Polymeric materials are being substituted for glass, ceramics, metals, and paper in many applications. As polymers with improved physical properties are developed, substitution for other polymers also occurs. Everything from microwave food packaging, with its multiple layers with barrier properties, to sporting goods, to automobile bumpers, to satellites and aircraft are now made with polymeric materials. Some areas of substitution encourage new product development by the polymer users such as food packaging. Others improve product durability and provide weight savings and/or cost savings.

Since the development of synthetic fibers, about 1940, structural applications of polymers have increased, and engineering plastics of great strength and durability have replaced metals in many applications.[40] Recent advances in the understanding of materials design has led to designing highly engineered multicomponent systems based on the special characteristics of polymers. In the past, many applications of polymers failed because the parts were simply made to look just like the metal parts they were replacing. This did not take advantage of the physical properties of polymers or take into consideration their limitations. Using designs intended for metal often resulted in poor performance and failure. As designers have learned to better utilize the unique properties of various polymers, the development of polymeric materials suitable for critical load-bearing applications has accelerated.

Plastics have advantages over metal in that they do not rust or corrode the way metals do. They may be less expensive on a volume basis than some metals, have specific strength equivalent to or greater than most metals, be easier to fabricate, be adaptable to a single-part fabrication of a multifunction component, and require less energy to produce. Polymeric materials are produced from hydrocarbon feedstocks. However, the production of polymers uses far less energy than that consumed as a fuel in the production of most metals. The amount of energy contained in the feedstock materials for polymers is also low, and so the total amount of energy used to produce a given volume of structural materials is significantly less for plastics than for metal.[41]

Substitution is encouraged not only by improved function, but by cost savings as well. Because polymeric materials and composites are generally lighter than the materials they are replacing, advantages in areas such as materials-product-shipping costs may be critical in the decision to switch from glass or metal to plastic. Lighter automobiles and aircraft have lower fuel requirements and, thus, are more cost effective. One manufacturer announced that an all-composite aircraft of its design resulted in a 2.5-fold improvement in fuel usage and a 60% increase in range over that of a comparable, but heavier, aluminum aircraft.[42]

Consolidation of multiple parts to a single part is another potential cost-saving aspect of materials substitution. One estimate of the assembly advantages of an all-composite aircraft includes a fivefold decrease in the number of airframe parts and a twelvefold decrease in the number of fasteners used in assembly.[43] The simplified fabrication allowed with consolidation is, in and of itself, an advantage over other conventional (metal) materials.

Economic Factors.—Prices for plastic resins in 1990 were affected by the August invasion of Kuwait by Iraq. The effects, however, were not as immediate as they were on the price of crude oil, nor were they as severe. Increases in prices for virgin resins were generally on the order of 10% to 15% or less over preinvasion levels, as shown in table 10. For some of the commodity-grade resins, particularly the polyethylenes, price ranges cited in the literature tended to widen near the end of the year. Typical was the price for injection-grade HDPE, which started the year with large-volume prices near 40 cents per pound. A softening of price occurred at midyear, generally attributed to competitive price cutting, leading to prices near 39 cents per pound in July. By October, HDPE was selling in large volumes for 41 to 43 cents per pound and continued to strengthen to close the year in the 45 to 48 cents per pound range.

Prices for recycled plastics showed a different pattern. Both PET and HDPE, by far the largest volume of recycled resins traded, suffered from the general weakening of prices at midyear and rebounded to near January levels just prior to the invasion. Both PET and HDPE recycled flake and regrind prices were maintained at early August levels through the end of the year, but no further increases occurred. The price for recycled PVC stayed unchanged all year, while recycled polypropylene prices rose slightly subsequent to the invasion.

Annual Review

Legislation and Government Programs.—There were a number of moves by governments at various levels to affect materials disposal or materials use, especially for packaging. One very controversial proposal was a bill introduced in Congress to tax virgin materials so as to encourage the use of recycled materials. Though the bill did not gain widespread support, it reflected the tone of many State

TABLE 10

PLASTIC PRICES

(Cents per pound)

	January 1990	July 1990	December 1990
HDPE, injection molding	40	39.50	45-48
HDPE, recycled, natural	35-40	23-35	30-33
LDPE, liner grade	52	39	45
PET recycled, clear	33-37	31-35	35-36
Polypropylene	34	36.50	43-47
Polypropylene, recycled	13-18	13-18	16-26
Polystyrene	47	47.50	56-58
Polyvinyl chloride	34	36.50	37
PVC, recycled	18-22	18-22	18-22

Sources: Plastics World and Plastics News.

and local legislatures. On a positive note, the FDA approved the use of recycled PS as a material for egg cartons.

Another significant move related to materials recycling occurred in December when President Bush blocked an Environmental Protection Agency regulation just days before it was to become law. Part of a broader regulation on incinerators would have tied together recycling and waste-to-energy issues by requiring removal of 25% of recyclable garbage before burning. While the general goals of greater recycling were not disputed, the objections of State and local government operators of such facilities cited the lack of definition of which materials were to be considered recyclable and the level of responsibility this provision would have given them for recycling.

Several States passed legislation during the year related to banning some plastic materials, forcing the use of recycled materials, or limiting which materials would be allowed into municipal landfills. Several other States were in court attempting to have similar laws passed in previous years upheld. A ban on PS packaging in Portland, OR, was upheld. A more extensive law in Suffolk County, NY, remained under litigation. Wisconsin passed a wide-ranging law focused on the recycling of containers, especially plastics, and banning certain materials, including tires and plastic containers, from landfills. A Massachusetts ballot initiative that will require a recycled content in packaging materials and packaging materials to be recyclable was passed. New Haven, CT, and Berkeley, CA, passed bans on PS foam packaging. Howell, NJ, passed a law that will require a 60% recycle rate for packaging materials.

In Europe, several countries made moves toward banning PVC as a material for containers, but the European Community came out publicly opposed to individual country bans on materials. The concerns focused on potential dangers from the leaching of additives, plasticizers, and heavy-metal colorants. Also cited was a concern over the environmental effects of a chlorine-containing material going into incinerators, a waste disposal technology that is more widespread in Europe than in the United States. Switzerland was the only country to pass an outright ban—on PVC soda bottles.

The effects of last year's Montreal Protocol agreement on the reduction of chlorofluorocarbons (CFC's) was also felt in the polymers industry. Major uses are as a blowing agent for PS and rigid urethane insulation foam and as a cleaning solvent. Adequate substitutes have been found for CFC's usage as a PS foam blowing agent, and its use in that area is nearly completely gone. Some substitutes or alternative technologies exist for insulation foam and solvents, but there are cost and/or performance penalties to this substitution.

A preliminary ruling came in November from the U.S. Department of Commerce assessing penalties against Japanese and South Korean producers of PET film for dumping in the U.S. market. The suit had been filed in the spring by U.S. film producers.

Issues.—Plastics were under attack on a variety of environmental fronts during the year, many of them related to growing public concern with materials recycling and landfill disposal. Several companies introduced resins or products that were said to degrade. Controversy over the definition of degradability and whether this was true under normal landfill conditions led many of the companies involved to withdraw these claims, except for specialized products. Degradable resins are being used as pharmaceutical gelatin capsules, for example, and were mandated in several States for use in six-pack rings for beer and soft drinks. By the end of the year, there were 35 States and many localities that had degradability requirements written into law.

Another visible area related to degradability was disposable diapers, viewed as a materials issue where plastics compete with cloth. Disposable diapers are thought to make up approximately 2% of municipal waste streams. Two potential solutions were offered on a small scale during the year; degradable diapers made from starch-based polymers and compostable diapers that necessitate a materials switch from PE liners to a starch-based product. Both experiments are likely to be continued into the next year.

Recycling was also an important area where a large amount of activity was occurring. The development and spread of technology and machinery for recycling organic materials was strong. Likewise, there were some major developments in new products utilizing recycled resins. For example, a number of companies announced new programs that utilize recycled HDPE as a middle layer in a coextruded parison used to blow mold soap, cosmetic, and motor oil bottles. The total amount of secondary material will be as high as 70%, but of that only 25% is guaranteed to be postconsumer. Firms in Alabama, Arkansas, and Wisconsin opened new facilities to produce plastic "wood" from recycled HDPE and mixed-resin streams. Although this product will be higher cost, it has properties that may give it an advantage in markets that demand resistance to moisture or corrosion.

One of the biggest moves during the year, however, came amidst the debate over what role FDA had in controlling the recycled content of packaging that came into direct contact with food. Two resin companies announced in the fall that they had developed processes for reducing postconsumer PET bottles to basic monomers, a closed-loop process that allows identical products to be fabricated over and over. Then, in December, both Coca Cola Co. and Pepsi Cola Co. announced programs to use these resins in 1-, 2-, and 3-liter soft drink bottles. Both companies requested FDA consent, but it appears FDA will have to ask for new legislation in this area if they are to have the power to deny such applications. Some question remains whether the process can be accomplished at a competitive price, but still this move was hailed as a potentially significant expansion in new markets for recycled materials.

Perhaps the most controversial move during the year was the switch by McDonald's away from polystyrene foam packaging to a paper-based product, a potential loss of more than 20,000 metric tons to the PS industry. The court ruling in February upholding the Portland, OR, ban on PS may have set the stage. A European initiative sponsored by McDonald's to develop a dissolvable PS resin was announced in March, but fizzled later in the year. Another McDonald's initiative to recycle PS into "wood" products was considered in June. In August, the Environmental Defense Fund and McDonald's announced the formation of a task force on waste reduction. Finally, in November, McDonald's announced it would dump PS in favor of paper-based packaging, citing consumer preferences and a reduction in the overall volume of waste generated from discarded packaging. "We are trying very hard to find products that are fully recyclable, but our ultimate goal is source reduction," said Ed Rensi, McDonald's president.

Source reduction was a major topic during the year. The linear low-density polyethylene (LLDPE) milk pouch was given special emphasis, both in the United States and Canada, where it has long held a significant market share. The potential for reduced materials use is substantial. Currently, almost 450,000 metric tons of PE is

used as milk jugs or coatings on paper milk cartons. This could be reduced by more than three-fourths if complete substitution occurred.

Markets and Prices.— In 1990, plastics sales totaled 27.9 million metric tons, or 36% of world sales, as shown in table 11. Compared with last year, this represents an increase of 4.5% in domestic sales. Near yearend, U.S. producers were able to boost sales as a result of a price advantage abroad that led to an increase in plastics exports. Among the major large-volume plastics, a combination of LDPE and LLDPE, with 17.6% of sales, ranked first in volume sold during the year, followed by PVC, with 15.1%; and HDPE, with 13.8%. The fastest growing markets in 1990 were PVC, PP, LLDPE, and the category combining the engineering resins PBT, PCT, and PET.

Foreign Trade.—International trade is an important component of the plastics industry, as shown in table 12. Exports of plastic resins accounted for about 15% of U.S. plastic sales, while imports were equivalent to about 5% of sales. Imports grew at a faster rate than exports in 1990. In value terms, net exports of plastic resins were larger in 1990 than net imports of plastic products, the first time this has happened in recent years.

There was also growth in the value of plastic machinery imports and exports, with the level of exports growing at a much faster rate. The United States continues to be a net importer of plastic machinery, but the level of net imports actually dropped in 1990. The value of net imports of plastic molds also dropped in 1990 because of an 18% rise in exports and a 4% drop in imports.

World Review.— Sales of plastics in Western Europe totaled 22 million metric tons in 1990, or 28% of world sales, as shown in table 13. Compared with that of a year ago, this represents an increase of 5.8% in sales. Sales of LDPE, at 5.2 million metric tons, vinyls, at 5.2 million metric tons, and PP, at 3.7 million metric tons, accounted for more than one-half of all the region's plastics sales during the year. For LDPE, the major market was the film and sheeting market, which accounted for the lion's share of usage, followed by the extrusion coating and the injection molding markets. For vinyls, the major markets were the pipe and conduit, profile extrusion, and film and sheet markets. For PP, the major markets in Western Europe were the molding and extrusion market and the film market.

TABLE 11

U.S. PLASTICS RESIN SALES

(Thousand metric tons)

	1986	1987	1988	1989	1990
ABS	490	548	580	561	552
Acrylic	287	302	316	335	341
Alkyd	132	138	145	147	145
All others	98	118	131	141	150
Cellulosics	39	40	41	41	36
Epoxy	169	190	212	219	210
EVA	528	517	503	475	492
HDPE	3,188	3,699	3,667	3,707	3,856
LDPE	2,065	2,331	2,962	2,975	2,797
LLDPE	1,393	1,507	1,500	1,763	2,113
Nylon	201	226	260	263	258
Other styrenics	517	569	499	535	506
Other vinyls	463	414	431	408	415
PBT/PCT/PET	712	802	927	951	1,060
Phenolic	1,207	1,364	1,385	1,282	1,282
Polyacetal	53	55	63	65	65
Polycarbonate	163	178	267	283	281
Polyester, unsaturated	560	596	623	598	566
Polyphenylene alloys	73	77	78	89	90
Polyurethane	1,198	1,283	1,467	1,462	1,481
PP	2,642	3,048	3,215	3,313	3,689
PS	2,024	2,204	2,280	2,327	2,330
PVC	3,362	3,666	3,759	3,849	4,204
SAN	39	53	66	49	61
Thermoplastic elastomers	182	200	223	246	265
Urea/melamine	662	710	687	626	663
Total	22,446	24,836	26,287	26,712	27,908

Sources: Society of the Plastics Industry, Inc. and Modern Plastics.

Growth in plastics production in Japan led that of all other categories in 1990, outpacing production growth for both synthetic rubber and synthetic fibers. Sales of plastics in 1990 totaled 11.0 million metric tons, an 8.0% increase over the 1989 level. All plastics sales contributed to the overall increase, except urea-melamine sales, which declined slightly from those of a year ago. Among the sales of the major commodity plastics, PP sales in 1990 jumped 16.4% to 2.1 million metric tons above the 1989 level; this increase was mainly due to growth in the injection molding market. PVC sales increased 1.4% to 2 million metric tons in 1990 owing to modest growth in the rigid, flexible, and wire markets. LDPE sales in Japan rose 17.3% to 1.7 million metric tons, largely owing to increased growth in the film, wire, and cable markets.

Sales of plastics in Canada in 1990 increased to 2.6 million metric tons, an 8.1% increase from that of a year ago. LDPE sales, at 1.3 million metric tons, led that of all plastics. Growth of LDPE jumped 10.6% over the 1989 level. This increase was mainly due to an increase in exports and in domestic film applications. Also, sales of PVC increased 8.8% to 0.5 million metric tons, and sales of HDPE increased 8.2% in 1990 to 0.4 million metric tons, largely owing to an increase in exports.

Outlook

Plastics are used, in quantitative order, as packaging materials, building materials, as electronic and transportation hardware parts, in appliances, and in furniture. Thus, the future use of plastics is tied to the behavior of the markets for these products.

The economic recession that affected the world economy in 1990 is having an effect in slowing total plastic production, as did

TABLE 12

U.S. PLASTICS INDUSTRY TRADE SUMMARY

	1986	1987	1988	1989	1990
Imports: thousand dollars					
Plastics products	11,278,913	14,171,146	17,019,686	16,400,368	17,556,663
Resins	866,992	974,879	1,221,494	1,588,114	1,900,372
Machinery	566,373	722,002	826,003	911,055	949,158
Molds	257,852	302,373	310,950	412,511	395,304
Exports: thousand dollars					
Plastic products	6,133,262	7,307,569	9,016,838	11,511,480	13,330,475
Resins	3,211,480	4,138,346	5,618,428	5,704,359	6,365,891
Machinery	276,341	331,619	405,178	492,334	575,762
Molds	72,242	70,361	67,476	131,191	154,865
Resins: metric tons					
Imports	754,317	754,274	793,934	1,013,054	1,263,625
Exports	2,588,117	3,027,532	3,409,977	3,951,637	4,405,646
Net exports: thousand dollars					
Plastic products[1]	-5,145,651	-6,863,577	-6,002,850	-4,888,888	-4,226,188
Resins	2,344,488	3,163,467	4,326,934	4,116,245	4,465,519
Machinery	-290,032	-390,363	-420,675	-418,721	-372,306
Molds	-185,610	-232,012	-243,472	-281,320	-240,529
Resins metric tons	1,633,800	2,273,258	2,615,994	2,938,583	3,142,021

[1]Negative numbers indicate net import.

Sources: European Plastics News and Bureau of Census.

the Middle East crisis by causing at least a temporary increase in resin prices that persisted into 1991. Another factor is the environmental concerns caused by the solid waste issue and the problems created by plastics disposal.

In spite of all of these disruptions, plastics are still experiencing the benefits of an 8-year boom that is expected to continue, although at a slower rate. World demand for the commodity plastics, polyethylene, polypropylene, polystyrene, and polyvinyl chloride grew at a rate of 5.7% through the years 1980-87. It is predicted that this growth will continue through the year 1995 at a rate of 3.5%.[44]

The Middle East crisis and a destructive fire at Phillips 66's Houston HDPE plant combined to reduce polyethylene supplies and raise prices by 6 cents per pound by the end of 1990. Capacity increases of 3.2 million pounds by the end of 1990 and future expansions expected by 1992 should increase polyethylene supplies and cause a decline in prices in the near future.[45]

A new trend in technology is the use of bimodal HDPE resins that use a combination of high and low molecular weight resins, allowing for an increase in variance of properties and processability. The major gains because of the use of this bimodal technology have been the grocery and trash bag markets. The increase in strength allowed downgaging of the HDPE film.[46]

Polypropylene exhibited an increase of 11% in U.S. sales in 1990, and it is predicted that it will continue to grow at a rate of 5.7% per year through 1994. There are plans to increase U.S. production capacity by 2.3 billion by 1993, but this gain may be offset by closure of some older plants. Globally, there are planned increases in polypropylene production capacity in China and Latin America, which could lead to only a 75% capacity utilization by 1993. This could affect U.S. export markets.[47]

Polystyrene sales were flat in 1990, although there was a noticeable decline in several uses because of environmental issues. There was a combined 45-million-pound decline in six categories of an overall 5-billion-pound U.S. market. The decline in uses of polystyrene occurred in the following products: egg cartons, hinged containers, nonthermoformed foam cups, EPS cups and containers, and loose fill. Offsetting these declines were increases in the use of the following products: PS film and sheet, vending and portion cups, medical disposables, audio and/or videocassettes, and housewares.[48]

Other areas are expected to grow in the future because of technological changes that have allowed production of polystyrene

TABLE 13

WORLD SALES OF PLASTICS RESINS

(Thousand metric tons)

	1989	1990
Australia	2,393	2,065
Bulgaria	231	328
Canada:		
ABS	59	63
HDPE	364	394
LDPE	1,134	1,254
PP	241	263
PVC	420	457
PS	202	184
Total[1]	2,420	2,615
China	2,249	1,973
Czechoslovakia	1,174	1,186
Hungary	603	638
Japan:		
HDPE	1,046	1,113
LDPE	1,426	1,672
Nylons	167	186
ABS	582	607
Acrylics	146	153
PVC	1,976	2,003
PP	1,787	2,080
PS	1,094	1,183
PET/PBT	171	190
Urea/melamine	606	594
Thermosets[2]	515	523
Polyesters[3]	680	712
Total[1]	10,196	11,016
Poland	624	721
Romania	520	640
Taiwan	1,665	1,460
U.S.S.R.	5,500	5,763
United States	26,712	27,908
Western Europe:[4]		
HDPE	2,679	2,973
LDPE	5,056	5,245
PP	3,274	3,685
PS	2,198	2,321
PU	1,516	1,576
Acrylics	203	208
ABS	491	501
Nylons	346	366
Vinyls	5,069	5,158
Total[1]	20,832	22,033
Grand total[5]	75,119	78,346

[1]Country subtotals are for resins shown only.

[2]Includes epoxy and phenolic.

[3]Includes unsaturated polyesters and reinforced polyester.

[4]Includes all common market countries plus Austria, Finland, Norway, Sweden, and Switzerland.

[5]Total is for countries and resins listed only.

Sources: Modern Plastics International and Chemical & Engineering News.

with low levels of residuals such as ethylbenzene. These residuals can affect taste and odor, and their reduction improves toughness and gloss and allows polystyrene to effectively compete for products normally made from ABS such as videocassettes and appliances.

The environmental issues involved in use of polyvinyl chloride (PVC) as a packaging material have led some to predict a decline in use of PVC in the United States in 1991. However, this may be somewhat offset by the recession, because during times of recession, there tends to be more repair or remodeling work on existing structures, leading to the use of more PVC siding, windows, and piping.

Polyethylene terephthalate (PET), the most recycled of all plastics, was explored for closed-loop recycling with the removal of the FDA's proscription against using recycled plastics in food containers. This will not increase PET use directly but may aid in its continuing use because of the perception that a solution to the solid waste disposal problem is being achieved. The current and impending legislation against the use of PVC in containers has led to research in the use of PET in the extrusion blow molding process to produce alternative environmentally benign containers. This new niche for PET use may expand its market share in the early 1990's.

The engineering resins are attempting to expand their share of the market by moving into new products through the use of new additives to create alloys with specific property increases in such factors as toughness, weatherability, and heat resistance.

Polyurethanes are being developed that allow for RIM grades that react faster to decrease cycle times in processings and are more recyclable for use in such products as auto body panels and fascia.

SYNTHETIC FIBERS

Synthetic fibers have enveloped our everyday world and provided a vastly improved living environment. They make up almost every textile and are incorporated into an infinite number of consumer and industrial products. Likewise, they are important to the U.S. economy. Synthetic fiber industries employ more than 50,000 workers. In addition, the fiber-textile-apparel industry employs more people than the auto, computer, steel, oil, and coal industries combined. Synthetic fiber production in 1990 was almost 4 million metric tons, with sales of approximately $11.5 billion.

Reviewing the utilization of manufactured fibers, most would rank the garment industry as the prime user. Synthetic fibers are incorporated into many other areas, including home furnishings, carpeting, filtering media, composite reinforcement, and disposable diapers. Roughly 45% of all manufactured fibers are utilized in home furnishings, 25% in industrial products, and 30% in clothing.

Background

Manufactured fibers have been in existence for more than 50 years. "Artificial silk," rayon, was commercially produced in the United States in the mid-1920's. Costing one-third the price of silk and with similar properties, rayon initiated the manufactured fibers conquest of the commercial textile market. Nylon was commercialized by Du Pont in 1939 and, by the end of the 1940's, industrial America was incorporating nylon into everything from hosiery to carpets to upholstery. New fibers developed over the next several decades included olefin, acrylic, and polyester fibers. In the early 1950's, blends of these fibers with cotton were transformed into "wash and wear" garments and became a way of life for the American public. In the 1960's and 1970's, these fibers were modified and engineered, both chemically and physically, to produce tailored fibers with specific and sometimes unique applications. Polyester tire cords, stretchable Spandex apparel, high-temperature-resistant polyamide space suits, and nonwoven diapers are several examples. Today, manufactured fibers are assimilated into artificial organs, surgical gowns, roofing materials, and floppy disk envelopes. Their diversified characteristics and performance properties provide an endless array of products, as simple as polyester sewing thread and as tough as a bullet-stopping aramid undervest.

Manufactured fibers are typically broken down into two main areas, artificial (cellulosic), which consists of acetate, rayon, and triacetate*, and synthetic (noncellulosic), with the largest consumption materials being nylon, polyester, olefin, and acrylic (minimum of 85% acrylonitrile). The other synthetic fibers include anidex*, aramid, azlon*, glass, lastrile*, metallic, modacrylic (minimum of 35% acrylonitrile), novoloid*, nytril*, PBI, rubber, saran, spandex, sulfar, vinal*, and vinyon. (The * denotes that these synthetic fibers are not currently produced in the United States.) The Federal Trade Commission (FTC) has assigned these generic names based on their significantly different chemical composition. If a new fiber were invented with a different chemical design, then the FTC would assign a new "official" generic name. If any of the generic fibers are modified, then it would be named a variant. The custom engineering of these generic fibers produces variants that have specific properties for specific applications. Likewise, when a manufacturer develops a new fiber, a trademark is usually issued by the U.S. patent office for that fiber class.

Products for Trade and Industry.—The most widely used fiber is polyester, employed both alone and as a blend with natural or other synthetic fibers. Some common industrial applications are carpeting, boat sails, ropes, and geotextiles for highway construction. Nylon fibers have a wide range of uses, including carpets, sheer hosiery and lingerie, and sleeping bags. Olefin fibers are incorporated in sportswear because of their hydrophobic nature and wicking properties, which allow body moisture to pass to the surface of the fabric and away from the skin. Acrylic fiber is soft and warm and is utilized in blankets and sweaters. The cellulosic fibers, rayon and acetate, are both used in the manufacturing of fabrics for wearing apparel and home furnishings and curtains and drapes.

The specialty fibers provide extraordinary properties. Aramid is used in protective clothing due to its flame retardancy. Because aramid fibers have a high modulus, they are utilized in tires, military protective equipment, and advanced composites in aircraft. Spandex is often blended with other fibers and converted into stretchable clothing. Additional major generic synthetic fibers produced today are modacrylic for flame-retardant sleepwear; vinyon for teabags; PBI, which will not burn in the air, for special protective garments; and sulfar, with a melting point of 285° C, for industrial filtration fabrics.

Technology.—Cellulosic fibers are regenerated natural polymers, and noncellulosic fibers are polymers created by chemical synthesis. The basic process involves preparation of the selected raw material into a liquid form or solution by dissolving or by melting it. After extruding and hardening the filaments, called spinning, the material is collected for further processing if required. This extrusion, or fiber forming, is achieved by forcing the fluid or molten material through a plate (spinneret) containing numerous, minuscule openings. Stretching of the filaments is a

method of orientation that may increase the fibers strength and also reduce the fiber to a desired diameter. The fiber industry uses the terms denier or tex to identify the diameter of different fibers. (Denier is the weight in grams of 9,000 meters of fiber. Tex is the weight in grams of 1,000 meters of yarn.) The large, ropelike bundle of these many continuous filaments is named tow. Staple fibers are the results of cutting the tow to desired lengths. Uncut tow may be shipped to mills where it is converted into yarn that can be either monofilament or multifilament. Numerous postmanufacturing processes can now take place. The yarns may be textured, spun, or combined. Fibers can be crimped or blended.

There are variations of this process that provide truly specialized fibers. Two different polymers can be extruded side by side or in a concentric fashion, producing a bicomponent fiber. By modifying the spinneret, fibers may be extruded into different shapes or they may be made hollow. An example of engineered modification is the manufacturing of spandex fibers. By careful selection of the monomers, short polymers, some of which are rigid and others flexible, are joined together to produce a block copolymer containing both hard and soft segments. The flexible segments provide stretch while the rigid ones allow recovery when the force is removed.

Presently, work is being focused on the improvement of existing fibers by optimizing their properties through process modifications such as stretching during forming. The development of new polymeric fibers is not a high priority. Another area of research is the alloying and blending of different fibers to obtain a product that provides the best resultant product for a multitude of applications.

Economic Factors.—Since the end of World War II, international trade agreements promoted apparel and textile imports to help the devastated nations and more recently small, developing nations recover their economies. But these foreign manufacturers, with the luxury of inexpensive labor, produce imports that have become more than 50% of the domestic clothing market. The effects have resulted in domestic plant closures and wide-scale layoffs. According to the Fiber Economics Bureau, the fiber, textile, and apparel industry does not wish to ban imported textiles and apparel from the American markets. But it does support legislation and international trade agreements that would limit the growth of imports to the growth of the domestic market.

International competition continues to be a sensitive area and has basically kept the U.S. commodity fibers industry at a near 0% growth rate for the past decade.

Operating Factors.—Today there are unlimited variations of the major generic fibers that have been engineered to accomplish specific tasks. Within these generic names are trademarks for the individual fibers. The FTC will establish a new generic name only when a fiber is developed that is different in chemical composition from other fibers. The Federal law also requires that textile products be labeled with three kinds of useful information: a sewn-in label identifying the country in which the product was made, a label or tag that includes those fibers that compose 5% or more of the item, and a permanent label giving care instructions.

The Consumer Product Safety Commission established a flammability standard in the early 1970's that created a major upheaval in the fabric market. The use of cotton was almost eliminated in children's sleepwear and in carpeting.

Annual Review

Markets and Prices.—Overall domestic production of synthetic fibers during the past 5 years has varied only slightly, with a maximum of 4.1 million metric tons in 1988 and a minimum in 1986 of 3.8 million metric tons (table 14). Comparing total production in 1986-90, there was a modest increase of almost 3%. Production of synthetic fibers totaled 3.9 million metric tons in 1990, representing a decrease of 4.5% from that of the 1989 level. All fibers registered a decrease in production compared with prior years, except polyolefins. Polyester accounted for 36.8% of total production, followed by nylon, with 30.6%; and polyolefins, with 21.0%.

U.S. trade in synthetic fibers, including woven cloth, has been relatively minor in recent years, as shown in table 15. The total values for both exports and imports have been between 2% and 4% of U.S. fiber production levels in recent years. Exports and imports have been at comparable levels, with a slight net export position.

Prices of synthetic fibers have risen only slightly in recent years. An index for gray synthetic broadwovens, typical for the industry, showed an increase in prices of only 1.5% over 1989 levels. Increases in price since 1987 have averaged 3% per year.

World Review.—World production of synthetic fibers dropped to 13,178 thousand metric tons in 1990, representing a decline of 2% from the 1989 level for those countries shown in table 16. Leading producers included the United States with a production of 3.9 million metric tons; China, with 1.6 million metric tons; Taiwan, with 1.3 million metric tons; and Germany, with 1 million metric tons.

Outlook

The major synthetic fibers produced from oil and gas are polyester, nylon, acrylic, and polypropylene. These were produced in the United States in 1990 at the following percentages of total fiber output: polyester, 39%; nylon, 33%; acrylic, 22%; and polypropylene, 6%. There was a general decline in production of all synthetic fibers during the year, except for polypropylene, because of consumers' preference for natural fibers, especially cotton. Du Pont phased out acrylic production in 1990 because of this decline.[49] It is expected that synthetic fibers as a sector will continue to grow at a slow rate of 1.4% per year over the next 5 years, with polyester production being responsible for most of this growth.[50] Worldwide installed production capacity is expected to meet demand for the next 10 years.[51]

SYNTHETIC RUBBER

The principal consumer of synthetic rubber in the United States is the tire industry, where about 50% of all commodity synthetic rubber is deployed. With technology providing improved tire wear, the replacement timeframe is being extended and causing general sales declines. Intense domestic competition continues to hold prices at levels from previous decades. The combined effects on this market have created losses for many major tire producers. Growth in the tire and tire products industry is effectively sluggish.

Growth in the nonautomotive businesses continued at a modest rate in 1990, with future estimates yielding higher potentials. These other areas of consumption encompass belts, gaskets, and hoses for industrial applications. Also, lesser areas, but of equal importance, are footwear, roofing materials, pond linings, wire coverings, and adhesives.

TABLE 14

U.S. SYNTHETIC FIBERS PRODUCTION

(Thousand metric tons)

	1986	1987	1988	1989	1990
Noncellulosic fibers:					
Acrylic	279	269	267	246	230
Nylon	1,140	1,220	1,211	1,243	1,207
Olefin	632	678	720	743	826
Polyester	1,499	1,606	1,670	1,630	1,449
Cellulosic fibers	281	274	279	263	229
Total	3,831	4,047	4,147	4,125	3,941

Source: Chemical & Engineering News.

TABLE 15

U.S. SYNTHETIC FIBER TEXTILE TRADE

(Thousand metric tons)

	1985	1986	1987	1988
Exports:				
Yarn, tops, thread	36.9	42.7	48.8	51.2
Woven cloth	56.7	61.1	69.3	76.8
Total	93.6	103.8	118.1	128.0
Imports:				
Yarn, tops, thread	37.1	45.0	44.2	35.8
Woven cloth	84.5	93.9	82.8	81.3
Total	121.6	138.9	127.0	117.1

Source: Survey of Current Business, U.S. Department of Commerce.

TABLE 16

SYNTHETIC FIBERS PRODUCTION, SELECTED COUNTRIES

(Thousand metric tons)

	1987	1988	1989	1990
Austria	151	163	171	173
Benelux countries	230	229	290	311
Bulgaria	94	72	66	e49
China	1,157	1,284	1,466	1,625
Czechoslovakia	197	205	208	200
Finland	55	63	68	69
France	196	193	180	156
Germany, Federal Republic of	981	995	1,014	1,021
Hungary	34	37	36	30
Ireland	78	80	94	93
Italy	683	690	675	494
Korea, Republic of[1]	496	593	654	730
Poland	238	245	238	149
Portugal	64	59	65	64
Romania	287	297	273	e221
Spain	308	304	308	301
Switzerland	103	116	120	118
Taiwan[1]	1,076	1,100	1,193	1,290
Turkey	268	278	302	251
U.S.S.R.	1,517	1,555	1,557	e1,541
United Kingdom	327	342	339	350
United States	4,047	4,146	4,125	3,942
Total[2]	12,587	13,046	13,442	e13,178

eEstimated.
[1]Polyester fibers only.
[2]Total is for countries listed only.
Source: Chemical & Engineering News.

Background

Examples of synthetic rubbers are styrene-butadiene rubber (SBR), polybutadiene rubber (BR), ethylene-propylene (EPR), nitrile rubber (NR), and other. This "other" category contains a variety of specialty elastomers that include poly-chloroprene, polyisoprene, silicones, urethanes, and thermoplastic elastomers (TPE). (Elastomers are materials, which at room temperature, can be stretched repeatedly to at least twice their original length and, upon release of the stress, will immediately return with force to their approximate original length.)

TPE's are growing faster than the basic elastomers owing to this group's versatility and uniqueness in applications. Within the TPE family exists thermoplastic polyolefin (TPO). There is no industrywide definition of a TPO, nor even common terminology. TPO is also known as olefinic thermoplastic elastomer (OTPE) and elastomer modified polypropylene (EMPP). The most common designation, TPO, is usually applied to any blend of polypropylene (PP) and rubber, and physical properties can vary widely.

A major potential growth market for TPO's is the automobile fascia, or bumper cover, where the dominant plastic in North America has been RIM urethane.

Annual Review

Markets and Prices.—Synthetic rubber profitability is currently decreasing, particularly in the commodity rubbers. This is mainly due to two materials, SBR, the largest volume product, and BR. Two-thirds of their total output goes into the tire market, where recent changes in the size and type of tires has greatly affected rubber use. Although the number of SBR solid producers in the United States has dropped from nine in the early 1980's to five, cheaper imports, especially from South America, are holding prices down.

Table 17 reveals very flat production growth within the United States over the past several years. Production of synthetic rubber in 1990 totaled 2.1 million metric tons, down 6.5% from that of the 1989 level. Of the major volume products, styrene-butadiene rubber accounted for 40% of total production; polybutadiene rubber, 19%; and ethylene-propylene rubber, 12%.

World Review.—The International Institute of Synthetic Rubbers Producers

(IISRP, Houston) estimates total world consumption of synthetic rubber was 7.07 million metric tons in 1990.

In Western Europe, approximately 2.4 million metric tons of synthetic rubber was produced in 1990, as shown in table 18. This corresponds to a growth of approximately 1.6% compared with that of the previous year. Except for the Federal Republic of Germany, all large-volume producers posted declines in production levels in 1990 compared with the 1989 levels.

Current Research.—The commodity synthetic rubbers have drawn very little research and development attention in recent years, with specific emphasis being directed toward reducing production costs and increasing productivity. Current research is mostly involved with thermoplastic elastomers (TPE). One arena drawing attention is the thermoplastic pololefin elastomers (TPO), which are highly engineered polypropylene products. The range of properties obtainable, both flexural and service temperature, make the PP-based TPO the least cost engineered material for many demanding automotive applications. Also, their lower specific gravity compared to their typical competitive materials allow a much desired weight savings.

Outlook

The past several years have exhibited little or no growth, consolidation of production capacity within this industry, and development of more versatile polymers. Although the commodity elastomers businesses are relatively mature, the specialty areas, which are presently low volume, continue to grow at moderate rates. Any real growth may be delayed until after a recovery in the construction and automotive industries, which are the primary users of these materials.

World demand for synthetic rubber is expected to remain low, with installed production capacity able to meet demand over the next 5 years. A growth rate in production is estimated at 2% for the world market until 1995, with developing countries exhibiting an increase in demand and many industrialized nations experiencing slow growth or even a decline in demand.[52]

In Western Europe, for 1991, IISRP expects a growth in consumption of 2.5%. Overall synthetic rubber consumption is expected to reach 2.6 million metric tons by 1995, up from the 1990 level of 2.4 million metric tons.[53]

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[5]_____. Energy Information Administration. Natural Gas Monthly, May 1991. DOE/EIA-0131(86)/1. May 1991, 18 pp.

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[12]Oil & Gas Journal. Mar. 11, 1991, 23 pp.

[13]_____. Feb. 11, 1991, 38 pp.

[14]Petroleum Supply Annual 1990. May 1991, V. 1, p. xi.

[15]Oil & Gas Journal. Apr. 1, 1991, 21 pp.

[16]Page xii of work cited in footnote 14.

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[19]_____. Apr. 1, 1991, pp. 21-28.

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[21]Work cited in footnote 19.

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[46]Work cited in footnote 45.

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[48]Work cited in footnote 45.

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[52]Work cited in footnote 17.

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TABLE 17

U.S. SYNTHETIC RUBBER PRODUCTION

(Thousand metric tons)

	1986	1987	1988	1989	1990
Ethylene-propylene	230	254	263	260	256
Nitrile	59	69	76	69	56
Polybutadiene	336	371	407	411	403
Styrene-butadiene rubber	792	850	909	874	853
Other[1]	596	638	679	647	546
Total	2,013	2,182	2,334	2,261	2,114

[1]Includes butyl, polychloroprene, polyisoprene, silicone, and other synthetic elastomers.

Source: Chemical & Engineering News.

TABLE 18

SYNTHETIC RUBBER PRODUCTION, SELECTED COUNTRIES

(Thousand metric tons)

Country	1989	1990
China	289	316
Czechoslovakia	75	70
Poland	125	103
Romania	149	102
U.S.S.R.	2,400	NA
United States	2,261	2,114
Western Europe:		
Germany, Federal Republic of	508	523
United Kingdom	312	299
France	590	522
Other Western Europe[1]	911	1,013
Total Western Europe[1]	2,321	2,357

NA Not available.
[1]Values are for consumption.
Sources: Chemical & Engineering News and Kunststoffe Europe.

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PEAT

By Raymond L. Cantrell

Mr. Cantrell, a physical scientist with 27 of years industry and U.S. Bureau of Mines experience, has been the commodity specialist for peat since 1988. The peat survey was monitored by Virginia Harper and Maureen Riley, mineral data assistants; Virginia Harper also prepared domestic data tables. International data tables were prepared by Audrey Wilkes, international data coordinator.

Peat is a natural organic material of the Earth that is found in great abundance in the United States. Nature enthusiasts and home gardeners alike benefit from the aesthetic appeal of peat and its utility in cultivating flowers, plants, and vegetable gardens. Commercial greenhouses and nurseries culture beautiful flowers and plants from peat-based growing media that contribute significantly to our well-being.

A review of the projections by various members of the U.S. horticultural 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.[1]

Peat is used in a variety of other commercial applications, including turf cultivation, golf course greens construction and course maintenance, mushroom cultivation and earthworm culture, poultry litter, fertilizers, seed innoculants, humic acid extracts, toxic waste filtration, hygienic products, and fuel for electrical power generation.

The U.S. peat industry developed from small "mom and pop" operations that today comprise 70% of all active peat operations and 20% of total production. They provide a valuable service to their local communities at a marginal profit. 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.

In 1990, the U.S. peat industry continued to be negatively impacted by recessionary forces, although there were indications that the industry had begun to stabilize relative to the downturn of the previous 2 years. Production, sales, and apparent domestic consumption stabilized in 1990, and there was a firming of prices relative to 1989. Canadian imports continued to increase and reached record proportions in terms of volume, value, and market share. Canadian peat movement across the U.S. border in 1990 reached a record 44% of the total U.S. supply. The total U.S. supply was valued at about $110 million based on f.o.b. domestic plant and U.S. Customs values.

Large-scale composting operations, driven by environmental concerns, continued to proliferate in both the public and private sectors during 1990 and competed with peat in selected applications. Compost may lead to further growth in mulching and soil amendment activity dependent upon economic factors. In any event, several peat-compost product blends were introduced by major U.S. peat producers in 1990, representing a new trend that will most probably continue to increase in proportion to the availability of quality compost materials.

EcoPeat Co., a U.S. affiliate of the Finnish firm Outokumpu, was formed to develop 360 megawatts of peat-fueled electrical powerplants in cooperation with south-central Florida utility companies. The plants were scheduled on-stream beginning in mid-1995, and at full capacity, would quadruple current U.S. peat production.

In 1990, global peat production was estimated at about 200 million short tons and was valued at $4 billion, f.o.b. plant.

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 109 peat operations surveyed in 1990, 82 were reported to be active and 23 idle or closed permanently. Estimates were made for active operations that did not report data in 1990, based on past trends.

Alaskan peat producers were surveyed independently by the Department of Natural Resources, Division of Geological & Geophysical Surveys, Fairbanks, AK. In 1990, operations in the Anchorage and Fairbanks areas reported active production.

BACKGROUND

Peat deposits developed typically through the gradual decomposition of plant matter under anaerobic conditions in shallow 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 are known to lie buried beneath the sands of Trail Ridge in Bradford and Clay Counties, FL. 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 or fens 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 an acidic peatland that depends principally on rainfall to perpetuate the waterlogged conditions necessary for its survival. Because there is less decomposi-

TABLE 1

SALIENT PEAT STATISTICS

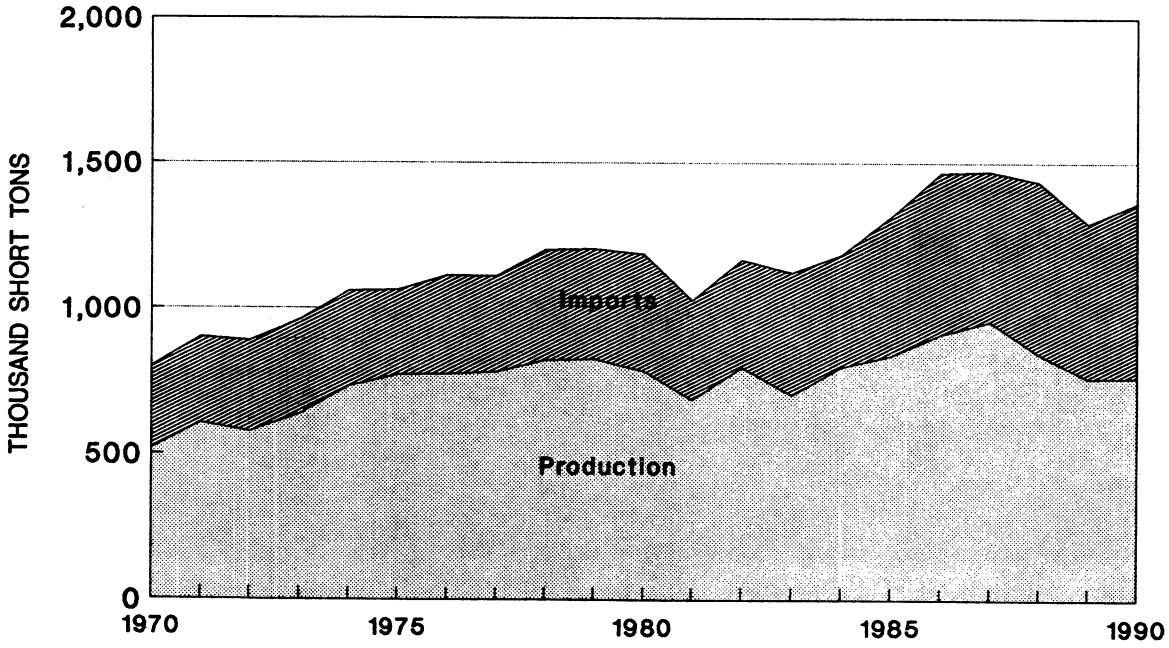
		1986	1987	1988	1989[r]	1990[p]
United States:						
Number of active operations		92	92	88	80	82
Production	thousand short tons	912	955	844	761	763
Sales by producers	do.	1,038	958	908	775	795
Bulk	do.	522	499	457	384	397
Packaged	do.	516	459	451	391	398
Value of sales	thousands	$23,988	$21,020	$20,320	$17,703	$19,200
Average per short ton		$23.11	$21.94	$22.37	$22.84	$24.16
Average per short ton, bulk		$16.44	$17.72	$18.14	$18.98	$17.76
Average per short ton, packaged or baled		$29.86	$26.51	$26.67	$26.63	$30.53
Imports for consumption	thousand short tons	553	515	590	530	599
Consumption, apparent[1]	do.	1,548	1,544	1,468	1,336	1,372
Stocks, December 31: Producers'	do.	555	481	447	402	393
World: Production	do.	[r]218,381	[r]207,323	[r]213,988	217,531	[e]198,489

[p]Preliminary. [r]Revised.

[1]Apparent consumption equals U.S. primary production plus imports minus exports plus adjustments for industry stock changes.

FIGURE 1

PRODUCTION AND IMPORTS OF PEAT IN THE UNITED STATES



tion in these nutrient-poor, acidic environments, very fibrous peats are produced. A variety of other peats may also be formed under boggy conditions in marshes and swamps.

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 known as muck or peaty muck. The majority of fens are over sites of sand and gravel deposits that are buried within more clayey glacial materials (intertill), providing a ground water seep over which the peat forms. It, therefore, is not uncommon to find fens situated on hillsides.[2]

Definitions, Grades, and Specifications

Methods adopted by the American Society for Testing and Materials (ASTM) find widespread use for the characterization of peat matter.[3] 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.[4]

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. 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.[5]

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. 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 available for harvesting in the 48 contiguous United States. At current mining rates, the U.S. permitted reserve base estimate of 16 million tons could theoretically be depleted within the coming 20 years.

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."[6]

TABLE 2

WORLD PEAT RESERVES AND RESERVE BASE

(Million short tons of air-dryed peat)

	Reserves[1]	Reserve base[2]
North America:		
Canada	24	336,000
United States	16	7,000
Total	40	343,000
Europe:		
Finland	70	7,000
Germany, Federal Republic of[3]	46	500
Ireland	171	900
U.S.S.R.	5,320	160,000
Total	5,607	168,400
Other countries	3	1,600
World total	5,650	513,000

[1]Estimated reserves currently under active cultivation or economically recoverable under current market conditions.
[2]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).
[3]Western states.

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.

With our Nation's renewed emphasis on the environment and energy independence, as promulgated by the President's recent National Energy Strategy,[7] peat has resurfaced as an important resource in both categories. Perhaps the previous proposal to quantify our Nation's strategic peat reserve base should be reconsidered.

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 passing the 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 gravity fed into plastic containers and compressed into bales on a 2:1 volume ratio. 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. Peat-sand mixtures are popular bulk materials that are sold to golf courses for top dressing greens, tees, and fairway turf.

Economic Factors

The data of table 3 show the long-term peat price trend for the period 1970-90. Actual prices, without adjustment for inflation, increased at an average annual rate of 6% per year over the 20-year period. Prices expressed in terms of constant 1982 dollars, however, declined at an average annual rate of 2% per year over the same period. The U.S. peat industry overcame inflationary pressures principally through the rationalization of capacity, together with a move to higher volume modern and efficient plants.

TABLE 3

TIME-VALUE[1] RELATIONSHIPS FOR U.S. PEAT

Year	Average annual price, dollars per short ton	
	Actual price	Based on constant 1990 dollars
1970	11.39	35.66
1971	11.69	34.62
1972	11.72	33.14
1973	12.16	32.30
1974	15.56	37.89
1975	16.49	36.57
1976	16.52	34.43
1977	17.25	33.71
1978	17.32	31.55
1979	19.44	32.52
1980	20.54	31.52
1981	24.82	34.72
1982	21.94	28.85
1983	25.73	32.56
1984	24.47	29.88
1985	24.81	29.42
1986	23.11	26.70
1987	21.94	24.58
1988	22.37	24.25
1989	r22.84	23.76
1990p	24.16	24.16

pPreliminary. rRevised.

[1]U.S. producer price, f.o.b. plant; average all kinds of peat.

Sources: U.S. Bureau of Mines; Council of Economic Advisors (1990 implicit price deflators for gross national product); 1982 = 100.

ANNUAL REVIEW

Issues

Peat mining experienced the pressures of environmental regulation in the States of Colorado, Connecticut, Maine, North Carolina, Pennsylvania, and South Carolina. There were no active peat operations in Connecticut and only one each in North Carolina and South Carolina.[8]

Concerns about environmental regulations were expressed by the Pennsylvania peat industry where several small operations have been forced to close during recent years. Pennsylvania producers felt pressure from a number of environmental regulatory agencies, including the State Department of Environmental Regulation (DER), the Environmental Protection Agency, and the U.S. Corps of Engineers.

Mining permits were reportedly being terminated upon expiration or renewed for a short timeframe that made the economics of investing in new plants and equipment prohibitive. The producers were reportedly affected on both public and private lands.

Peat operations in Pennsylvania were relatively small, and the acreages that would potentially be affected by the opening of new peat operations were reported to be minor relative to the overall wetlands areas involved. Producers were concerned that new regulatory policies formulated by DER would preclude the opening of new bogs.

Examples were cited in which golf course greens had been severely damaged when alternate materials were applied owing to the absence of quality peat-sand mixtures. In other instances, the scarcity of peat in the State made its use as an earthworm culture medium economically prohibitive, dictating the use of less desirable alternate substitutes.

Producers and consumers alike felt that a more reasonable balance between environmental regulation and peat mining was needed in Pennsylvania, given the positive impact of peat mining on local economies and its value to local consumers.

A petition to mine a 3-acre wetlands tract at Mansfield, CT, was rejected by the Mansfield Conservation Committee, as well as the State Inland-Wetlands Agency. The property would have yielded about 22,000 cubic yards of marketable peat that was to be sold to landscape and nursery firms in the area. In rendering its judgment, the regulatory agencies expressed concern over the absence of detail in the peat removal operation application, particularly with regard to stockpiling and trucking peat from the site. There was no known peat activity in the State of Connecticut.

In August 1990, the Conservation Fund, in coordination with the Richard King Mellon Foundation, turned over 93,000 acres of partially altered wetlands on the environmentally sensitive Pamlimarle Peninsula in northeastern North Carolina to the U.S. Fish and Wildlife Service. About 35 million dry tons of high-energy fuel-grade peat was deposited to an average depth of 6 feet over about 70,000 acres of the property.

The Fish and Wildlife Service was charged with preserving the property as a wildlife habitat to include fire control, maintenance of drainage canals, provision of grain for feeding, and enforcement of wild game hunting. Peat processing equipment on the property that was formerly owned by First Colony Farms was sold at auction in September 1990 to help fund the project.

Fish and Wildlife planned to combine these lands with its adjacent 10,000-acre Pungo National Wildlife Refuge to form Pocosin Lakes National Wildlife Refuge. Deer, black bear, and wood duck were native to the area.[9]

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.

Production

In 1990, U.S. peat production held level at about 0.8 million short tons. This was in sharp contrast to the 20% decline experienced during the previous 2-year period of recession that resulted in the closure of 12 peat operations in the United States.

Peat was harvested and processed by 82 operations in 22 of the contiguous States in 1990. The majority of U.S. peat production, about 80%, was conducted in high-volume operations that accounted for only 30% of the total number of active facilities. Twenty-three peat operations in Florida and Michigan produced about 60% of the U.S. total.

Geographically, about 50% of the total U.S. peat output was from seven contiguous States in the Midwest and north-central Great Lakes region, together with 4 Western States. Four States in the southeast provided about 40% of the total, and seven States in the northeast provided 10%.

On a weight basis, reed-sedge peat was 58% of total U.S. production; humus, 25%; sphagnum moss, 8%; hypnum moss, 3%; and other forms, 6%. On a volume basis, reed-sedge was 56% of the total; humus, 19%; sphagnum, 16%; hypnum, 5%; and other forms, 6%.

In 1990, the State of Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys, Fairbanks, reported that 65,000 cubic yards of peat was produced at an f.o.b. plant value of about $400,000. This represented an increase of 27% in volume and 14% in value relative to 1989. Geophysical Survey officials indicated that the reported quantities were probably on the low side owing to survey methodology.

Hyponex Corp. and Michigan Peat are major producers and distributors of peat products in the United States. In 1990, Hyponex harvested and processed reed-sedge peat from nine facilities in seven States extending from New Jersey to Colorado. Michigan Peat operated three plants in Sanilac County, MI, that processed reed-sedge and sphagnum peats and one plant near Cromwell, MN, that processed sphagnum peat.

Minnesota peat operations experienced a good year in 1990. Production and sales volume were up about 20% and 40%, respectively. The f.o.b. plant value of Minnesota peat was $62 per ton—160% above the national average of $24 per ton—because of the premium price commanded by sphagnum moss.

New horticultural peat projects were reported to be under consideration in the States of Georgia, Maine, and New Mexico.

Down East Peat LP was operating a 22.8-megawatt peat-fired electric powerplant near Cherryfield, ME. At full capacity, the powerplant will require about 165,000 tons of bone-dry peat annually. Fuel-grade peat was extracted from the adjacent Denbo Heath Bog by a private contractor.

Humates were mined from the San Juan Basin deposits of New Mexico and sold for use as a soil conditioner. In 1985, the last year of available data, humate production was about 23,000 cubic yards, with an f.o.b. mine value of $404,000. Mining and processing were conducted by three companies in McKinley, Sandoval, and San Juan Counties.

Consumption and Uses

U.S. producer sales continued to be adversely impacted by a general downturn in the economy, together with competition from Canadian producers. There were indications, however, that the domestic industry had begun to stabilize following 3 years of rationalization in which 12 peat facilities closed and sales volume declined by about 25%.

In 1990, producer sales volume rose 4% to 0.8 million tons and increased 8% in value to $19 million. Bulk and packaged forms, on a weight basis, commanded equal shares of the market. In terms of cubic yards, reed-sedge commanded 67% of the market; humus, 16%; sphagnum

TABLE 4

U.S. PEAT PRODUCTION AND SALES BY PRODUCERS IN 1990, BY STATE

State	Active operations	Production	Sales		
		Quantity (thousand short tons)	Quantity (thousand short tons)	Value[1] (thousands)	Percent packaged
Colorado	4	W	W	W	50
Florida	10	264	252	$4,381	15
Georgia	1	—	W	W	100
Illinois	4	25	W	W	99
Indiana	5	30	37	W	72
Iowa	2	W	W	W	70
Maine	2	W	W	W	—
Maryland	1	11	3	W	26
Massachusetts	1	W	W	W	100
Michigan	13	193	280	6,264	67
Minnesota	9	45	48	2,972	61
Montana	2	W	W	W	1
New Jersey	4	14	W	527	96
New York	2	W	W	W	—
North Carolina	1	26	13	W	100
North Dakota	1	W	W	W	18
Ohio	3	8	12	182	—
Pennsylvania	8	12	18	730	62
South Carolina	1	W	W	W	86
Washington	3	5	W	W	—
West Virginia	1	W	W	W	—
Wisconsin	4	W	12	256	25
Total[2] or average	82	763	795	19,200	50

W Withheld to avoid disclosing company proprietary data; included in "Total or average."
[1]Values are f.o.b. producing plant.
[2]Data may add not add to totals shown because of independent rounding.

TABLE 5

RELATIVE SIZE OF PEAT OPERATIONS IN THE UNITED STATES

Size in short tons per year	Active operations		Production (thousand short tons)	
	1989	1990	1989	1990
25,000 and over	8	9	349	372
15,000 to 24,999	9	11	154	197
10,000 to 14,999	7	6	86	66
5,000 to 9,999	r16	11	r114	68
2,000 to 4,999	13	14	43	42
1,000 to 1,999	6	7	9	10
Under 1,000	21	24	8	9
Total[1]	r80	82	r761	763

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

moss, 13%; hypnum moss, 3%; and other forms, 1%.

Total U.S. apparent domestic peat consumption was unchanged, at 1.4 million tons in 1990, relative to 1989. In contrast to the 27% decline recorded in U.S. producer sales between 1986 and 1989, total apparent U.S. domestic peat consumption declined by a more moderate 10% owing to the relatively constant increase in Canadian peat imports, together with a drawdown in field inventories.

About 92% of U.S. producer sales was for general soil improvement and horticultural use. Golf courses used peat and peat-sand mixtures for turf maintenance and greens construction. In agriculture, peat was used in mixed fertilizers, as a carrier and coating agent in seed innoculants, and for vegetable cultivation. Other specialty applications included peat's use in mushroom beds, as an earthworm culture medium, and for poultry litter.

Peat enjoyed widespread use in many other applications, including electrical power generation, toxic waste filtration, oil absorption, humic acid extracts for agriculture, composting, cranberry cultivation, and in medical and hygienic products.

Stocks

In 1990, producer peat stocks declined slightly, to 0.4 million tons, compared with 1989. Stocks at yearend were about 50% of production, which was typical for the peat industry. Reed-sedge peat accounted for about 63% of total stocks.

Transportation

Peat was moved predominately by truck in both bulk and packaged form. Small producers were restricted to local market areas because of the sensitivity of peat prices to transportation charges. High-volume producer costs were less sensitive to transportation charges, allowing for interstate movement of peat and peat products.

Markets and Prices

The average price for domestic peat in 1990 rose 6% to about $24 per ton in comparison to the prior year. Packaged and baled peat sold for about $30.50 per ton, a 15% increase, while bulk peat prices declined about 6% to 17.75 per ton. Packaged and baled peat were sold at a 70% premium relative to bulk peat.

Sphagnum moss sold at a premium $71 per ton, about 200% above the national average of $24 per ton. On a volume basis, sphagnum sold for $17.50 per yard, about 50% above the national average of $11.50 per cubic yard for all types of peat.

TABLE 6

U.S. PEAT SALES BY PRODUCERS IN 1990, BY USE

Use	In bulk		In packages		Total[1]	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Earthworm culture medium	2,913	$39	416	$14	3,329	$53
General soil improvement	106,666	1,973	369,200	10,918	475,866	12,890
Golf courses	18,335	477	200	12	18,535	489
Ingredient for potting soils	211,224	3,370	12,042	601	223,266	3,970
Mixed fertilizers	6,415	102	94	4	6,509	105
Mushroom beds	6,275	103	—	—	6,275	103
Nurseries	28,816	679	5,950	380	34,766	1,059
Packing flowers, plants, shrubs, etc.	646	8	622	83	1,268	91
Seed inoculant	832	42	4,127	106	4,959	148
Vegetable growing	2,084	37	5,359	37	7,443	73
Other	12,643	219	—	—	12,643	219
Total[1]	396,849	7,047	398,010	12,153	794,859	19,200

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

TABLE 7

U.S. PEAT SALES BY PRODUCERS IN 1990, 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	—	—	—	—	—	—	1,208	2,222	$24
General soil improvement	40,691	162,601	$3,147	7,150	17,500	$499	350,943	741,857	8,493
Golf courses	121	375	3	920	1,900	27	11,573	24,446	233
Ingredient for potting soils	898	3,370	78	10,920	21,900	480	133,277	270,018	2,420
Fixed fertilizers	—	—	—	170	400	12	1,000	2,000	24
Mushroom beds	—	—	—	1,275	3,000	45	5,000	9,455	58
Nurseries	10,593	46,148	457	470	1,000	18	22,147	47,151	552
Packing flowers, plants, shrubs, etc.	758	3,303	85	—	—	—	—	—	—
Seed inoculant	—	—	—	—	—	—	4,959	10,044	148
Vegetable growing	—	—	—	78	155	1	767	1,540	22
Other	501	2,075	33	—	—	—	1,691	3,511	30
Total[2]	53,562	217,872	3,804	20,983	45,855	1,049	532,565	1,112,244	12,004

Use	Humus			Other			Total[2]		
	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	2,121	3,328	$30	—	—	—	3,329	5,550	$53
General soil improvement	72,582	99,593	763	4,500	9,000	$22	475,866	1,030,551	12,890
Golf courses	5,921	10,294	225	—	—	—	18,535	37,051	489
Ingredient for potting soils	78,171	116,216	992	—	—	—	223,266	411,504	3,970
Fixed fertilizers	5,339	8,977	69	—	—	—	6,509	11,377	105
Mushroom beds	—	—	—	—	—	—	6,275	12,455	103
Nurseries	1,556	2,380	31	—	—	—	34,766	96,679	1,059
Packing flowers, plants, shrubs, etc.	510	800	6	—	—	—	1,268	4,103	91
Seed inoculant	—	—	—	—	—	—	4,959	10,044	148
Vegetable growing	6,598	10,991	51	—	—	—	7,443	12,686	73
Other	10,451	20,902	155	—	—	—	12,643	26,488	219
Total[2]	183,249	273,481	2,321	4,500	9,000	22	794,859	1,658,452	19,200

[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 8

AVERAGE DENSITY OF DOMESTIC PEAT SOLD IN 1990

(Pounds per cubic yard)

	Sphagnum moss	Hypnum moss	Reed-sedge	Humus	Other
Bulk	576	959	982	1,384	—
Packaged	472	890	941	1,128	1,000
Bulk and packaged	492	915	958	1,340	1,000

TABLE 9

U.S PEAT PRODUCTION AND PRODUCERS' YEAREND STOCKS IN 1990, BY KIND

Kind	Active operations	Production (short tons)	Percent of production	Yearend stocks (short tons)
Sphagnum moss	14	61,023	8.0	30,222
Hypnum moss	6	21,310	2.8	19,250
Reed-sedge	41	441,511	57.8	246,311
Humus	25	194,159	25.4	51,291
Other	3	45,464	6.0	45,464
Total	[1]82	763,467	100.0	392,538

[1]Data do not add to total shown because some plants produce multiple kinds of peat.

TABLE 10

PRICES[1] FOR PEAT IN 1990

(Dollars per unit)

	Sphagnum moss	Hypnum moss	Reed-sedge	Humus	Other	Average
Domestic:						
Bulk:						
Per short ton	25.20	30.06	21.00	12.01	—	17.76
Per cubic yard	7.26	14.41	10.31	8.31	—	9.61
Packaged or baled:						
Per short ton	84.25	62.48	23.62	16.59	4.89	30.53
Per cubic yard	19.87	27.79	11.12	9.36	2.44	13.13
Average:						
Per short ton	71.02	49.99	22.54	12.67	4.89	24.16
Per cubic yard	17.46	22.88	10.79	8.49	2.44	11.58
Imported, total, per short ton[2]	146.18	XX	XX	XX	XX	146.18

XX Not applicable.
[1]Prices are f.o.b. plant.
[2]Average customs value.

Foreign Trade

In 1990, Canada continued to provide more than 99% of total U.S. peat imports, and new records were established for both volume and value. Canadian imports reached a record of 599,000 tons, 44% of the total U.S. supply, and carried a U.S. Customs value of $87.3 million or $146 per ton. The value of Canadian shipments at the U.S. border exceeded total U.S. domestic peat sales by $68 million (355%).

Another $4 to $6 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 imports entered the United States duty free, a tariff of 4.7% was imposed by Canada on U.S. peat. The United States, to date, has not exported peat to any destination, according to U.S. Bureau of the Census data.

About 77% of Canadian shipments in 1990 originated from Quebec and New Brunswick in eastern Canada. Alberta, in western Canada, supplied about 8% of the total. About 15% of Canadian shipments was reported to originate from Prince Edward Island, Nova Scotia, and Newfoundland in eastern Canada; Ontario in central Canada; and British Columbia, Saskatchewan, and Manitoba in western Canada.[10]

World Review

Global peat production was estimated at about 198 million short tons in 1990, roughly 10% below the 218 million tons produced in 1989. The total value of world peat production, assuming an average f.o.b. plant value of $20 per ton, was $4 billion.

About 17 million tons, or 85% of the estimated 20-million-ton decline, was attributed to the U.S.S.R., where output was thought to be negatively impacted by significant political restructuring. Production was projected to be off about 1.5 million tons in Ireland and about 0.4 million tons in Finland because of above-average harvests in 1989.

Although peat was known to be deposited in the tropics of Africa, Argentina, Brazil, China, Indonesia, Malaysia, New Zealand, Paraguay, and Uruguay, production data were not available.

Industry Structure.—The U.S.S.R. accounted for about 90% of global peat production in 1990, followed by Ireland, 4%; Finland, 3%; Germany (Western states), 1%; the United States and Canada, 1%; and Sweden and other countries, 1%.

In the U.S.S.R., production was confined to the Baltic Republics, the Moscow-Gor'kiy area, and Belorussia, although peat was known to be deposited throughout much of the country. Peat was burned in thermal powerplants in European U.S.S.R. and was also used to fire industrial boilers and large heating plants.

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF PEAT MOSS, BY COUNTRY[1]

Country	1989		1990	
	Quantity (short tons)	Value[2] (thousands)	Quantity (short tons)	Value[2] (thousands)
Canada	526,903	$69,688	597,854	$87,250
Denmark	—	—	238	48
Ireland	484	116	411	85
United Kingdom	111	46	228	75
Other[3]	2,208	81	70	74
Total[4]	529,706	69,931	598,802	87,533

[1]Poultry and fertilizer grade.
[2]Customs value.
[3]Includes Australia, Cameroon, Finland, France, the Federal Republic of Germany, Hong Kong, Japan, the Netherlands, Sweden, Switzerland, the U.S.S.R., and Vatican City.
[4]Data may not add to totals shown because of independent rounding.
Source: Bureau of the Census.

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF PEAT MOSS, BY CUSTOMS DISTRICT[1]

Customs district	1989		1990	
	Quantity (short tons)	Value[2] (thousands)	Quantity (short tons)	Value[2] (thousands)
Baltimore, MD	—	—	20	$48
Boston, MA	22	$2	—	—
Buffalo, NY	15,793	2,471	27,742	4,585
Chicago, IL	1,393	33	146	63
Cleveland, OH	161	23	—	—
Detroit, MI	55,282	7,905	63,587	9,867
Duluth, MN	1,518	177	5,074	533
Great Falls, MT	79,862	10,901	93,485	13,708
Honolulu, HI	23	5	—	—
Los Angeles, CA	286	89	192	31
Miami, FL	—	—	2	5
Milwaukee, WI	131	13	—	—
New Orleans, LA	12	3	—	—
New York, NY	619	14	19	12
Ogdensburg, NY	190,934	23,928	197,782	27,351
Pembina, ND	79,813	10,385	90,234	14,382
Philadelphia, PA	18	5	—	—
Portland, ME	57,320	7,114	67,029	8,659
San Juan, PR	96	26	497	109
Savannah, GA	17	8	—	—
Seattle, WA	20,365	3,068	21,424	3,401
St. Albans, VT	25,981	3,750	31,570	4,780
U.S. Virgin Islands	60	11	—	—
Total[3]	529,706	69,931	598,802	87,533

[1]Poultry and fertilizer grade.
[2]Customs value.
[3]Data may not add to totals shown because of independent rounding.
Source: Bureau of the Census.

TABLE 13

WORLD PEAT ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990

(Thousand short tons per year)

Country	Rated capacity[1]
North America:	
Canada	820
United States	[2]1,000
Total	1,820
Latin America: Argentina	5
Europe:	
Denmark	60
Finland	6,000
France	250
Germany, Federal Republic of:	
Western states	2,500
Hungary	100
Ireland	8,000
Netherlands	500
Norway	50
Poland	300
Spain	80
Sweden	70
U.S.S.R.	200,000
Total	217,910
Asia: Israel	30
Africa: Burundi	20
Oceania: Australia	20
World total	219,805

[1]Includes capacity at operating plants as well as at plants on standby basis.
[2]Includes rated capacity of 24 idle plants.
Source: Branch of Industrial Minerals, U.S. Bureau of Mines.

The use of peat as an energy source in the U.S.S.R. was reportedly declining because of insufficient reserves in the primary consuming areas and increasing demand in the agricultural sector. The chemical industry produced methanol and synthetic natural gas from peat.[11]

Ireland and Finland, in order of importance, accounted for more than 70% of the estimated 17 million tons of peat produced outside the U.S.S.R. in 1990. In Ireland, greater emphasis was being placed on fuel peat technology transfer, environmental technology, and the marketing of horticultural peat, while in Finland plans were being formulated for additional peat-fueled powerplants.

TABLE 14

PEAT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Argentina: Agricultural use	3	4	3	3	3
Australia[3]	8	10	11	[e]12	12
Burundi	14	19	19	16	17
Canada: Agricultural use (shipments)	814	[r]730	811	875	[4]826
Denmark: Agricultural use (sales)	53	[e]55	55	[e]55	55
Finland:					
Agricultural use	370	210	400	490	530
Fuel	5,600	2,000	4,100	4,900	4,500
France: Agricultural use[e]	240	230	220	220	220
Germany, Federal Republic of:					
Western states:					
Agricultural use	2,223	2,207	2,342	1,742	1,653
Fuel	271	265	256	256	254
Hungary: Agricultural use[e]	77	77	77	77	77
Ireland:					
Agricultural use	[r]251	[r]285	332	293	330
Fuel	5,193	6,765	4,473	8,557	7,000
Israel: Agricultural use[e]	22	22	22	22	22
Netherlands[e]	440	440	[r]330	[r]330	330
Norway:[e]					
Agricultural use	33	33	33	33	33
Fuel	1	1	1	1	1
Poland: Fuel and agricultural use[e]	220	275	220	220	220
Spain	[r]70	74	83	[r e]83	77
Sweden: Agricultural use[e]	66	66	66	66	66
U.S.S.R.:					
Agricultural use[e]	180,000	180,000	180,000	180,000	165,000
Fuel	21,500	12,600	19,290	18,519	16,500
United States:					
Agricultural use	912	955	844	761	[4]763
Fuel	—	—	—	—	W
Total	[r]218,381	[r]207,323	213,988	217,531	198,489
Fuel peat included in total	[r]32,785	[r]21,906	28,340	32,453	28,475

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data.

[1]Table includes data available through May 31, 1991.

[2]In addition to the countries listed, Austria, Iceland, and Italy produce negligible quantities of fuel peat and the Eastern states of the Federal Republic of Germany and Venezuela are major producers, but output is not officially reported, and available information is inadequate for formulation of reliable estimates of output levels.

[3]Excludes data from some States.

[4]Reported figure.

In 1989, Ireland's Bord na Móna achieved a new production record of 9 million tons. Bord na Móna was established by the Turf Development Act of 1946 to develop Ireland's peat resources. The Bord sells peat fuel to the Electricity Supply Board for use in peat-burning power stations, markets moss peat and other growing media to the garden and horticultural industries on a worldwide basis, sells briquettes and machine turf on the domestic fuel market, and manufactures pollution abatement products.

Bord na Móna reorganized in 1988, establishing three separate divisions covering milled peat operations, solid fuels, and horticultural products. Each division was headed by a chief executive officer at three separate locations within Ireland. The payback in terms of competitiveness, growth, and innovation was expected to be substantial.

The Horticultural Division sold 1.2 million cubic meters of peat and compost in 1989 compared with 1.3 million cubic meters for the previous year. Of the total sold, 90% was exported to the European Community (EC) and several other countries.

Bord na Móna purchased the French horticultural peat company Pouget-Solami S.A., which operated profitably as a subsidiary during 1989. Effective January 1990, the Bord also established its own distribution subsidiary, Du Móna France S.A., with offices in Lyon. With the complimentary manufacturing and marketing structures of Pouget-Solami and Du Móna, Bord na Móna established a competitive advantage in the French peat market.

Bord na Móna was also active in technology transfer activities in the United States during 1990.[12]

Peat accounts for about 4% of Finland's present energy supply, but plans were formulated to increase future peat production dramatically as a fuel for electric power generation. Finland's product distribution consists of about 80% milled peat and 20% sod peat. Plans were also formulated to increase the production of peat for horticultural purposes and for industrial and environmental applications. Finland's current production capability is about 6 million annual tons.[13]

Sweden currently produces about 1 million cubic meters of horticultural peat and about 2 million cubic meters of fuel-grade peat, annually. Swedish peatlands cover an area of about 6.3 million hectares (15.6 million acres), or about 15% of the total land area. About 865,000 acres of peatland is available for fuel peat production. The overall area suitable for horticultural peat production has not yet been surveyed.

Sweden has about 50 producers of horticultural peat, mainly in the south and middle regions. Roughly 400,000 cubic meters is produced as milled peat and 600,000 cubic meters as sod peat, of which 30% to 35% is exported. More than one-half of the domestic consumption is used by amateurs for home and garden applications.

After reaching a maximum production and sales of about 2.5 million cubic meters in 1950, fuel peat declined dramatically because of its economic disadvantages to cheaply priced fuel oil. By 1970, fuel peat production in Sweden was nonexistent. There was a subsequent revival in fuel peat demand beginning in the early 1980's, however, as an aftershock of the global energy crises of the 1970's.[14]

Capacity.—The data of table 13 are

rated capacity for peat operations as of December 31, 1990. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Current Research

There was much activity in peat research during 1990 and many outstanding accomplishments. Peat was demonstrated to act as an effective oil absorbent, and plans were formulated for active production and marketing in the United States. Peat was also shown to be an effective filtration source for the removal of toxic wastes and offensive odors and a superior bulking agent for composting organic wastes. Plans continued for the development of up to 360 megawatts of peat-fueled powerplants in south-central Florida beginning in mid-1995.

Humic acid extracts were developed that served as growth stimulants for agricultural and horticultural products and as a medium for animal health, growth, and development. Humic acids were also demonstrated to stimulate the anaerobic digestion processes used for municipal and industrial wastewater treatment.

Peat-based feminine hygienic products that demonstrated the potential for eventual commercialization were developed and test marketed in Canada. Peat also showed promise as a biodegradable medium in disposable diapers and in food packaging.

The Natural Resources Research Institute (NRRI), University of Minnesota at Duluth, conducted research with sphagnum papillosum, a high-fiber top moss that could be cultivated and continuously harvested from Minnesota sphagnum bogs. The material showed promise in the areas of oil sorption, composting, and as horticultural peat.[15]

Diversified Marketing Sales & Distribution (DMS&D) of Eatontown, NJ, was formed to market Berthonate peat oil absorbent, developed in cooperation with Encon Enterprises Inc. of Calgary, Alberta. Berthonate was reported to absorb up to six times its weight in oil.

Encon constructed a mobile pyrolysis unit that was capable of heating sphagnum peat to the hydrophobic stage between 225° and 650° F. The unit also demonstrated the potential to recover petroleum products absorbed by Berthonate. DMS&D planned to market Berthonate in the United States and expressed an interest in using U.S. sphagnum moss supplies.[16]

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.[17]

The U.S. Bureau of Mines Salt Lake City, UT, Research Center developed sphagnum moss bioaccumulation processes that were effective in extracting toxic metal ions from a variety of waste waters.[18] 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.[19]

In July 1990, EcoPeat Co. was formed to develop, own, and operate peat-fueled electric power facilities in North America.[20] EcoPeat was a joint venture between Outokumpu EcoEnergy Inc. of Owings Mills, MD, and the Stanton Group of Cambridge, MA. EcoPeat's long-term business strategy called for the development of at least 15 peat power projects within the next 10 years. The Outokumpu Group, based in Helsinki, Finland, is one of the world's leading base metal companies.

To further its objectives, EcoPeat acquired the assets of General Peat Resources LP, of St. Petersburg, FL, which had previously obtained 312 megawatts of peat fuel power contracts with Florida Power Corp. (FPC) and Florida Power and Light (FP&L) in south-central Florida. The power units were to be adjacent to vast peat reserves in the area.

EcoPeat planned to build and operate two 80-megawatt units near Lake Placid, FL, under contract with FPC at a capital construction cost substantially below the $300 million estimate previously proposed for three 52-megawatt units. A 40-megawatt oil-burning power unit at Avon Park, FL, was to be retrofitted for peat firing under a 30-year contract with FP&L at a capital cost of $60 million and was planned onstream by mid-1995.[21] Two 80-megawatt peat-fueled powerplants were also planned in Palm Beach County, FL, under contract with FP&L.

Assuming that EcoPeat's projects materialize as planned, it is estimated that about 2.5 million annual tons of bone-dry peat would be required to fire the plants. This would conceptually quadruple current U.S. peat production by the mid-to-late 1990's. EcoPeat reported that the fuel peat powerplants would be economically competitive and environmentally attractive when compared with conventional coal-fired plants.

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.[22]

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.[23]

After 15 years of research, Johnson & Johnson (J&J) launched a new line of ultrathin feminine hygiene napkins in Canada having an absorbent core of processed peat moss. J&J officials said the processed moss could absorb 20 times its weight in liquid. The firm claimed that its peat moss pad provided the same absorbency at one-fifth the thickness of ordinary hygienic pads and was slightly thinner and superior to "ultra thin" pads that relied on superabsorbent polymers.

The product, named Sure & Natural Prima, was the first commercial application of J&J's patented peat moss technology and was developed by the company's Montreal-based Canadian unit. J&J, headquartered in New Brunswick, NJ, would not speculate on when its new product may be marketed in the United States and other countries.[24]

The International Peat Society (IPS), Helsinki, Finland, held its "International Conference on Peat Production and Use" at Jyvaskyla, Finland, June 11-15, 1990. The conference sessions covered the following topics: fuel peat production; peat production for nonenergy purposes; effects of peat production on waterways; artificial dewatering; peat storage and transportation; peat use for environmental purposes; peat combustion; case studies; chemical mapping; chemistry of peat utilization; peatlands and carbon balance; and quantitative analysis aims and limitations.[25]

The IPS announced that the United States National Committee of the International Peat Society would host the 1991 International Peat Symposium under the title "Peat and Peatlands; The Resource and Its Utilization," in Duluth, MN, August 19-23, 1991. The symposium was to be organized in cooperation with the Iron Range Resources and Rehabilitation Board (IRRRB) and the Natural Resources Research Institute (NRRI).[26]

The IPS also announced that its ninth International Peat Congress would be held in Uppsala, Sweden, June 22-27, 1992, under the theme "Peat in nature and industry—a matter of balance."

OUTLOOK

The outlook for peat supply-demand in the United States is shown in table 15. During the past 20 years, U.S. domestic peat production has grown at an average annual rate of about 2.4% per year. The most recent upturn in the U.S. peat supply-demand cycle was experienced between 1981 and 1987. Domestic peat production hit the bottom of the latest cycle in 1981 at 0.7 million tons and gradually increased to a record 1.0 million tons by 1987, representing average annual growth of about 7%.

Total apparent domestic consumption during the same period followed the domestic production trend and grew at an average annual rate of 6%, from 1.1 million tons in 1981 to a record 1.5 millon tons in 1987.

Between 1987 and 1990, domestic peat production and total apparent domestic consumption declined 20% and 11%, respectively, owing to a downturn in the U.S. economy. Canadian imports as a percent of the total U.S. supply, how-ever, increased from 35% in 1987 to a record 44% in 1990 during the period of domestic downturn.

The U.S. Bureau of Mines forecast for horticultural peat during the next 5 years is based on a recovery in the economy and a resultant rebound in domestic production and total apparent domestic consumption. Domestic production of horticultural peat is forecast to grow at an average annual rate of about 3% to levels approaching 0.9 million tons by 1995. Per capita consumption is forecast to approximate 12 pounds by 1995, somewhat lower than the 12.7 pound average experienced during the peak years of 1986 and 1987.

Total apparent domestic consumption for horticultural purposes is also forecast to grow at an average annual rate of 3% per year to about 1.6 million tons by 1995. Canadian imports are forecast to rise by another 100,000 tons by 1995 and to compose 45% of the total U.S. horticultural peat supply.

Domestic peat production for fuel purposes is projected to reach about 650,000 tons in 1995 and to account for more than 50% of total domestic production. The forecast assumes that about one-half of the announced fuel peat powerplants in Florida will come on-stream by mid-1995. At full capacity, the total 360 megawatts announced by EcoPeat in Florida would consume about 2.5 annual tons and increase current U.S. production fourfold.

The global outlook for peat supply-demand is shown in table 16. Although the long-range outlook for balanced supply-demand conditions has not changed relative to last year's forecast, near-term prospects are less favorable because of the projected downturn in U.S.S.R. production. If the projected downturn only impacts the U.S.S.R.'s in-

TABLE 15

PEAT U.S. PRODUCTION AND DEMAND[1]

(Thousand short tons)

Year	Primary production[2]	Primary demand[3]
1970	517	809
1971	605	896
1972	577	917
1973	635	945
1974	731	1,033
1975	772	1,036
1976	774	1,069
1977	781	1,056
1978	822	1,130
1979	825	1,179
1980	785	1,207
1981	686	1,089
1982	798	1,080
1983	704	1,042
1984	800	1,146
1985	839	1,255
1986	912	1,548
1987	955	1,544
1988	844	1,468
1989[r]	761	1,336
1990[p]	763	1,372
1995[4]	[5]1,500	[5]2,200

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Calendar years.

[2]Gross production of U.S. peat.

[3]Apparent domestic consumption; calculated from sum of domestic production and imports, adjusted for yearend stock changes.

[4]Forecast.

[5]Includes 650,000 tons of fuel-grade peat required to operate 23-megawatt plant in Maine and 200-megawatts in Florida (assumed mid-1995 at 80% of rated capacity).

Source: Division of Mineral Commodities, Branch of Industrial Minerals, U.S. Bureau of Mines.

TABLE 16

WORLD PEAT SUPPLY-DEMAND RELATIONSHIPS[1]

(Million short tons peat)

	1985	1986[r]	1987[r]	1988[r]	1989[r]	1990[p e]	1991[2]	1992[2]	1993[2]	1994[2]	1995[2]
Capacity[3]	215.0	218.8	218.8	218.8	218.8	219.8	220.0	221.5	223.3	224.8	226.1
Demand:											
Agricultural	179.9	185.6	185.4	185.7	185.0	170.0	174.2	178.6	183.3	187.7	191.8
Fuel	24.6	32.8	21.9	28.3	32.5	28.5	29.1	29.6	30.1	30.6	31.5
Total	204.5	218.4	207.3	214.0	217.5	198.5	203.3	208.2	213.4	218.3	223.3
Operating rate[4]	95%	100%	95%	98%	99%	90%	92%	93%	95%	97%	99%
Consumption:											
Pounds per capita[5]	85.2	89.1	82.9	83.9	83.7	74.9	75.3	75.7	76.2	76.6	77.0
Population:											
Billion[6]	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8

[e]Estimated. [p]Preliminary. [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, 1990; Bureau of the Census.
Source: Division of Mineral Commodities, Branch of Industrial Minerals, U.S. Bureau of Mines.

ternal supply-demand situation, then the world outside the U.S.S.R. should still anticipate reasonably balanced conditions during the next 5 years. If the U.S.S.R. becomes pressured to move surplus product to the international marketplace, however, a global imbalance in peat supply-demand may be precipitated during the near-term.

The U.S. Bureau of Mines basic forecast methodology has been changed to include the assumption that production in the U.S.S.R. will gradually return to 1989 levels by 1995. 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 1985 and 1995, 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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PERLITE

By Wallace P. Bolen

Mr. Bolen, a physical scientist, is a graduate of the University of Virginia and has been the commodity specialist for perlite since September 1989. Domestic survey data were prepared by Blanche S. Hughes, mineral data assistant; and the international production table was prepared by Audrey Wilkes, international data coordinator.

U.S. production of processed perlite increased 6% in quantity and 7% in value. Expanded perlite sales increased 2% in quantity and 3% in value compared with those of 1989. Construction uses of expanded perlite accounted for 63% of total domestic sales in 1990.

DOMESTIC DATA COVERAGE

Domestic production data for perlite are developed by the U.S. Bureau of Mines from two voluntary surveys, one for domestic mine operations and the other for expanding plants. Of the 12 mining operations to which a request was sent, 10 responded, all active, and accounted for 100% of the total processed ore sold or used in table 1. Of the 67 expanding plants canvassed, 62 were active; of these, 44 plants or 71% responded, representing 79% of the total expanded perlite sold or used shown in table 1.

Perlite mined for processing came from 9 companies with 10 operations in 6 Western States and totaled 731,000 short tons. New Mexico operations accounted for a large majority of the total tonnage mined. The remaining tonnage came from Arizona, California, Colorado, Idaho, and Nevada. Apparent domestic consumption is defined as production plus imports minus exports. Apparent domestic consumption of processed perlite in 1990 was 669,000 tons, a slight increase from that of 1989.

PRODUCTION

Ore producers were Harborlite Corp. and Nord Perlite Co. in Arizona; American Perlite Co. in California; Persolite Products Inc. in Colorado; National Perlite Co. in Idaho; Delamar Perlite Co. in Nevada; and Grefco Inc., Manville Products Corp., and USG Corp. in New Mexico.

The quantity of expanded perlite sold and used from 62 plants in 33 States increased 2% in quantity compared with that of 1989. The value of expanded perlite increased 3% in 1990. Leading States, in descending order of sales, were Mississippi, Illinois, Pennsylvania, California, Georgia, Arizona, Kentucky, Minnesota, and Virginia.

CONSUMPTION AND USES

Construction-related uses, the major market for expanded material, decreased slightly to 332,300 tons. Expanded perlite used as filter aid, fillers, and in agricultural markets totaled 159,600 tons, an increase of 7% compared with that of 1989.

Perlite exports, primarily to Canada, were estimated to be 35,000 tons. Imports of perlite ore, mainly from Greece, were virtually the same as in 1989, about 65,000 tons.

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TABLE 1

PERLITE MINED, PROCESSED, EXPANDED, AND SOLD AND USED BY PRODUCERS IN THE UNITED STATES

(Thousand short tons and thousand dollars)

Year	Perlite mined[1]	Processed perlite					Expanded perlite		
		Sold to expanders		Used at own plant to make expanded material		Total quantity sold and used	Quantity produced	Sold and used	
		Quantity	Value	Quantity	Value			Quantity	Value
1986	735	303	9,536	204	6,110	507	480	479	83,700
1987	778	333	10,471	200	6,023	533	464	466	81,800
1988	830	375	11,588	201	6,064	576	480	479	88,900
1989	722	406	11,426	195	4,875	601	518	517	88,014
1990	731	430	11,101	209	6,342	639	534	527	90,625

[1] Crude ore mined and stockpiled for processing.

TABLE 2

EXPANDED PERLITE PRODUCED AND SOLD AND USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1989				1990			
	Quantity produced (short tons)	Sold and used			Quantity produced (short tons)	Sold and used		
		Quantity (short tons)	Value (thousands)	Average value per ton[1]		Quantity (short tons)	Value (thousands)	Average value per ton[1]
California	41,200	44,700	$8,363	$187	44,900	44,100	$8,098	$183
Florida	23,200	23,100	4,817	208	24,000	23,500	4,910	209
Indiana	22,200	22,200	5,839	263	22,800	22,700	5,947	261
Kansas	W	W	W	365	1,500	1,500	478	317
Pennsylvania	50,900	50,900	10,461	205	50,900	50,700	9,698	191
Texas	25,900	24,700	5,424	219	24,100	23,500	5,592	238
Utah	4,500	4,500	1,234	274	W	W	W	W
Other[2]	349,800	347,300	51,876	149	365,500	360,700	55,904	155
Total[3]	518,000	517,000	88,014	170	534,000	527,000	90,625	172

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1] Average value based on unrounded data and rounded to nearest dollar.
[2] Includes Alabama, Arizona, Arkansas, Colorado, Georgia, Idaho, Illinois, Iowa, Kentucky, Louisiana, Maine, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Nevada, New Jersey, New York, North Carolina, Ohio, Oregon, Tennessee, Virginia, Wisconsin, and Wyoming.
[3] Data may not add to totals shown because of independent rounding.

TABLE 3

EXPANDED PERLITE SOLD AND USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Short tons)

Use	1989	1990
Concrete aggregate	11,100	11,600
Fillers	28,200	26,600
Filter aid	70,800	83,400
Formed products[1]	291,200	292,400
Horticultural aggregate[2]	49,600	49,600
Low-temperature insulation	6,100	4,900
Masonry and cavity-fill insulation	10,200	13,300
Plaster aggregate	18,000	10,100
Other[3]	32,000	34,700
Total[4]	517,000	527,000

[1] Includes acoustic ceiling tile, pipe insulation, roof insulation board, and unspecified formed products.
[2] Includes fertilizer carriers.
[3] Includes fines, high-temperature insulation, paint texturizer, refractories, and various nonspecified industrial uses.
[4] Data may not add to totals shown because of independent rounding.

TABLE 4

PERLITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989	1990[e]
Australia[3]	4	6	5	r e6	6
Czechoslovakia	46	46	48	r e49	48
Greece	203	230	e230	r174	176
Hungary[3]	121	124	133	r120	121
Italy[e]	81	77	r77	78	78
Japan[e]	83	83	83	r e85	85
Mexico[3]	51	43	43	r41	40
Philippines[e]	4	r6	r8	r1	6
Turkey	r114	159	r170	r158	160
U.S.S.R.[e]	660	660	660	660	600
United States (processed ore sold and used by producers)	507	533	576	r601	[4]639
Total	r1,874	r1,967	r2,033	r1,973	1,959

[e] Estimated. [r] Revised.
[1] Unless otherwise specified, figures represent processed ore output. Table includes data available through May 17, 1991.
[2] In addition to the countries listed, Algeria, Bulgaria, China, Iceland, Mozambique, the Republic of South Africa, and Yugoslavia are believed to have produced perlite, but output data are not reported, and available information is inadequate for the formulation of reliable estimates of output levels.
[3] Crude ore.
[4] Reported figure.

PHOSPHATE ROCK

By William F. Stowasser

Mr. Stowasser, a physical scientist with 20 years of U.S. Bureau of Mines experience, has been the commodity specialist for phosphate rock since 1974. Domestic survey data were prepared by Christopher Lindsay, mineral data assistant; and the international data table was prepared by Audrey D. Wilkes, international data assistant.

The U.S. phosphate rock mining industry exists to primarily supply the demand for phosphate fertilizers. The fertilizer was used to promote production of food and feed grains for the domestic and international markets. The prospects for increased exports of U.S.-produced agricultural commodities was diminished when the European Community (EC) and the United States were not able to agree on modifying trading rules for agricultural products, which are not now included in the General Agreement on Tariffs and Trade. The EC resisted negotiating reductions in trade protection for agricultural products. The European Community Common Policy increased food prices inside Europe by purchasing excess farm production at artificially high prices. The overproduction was sold on world markets at competitive prices. It is probable that maintaining protectionism will reduce U.S. exports as well as those from the recognized more efficient farmers of Australia, Brazil, Canada, and New Zealand. Without the elimination of the EC's tariffs, other exporting countries will not be competitive in Europe. It is unlikely that the United States food and fertilizer export market share will increase.

World phosphate rock production declined an estimated 5% in 1990 to 154 million tons. It appears that several major producing countries produced less in 1990 compared with that of 1989. Production was controlled to meet demand and avoid unnecessary inventory in-

TABLE 1

SALIENT PHOSPHATE ROCK STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Mine production (crude ore)	135,683	148,426	162,299	170,268	151,277
Marketable production	40,320	40,954	45,389	49,817	46,343
P_2O_5 content	12,248	12,470	13,833	15,116	14,172
Value	[1]$897,131	[1]$793,280	$887,809	$1,084,022	$1,075,093
Average per metric ton[2]	$22.25	$19.37	$19.56	$21.76	$23.20
Sold or used by producers[3]	41,776	43,673	48,441	49,280	49,754
P_2O_5 content	12,750	13,286	14,760	14,935	15,098
Value	[1]$929,621	[1]$845,812	$947,721	$1,072,454	$1,154,422
Average per metric ton[2 4]	$22.25	$19.37	$19.56	$21.76	$23.20
Exports[5]	7,848	8,454	8,092	7,842	6,238
P_2O_5 content	2,521	2,737	2,608	2,522	2,019
Value[1]	$211,701	$194,691	$206,984	$227,272	$191,233
Average per metric ton[2]	$26.97	$23.03	$25.58	$28.98	$30.66
Imports for consumption	528	464	676	705	451
C.i.f. value	$25,435	$22,134	$26,310	$29,878	$21,905
Average per metric ton	[6]$48.18	$47.70	$38.92	$42.44	$48.57
Consumption[7]	34,456	35,683	41,022	42,143	43,967
Stocks, Dec. 31: Producers	13,277	10,884	9,323	11,027	8,912
World: Production	141,029	r147,617	r162,041	r158,966	154,106

[e] Estimated.
[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.

creases. A slackening in demand was probably caused by the political changes and uncertainties in Eastern Europe, by political changes in the U.S.S.R., and the invasion of Kuwait by Iraq.

DOMESTIC DATA COVERAGE

Domestic production data for phosphate rock are developed by the U.S. Bureau of Mines from two separate voluntary surveys of U.S. operations. Typical of these surveys is the semiannual Phosphate Rock Survey. Of the 19 operations to which a survey request was sent, all responded, representing 100% of the U.S. production data shown in table 1.

BACKGROUND

Phosphate rock deposits occur as marine phosphorites, apatite-rich igneous rock, and modern and ancient guano. All U.S. production was from marine phosphorites. It is the practice of the U.S. industry to express production and reserves in terms of beneficiated product. The grade of the product may be reported as percentage of phosphorus pentoxide (P_2O_5) or as tricalcium phosphate or expressed as percentage bone phosphate of lime (BPL). Conversion factors are $P_2O_5 = \%BPL \times 0.4576$; $\%BPL = P_2O_5 \times 2.1853$; and $P = P_2O_5 \times 0.436$. The phosphate ore bed or the zone of phosphorus-bearing material is commonly called the matrix in Florida and North Carolina.

Marketable phosphate rock was produced by 19 companies in the United States. Ten companies in Florida and one in North Carolina produced 87% of the phosphate rock. The 13% balance was produced in Idaho, Montana, Tennessee, and Utah. Approximately 95% of the phosphate rock was used to produce agricultural fertilizers and animal feed supplements. The balance was used in a variety of industrial chemicals.

Sedimentary apatite has a range of chemical compositions. The general formula for marine carbonate-apatite is $Ca_{10}(PO_4CO_3)_6Fe_{2-3}$. 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 is recoverable from the North Carolina deposit and another billion tons is recoverable from Florida deposits.

The deposits of phosphate rock in Tennessee in the Bigby-Cannon formation are small in size and irregular in shape. They were stripped and mined with 1.5- or 2.3-cubic meter (2- or 3-cubic yard) draglines. The ore was trucked or railed to washing and classification plants before agglomerating into electric furnace feed to produce elemental phosphorus.

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 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 mines in central Florida are in 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 clay 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.

ANNUAL REVIEW

In the history of the phosphate industry in the United States, the most important development was application of the flotation process to separate sand gangue from phosphate rock minerals. The process was applied in 1927 and 1928 at International Agricultural Corp. Phosphate Recovery No. 2 plant. More than one-half of the phosphate mined was wasted before the advent of flotation. Since 1928, there has been no other equivalent technological development.

Legislation and Government Programs

The U.S. Environmental Protection Agency (EPA) was required by the Clean Air Act to review standards of performance for new, modified, or reconstructed stationary sources every 4 years. The first review of the existing new source performance standards (NSPS) for phosphate rock plants was completed to determine the need to revise existing standards. EPA concluded that no revision to the standard was necessary at this time.

The EPA on January 23, 1990, removed 5 of 20 conditionally retained mineral processing wastes from the exemption of hazardous waste regulations provided by section 3001 (b)(3)(A)(ii) of the Resource Conservation and Recovery Act (RCRA), often referred to as the Bevill exclusion. Furnace off gas solids from elemental phosphorus production was removed from the Bevill exclusion. Of the 20 mineral processing wastes that were conditionally retained within the scope of the Bevill exemption were phosphogypsum, from phosphoric acid production, and slag, from elemental phosphorus production. Process wastewater from phosphoric acid production was proposed for temporary retention in the Bevill exclusion.

The EPA will either subject the special mineral processing wastes (i.e., phosphogypsum and phosphoric acid process wastewater) to regulation under subtitle C as hazardous wastes or conclude that

such regulation is unwarranted. Wastes for which the exclusion is retained will be subject to regulation under RCRA subtitle D as solid wastes and will likely be placed into the regulatory regime being developed for mineral extraction and beneficiation wastes.

Farmers made little change in 1990 cropland use as Congress prepared new farm legislation. The 1990 farm bill targeted additional land for conservation tillage, contouring, terracing grassed waterways, and diversions to reduce cropland erosion. In addition, the long-term Conservation Reserve Program was extended as was a program to implement water quality protection and restoration of drained wetlands.

The need to cut total spending caused the most significant changes in Federal farm programs. They included the following:

1. Establishment of a new system for determining subsidy payments for farmers participating in commodity programs. The new "triple base" system requires farmers to forego subsidy payments on another 15% of their cropland, over the percent of land set aside, to obtain subsidy payments on the remainder. On the 15% reduced acres, farmers can plant any commodity crop.
2. Allowance of additional planting flexibility.
3. Establishment of a new oilseed support program.
4. Modification of the existing 0/92 program to the 0/77 program that allows farmers to plant more profitable resource-conserving crops, including oilseed but not soybeans.
5. Establishment of an integrated farm management program.
6. Broadening of purposes of agriculture research.

The conservation section of the farm bill includes programs to protect erodible land and wetlands. By 1995, 16 to 18 million hectares (40 to 45 million acres) will be enrolled in the Agricultural Resources Conservation program.

Strategic Considerations

Food security for an expanding world population from a limited land base will be difficult to accomplish in future years. Increasing world population has been one of the factors promoting world grain trade as well as demand for higher per capita food consumption levels and improved living standards. World population has increased from 3.7 billion in 1960 to an estimated 5.3 billion in 1990. The U.S. Bureau of the Census estimates that world population will increase to 6.2 billion in the year 2000 and about 10 billion in the year 2040, a short 50 years into the future.

Phosphate rock, because of its availability, was not strategically stockpiled. As world population levels increase in future years, so will the demand for phosphate rock to produce phosphate fertilizers (plant nutrients) for food production to sustain the world population. The supply of phosphate rock to increase food production in the next century will not be from the same sources as it is today. To meet the anticipated demand, phosphate rock production will rise from 154 million tons in 1990 to an estimated 300 to 400 million tons in the year 2040. This will be difficult to achieve because many of the phosphate rock mines that supply today's world demand will be depleted within a 50-year timespan. The supply of phosphate rock from deposits in the United States will probably be only one-third of its present level, even assuming that the profitability will be sufficiently high to justify mining lower quality resources. Although the United States has a substantial phosphate rock reserve base, an estimated 4.4 billion tons, Morocco's 22 billion ton base supports the probability that, without major new discoveries, it will be the principal phosphate rock supplier to the world in the next century.

Issues

A number of phosphate rock mines in Florida will close as the reserves are mined out in future years. Without the construction of new mines in Florida, the supply of phosphate rock will decline from a planned production of 40 million tons in 1993 and 1994 to 22 million tons in 1997. Deposits of phosphate rock in the southern extension of the Bone Valley Formation are known, and mining centers can be constructed if the investments can be justified. It is probable, but not assured, that when the U.S. domestic supply of phosphate rock is reduced, phosphate rock exports will diminish. Manufactured phosphate fertilizers will be available to both domestic and export markets, and, in this situation, projected to occur in the mid-1990's, the selling price of these commodities will probably increase. Return on investments will then be able to justify investment in new phosphate rock mines. If new phosphate rock mines are not developed, phosphate rock and phosphate fertilizer imports will probably increase to make up a short fall in domestic supply, concurrent with a reduction in exports. An increase in the selling price of phosphate rock and phosphate commodities, if achieved, will improve its profitability in the market; however, it is also probable that the costs associated with production will increase to meet standards set to ensure land reclamation, control hazardous wastes, minimize water consumption, and maintain air and water quality.

Production

Production of marketable phosphate rock in the United States decreased 7% in 1990 to 46.3 million tons. This was 3.5 million tons less production than was planned by producers of phosphate rock as demand for phosphate fertilizers and phosphate chemicals was less than that of 1989. The 3.5 million ton decline of production compared with that of 1989 occurred in the producing States of Florida and North Carolina. Production from Tennessee and the Western States was the same as that of 1989.

Florida and North Carolina.—Phosphate rock was produced in central Florida by Agrico Chemical Co., a division of Freeport-McMoRan Resource Partners L.P.; CF Industries Inc.; Estech Inc., owned by C&G Holdings Inc.; Gardiner Inc., 80% ownership by Cargill, Inc.; IMC Fertilizer Inc. (IMC); Mobil Mining and Minerals Co.; U.S. Agri-Chemicals Corp., owned by Sinochem (USA) Inc.; Seminole Fertilizer Corp., owned by Tosco Corp.; and Nu-Gulf Industries Inc., owned by Gulf Atlantic Corp. In northern Florida, Occidental Chemical Agricultural Products Inc. produced phosphate rock for conversion to superphosphoric acid.

Low-fluorine soft phosphate rock was recovered from hard phosphate rock tailing ponds in north-central Florida by Manko Co., Howard Phosphate Co., and Loncala Phosphate Co.

Texasgulf Inc., a subsidiary of Elf Aquitane Inc., produced phosphate rock

for domestic consumption in its adjacent fertilizer plant and for export. The mine and plant are on the Pamlico River in eastern North Carolina. The U.S. Army Corps of Engineers issued a feasibility report and environmental assessment of harbor improvement for Morehead City, NC. If implemented, it will improve the competitive export position of Texasgulf.

Tennessee.—Occidental Chemical Corp. produced elemental phosphorus in three electric furnaces from local ores in Columbia, TN.

Stauffer Chemical Co., a division of Rhône-Poulenc Basic Chemicals Inc. also produced elemental phosphorus from local ores in Mount Pleasant, TN. Monsanto Co. closed its electric furnaces in Tennessee in 1986. As a matter of interest, Albright & Wilson Americas closed its electric furnace plant at Long Harbour, Newfoundland, in 1989. Rhône-Poulenc will close the phosphate rock mines in Tennessee in early 1991 and phaseout the electric furnaces thereafter. With rising energy costs and new purified wet-process phosphoric acid technology, purified wet process plants are proliferating in the United States. Olin Corp., Joliet, IL, purifies wet-process phosphoric acid to produce sodium phosphates. A joint venture by Olin, Texasgulf, and Albright & Wilson was formed to construct a wet-process purified phosphoric acid plant at Aurora, NC. Rhône-Poulenc was constructing a new wet-process phosphoric acid purification plant at Geismar, LA.

Western States.—Phosphate rock was mined in Idaho, Montana, and Utah to produce both elemental phosphorus and phosphate fertilizers. J.R. Simplot Co. produced phosphate rock from the Gay Mine on the Fort Hall Indian Reservation and from the Smoky Canyon Mine, Caribou National Forest. Mainbed ore from the Gay Mine was used by Simplot to produce wet-process phosphoric acid, and FMC Corp. used the lower grade shale in its electric furnaces near Pocatello, ID.

Monsanto Co. 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 its Wooley Valley Mine, Caribou National Forest, ID, and shipped the phosphate rock 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 Maybie Canyon, Mountain Fuel, and Champ Williams Mines in the Caribou National Forest. The phosphate rock was shipped by rail to Conda, ID, beneficiated, calcined, and used to produce wet-process phosphoric acid. Cominco American Inc. operated the only underground phosphate rock mine in the United States. The mine, beneficiation plant, and drying operation are near Garrison, MT. The product was exported to Canada. Chevron Resources Co. produced and concentrated phosphate rock from its mine near Vernal, UT. The slurry concentrate was pumped to Rock Springs, WY.

Consumption and Uses

In recent years, the demand pattern for phosphate rock has shown a gradual decline in phosphate rock exports, and about one-half of that consumed domestically was exported in a higher value form. More than 77% of the phosphate rock was used to produce wet-process phosphoric acid for the domestic and export markets, and the balance was used to produce a series of chemicals from elemental phosphorus.

Elemental phosphorus from electric furnace operations may be converted into cobalt phosphate for pigments and animal feed supplements; into copper phosphide for phosphor bronze; into red elemental phosphorus for safety matches and pyrotechnics; into phosphorus trichloride for phosphorus oxy-

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
			Used directly		Beneficiated		Totals			
	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content	Value[1]	
1989:[2]	170,268	27,490	3,899	1,058	45,919	14,058	49,817	15,116	1,084,022	11,027
1990:										
January–June										
Florida and North Carolina	71,789	8,135	r337	100	19,766	6,046	r20,103	6,146	r467,372	8,072
Idaho, Montana, Tennessee, and Utah	4,164	1,013	1,249	326	1,448	447	r2,697	773	r60,840	1,589
Total	75,953	9,148	r1,586	426	21,214	6,493	22,800	6,919	r528,212	9,661
July–December										
Florida and North Carolina	71,187	7,765	249	78	20,009	6,202	20,258	6,280	483,356	7,440
Idaho, Montana, Tennessee, and Utah	4,137	1,012	1,818	500	1,467	473	3,285	973	63,525	1,472
Total	75,324	8,777	2,067	578	21,476	6,675	23,543	7,253	546,881	8,912
Grand total	151,277	17,925	3,653	1,004	42,690	13,168	46,343	14,172	1,075,093	XX

r Revised. XX Not applicable.

[1] Computer-calculated value based on the weighted sold or used value.

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

chloride, phosphorus pentachloride gasoline additives, plasticizers, and dyestuffs; into phosphorus trisulfide for matches; and into phosphorus pentasulfide for lubricating oil additives, flotation reagents, rubber additives, and a stabilizer for aromatic amines. Phosphorus pentoxide was used to produce phosphoric acid for a large number of products—phosphorus oxychloride catalyst for air blown asphalt, for drying agents, for leather tanning, medicine, liquid paint remover formulations, dehydrating agents, and sugar refining. There are military applications for elemental phosphorus to produce smoke columns and screens and incendiary bombs and shells. The byproduct of elemental phosphorus, ferrophosphorus, was used in alloy steels and processed to recover contained vanadium.

Wet-process phosphoric acid was used to produce the fertilizers ammonium phosphates, triplesuperphosphate, monobasic and dibasic calcium phosphates for animal feed supplements, and detergents of sodium and potassium polyphosphates. Mineral feed supplement rock was produced from defluorinated phosphate rock. Byproducts from wet-process phosphoric acid include phosphogypsum, uranium, vanadium, calcium chloride, sodium fluorosilicate, and fluosilicic acid.

Phosphate rock exports as well as imports declined in 1990. Exports of phosphate fertilizers held at a high level in 1990, possibly explaining the fact that phosphate rock exports declined to 6.2 million tons in 1990, about 20% less than that of 1989. Most of the phosphate rock imports was used by producers of liquid fertilizer.

Stocks

About 90% of phosphate rock stocks in the United States was held adjacent to the beneficiation plants in Florida and North Carolina. Inventoried phosphate rock in Florida and North Carolina was either dried for export, calcined to increase grade and potential phosphoric acid quality, or wet ground to produce phosphoric acid. In the Western States, phosphate rock was stockpiled during the warm months of the year near electric furnaces and wet-process phosphoric acid plants to avoid the problem of unloading frozen ore from railroad cars and truck boxes in the wintertime.

The level of phosphate rock inventories declined from a peak of 20 million tons in 1981 to 9.3 million tons in 1988. Yearend stocks in 1989 and 1990 were about 11 million tons and 9 million tons, respectively, indicating producers were controlling phosphate rock inventories.

Transportation

From production centers in central and north Florida, phosphate rock and phosphate fertilizers were moved by rail to terminals on Hillsborough Bay, FL, and in Jacksonville, FL. In central Florida, CSX Transportation railroad moved product to terminals on Tampa/Hillsborough Bay. The Rockport terminal was owned and operated by the CSX railroad, Port Sutton was owned and

TABLE 3

U.S. PHOSPHATE ROCK SOLD OR USED GRADE DISTRIBUTION PATTERN

Grade (percent BPL[1] content)	Distribution (percentage)				
	1986	1987	1988	1989[2]	1990
74 or more	4.5	3.4	2.0	0.8	0.3
72 to less than 74	4.0	5.4	5.6	7.4	8.3
70 to less than 72	7.8	7.1	8.8	6.2	3.9
66 to less than 70	57.5	61.6	59.7	61.7	59.5
60 to less than 66	20.3	17.5	14.9	19.3	19.8
Less than 60	5.9	5.0	9.0	4.7	8.2

[1] 1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.
[2] Data do not add to 100% because of independent rounding.

TABLE 4

FLORIDA AND NORTH CAROLINA PHOSPHATE ROCK SOLD OR USED GRADE DISTRIBUTION PATTERN

Grade (percent BPL[1] content)	Distribution (percentage)				
	1986	1987	1988	1989	1990
74 or more	5.1	3.8	2.3	0.9	0.3
72 to less than 74	4.6	6.0	6.4	7.6	7.6
70 to less than 72	9.0	7.6	8.2	6.2	4.4
66 to less than 70	60.7	65.3	64.0	66.4	63.4
60 to less than 66	20.6	17.3	14.4	18.9	19.3
Less than 60	—	(2)	4.7	—	5.0

[1] 1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.
[2] Less than 0.1 of 1%.

TABLE 5

TENNESSEE AND WESTERN STATES PHOSPHATE ROCK SOLD OR USED GRADE DISTRIBUTION PATTERN

Grade (percent BPL[1] content)	Distribution (percentage)				
	1986	1987	1988	1989	1990
72 to less than 74	—	—	—	5.6	13.4
70 to less than 72	—	3.5	12.5	6.1	—
66 to less than 70	36.1	33.9	29.8	28.6	30.7
60 to less than 66	18.5	19.3	18.2	21.8	23.5
Less than 60	45.4	43.3	39.5	37.9	32.4

[1] 1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

TABLE 6

PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY GRADE AND REGION

(Thousand metric tons and thousand dollars)

Grade (percent BPL[1] content)	Florida and North Carolina			Tennessee and Western States[2]			Total		
	Rock	P_2O_5 content	Value[3]	Rock	P_2O_5 content	Value[3]	Rock	P_2O_5 content	Value[3]
January–June 1989	22,074	6,763	479,960	2,718	784	60,809	24,792	7,547	540,769
July–December 1989	21,056	6,422	472,034	3,431	968	59,650	24,487	7,390	531,684
January–June 1990:									
74 or more	21	8	681	—	—	—	21	8	681
72 to less than 74	1,620	541	49,430	379	127	13,372	1,999	668	62,802
70 to less than 72	1,135	369	34,478	—	—	—	1,135	369	34,478
66 to less than 70	14,850	4,543	313,001	782	243	20,549	15,632	4,786	333,550
60 to less than 66	4,425	1,251	115,086	688	193	12,253	5,113	1,444	127,339
Below 60	—	—	—	r764	192	12,758	r764	192	12,758
Total	22,051	6,712	512,676	r2,613	755	58,932	r24,664	7,467	571,608
July–December 1990:									
74 or more	104	36	4,238	—	—	—	104	36	4,238
72 to less than 74	1,702	568	52,805	408	135	14,840	2,110	703	67,645
70 to less than 72	823	266	25,342	—	—	—	823	266	25,342
66 to less than 70	12,962	3,967	295,548	1,020	320	24,857	13,982	4,287	320,405
60 to less than 66	4,048	1,264	76,839	692	197	9,760	4,740	1,461	86,599
Below 60	2,186	590	65,982	1,145	288	12,603	3,331	878	78,585
Total	21,825	6,691	520,754	3,265	940	62,060	25,090	7,631	582,814

r Revised.
[1] 1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.
[2] Includes Idaho, Montana, and Utah.
[3] F.o.b. mine.

TABLE 7

PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons)

Use	1989 total		1990					
			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	37,931	11,394	19,762	5,939	18,647	6,175	38,409	12,114
Normal superphosphate	937	297	308	94	2,075	101	2,383	195
Triple superphosphate	410	137	206	68	223	73	429	141
Defluorinated rock	—	—	—	—	—	—	—	—
Direct applications	3	1	2	1	1	—	3	1
Elemental phosphorus	2,122	575	1,015	278	1,241	341	2,256	619
Ferrophosphorus	37	9	r19	r4	17	5	36	9
Total[2]	41,437	12,413	r21,312	r6,384	22,204	6,695	43,516	13,079
Exports[3]	7,842	2,522	3,352	1,083	2,886	936	6,238	2,019
Grand total[2]	49,280	14,935	r24,664	r7,467	25,090	7,631	49,754	15,098

r Revised.
[1] Includes rock converted to products and exported.
[2] Data may not add to totals shown because of independent rounding.
[3] Exports reported to the U.S. Bureau of Mines by companies.

TABLE 8

PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE AND REGION

(Thousand metric tons)

Use	Florida and North Carolina		Tennessee and Western States[1]		Total	
	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content
1989:[2]	43,130	13,185	6,151	1,752	49,279	14,935
1990:						
January–June:						
Domestic:[3]						
Agricultural	18,716	5,635	1,561	466	20,278	r6,101
Industrial	46	13	989	270	r1,034	283
Subtotal	18,762	5,648	2,550	736	r21,312	r6,384
Exports[4]	3,289	1,064	63	19	3,352	1,083
Total	22,051	6,712	2,613	755	r24,664	r7,467
July–December:						
Domestic:[3]						
Agricultural	18,969	5,764	1,976	586	20,946	6,350
Industrial	27	8	1,231	337	1,258	345
Subtotal	18,996	5,772	3,207	923	22,204	6,695
Exports[4]	2,829	919	57	17	2,886	936
Total	21,825	6,691	3,265	940	25,090	7,631
Grand total	43,876	13,403	5,878	1,695	49,754	15,098

r Revised.
[1] Includes Idaho, Montana, and Utah.
[2] Data may not add to totals shown because of independent rounding.
[3] Includes rock converted to products and exported.
[4] Exports reported to the U.S. Bureau of Mines by companies.

TABLE 9

FLORIDA AND NORTH CAROLINA PHOSPHATE ROCK SOLD OR USED BY PRODUCERS

Year	Rock (thousand metric tons)	P_2O_5 content (thousand metric tons)	Value	
			Total[1] (thousands)	Average per ton f.o.b. mine
1986	36,333	11,236	$810,429	$22.31
1987	38,692	11,891	765,061	19.77
1988	42,395	13,036	829,963	19.58
1989	r43,130	r13,185	951,995	22.07
1990	43,876	13,403	1,033,430	23.55

r Revised.
[1] The total value is based on a weighted value.

operated by IMC, Eastern Associated Terminal (E.A.T.) was owned and operated by E.A.T, and Big Bend was owned and operated by Agrico Mining Co.

Markets and Prices

The price or value of phosphate rock was obtained by semiannually surveying the producing companies to obtain domestic and export selling prices for each grade of phosphate rock, f.o.b. mine. The data were used to calculate the average selling price for each grade of phosphate rock in the domestic and export market. Historical average selling prices from 1970 through 1990 are shown in table 12.

Estimates of phosphate rock export prices, unground, f.o.b. vessel, Tampa Range or Jacksonville, FL, by grade are shown in table 13. The estimates indicate that export prices increased about $3.00 per ton from Florida. Table 14 shows estimates of Moroccan phosphate rock export prices, U.S. dollars per ton, f.a.s. Laayoune, Casablanca, or Jorf Lasfar. Tables 15, 16, and 17 show the price or value of Florida and North Carolina, Tennessee and the Western States, and the United States, respectively, by grade for the domestic and export markets and an average selling price.

In north Florida, the Norfolk Southern Railroad moved phosphate rock from Occidental's mines to Occidental's terminal in Jacksonville, FL.

Rail freight published tariffs and loading charges for phosphate rock at central Florida terminals were $6.46 per ton. The published freight and loading cost in North Florida was $9.08 per ton.

The U.S. Corps of Engineers completed deepening the Tampa Bay Channel, Hillsborough Bay Channel, and Sparkman Channel to a depth of 13.7 meters (45 feet) to accommodate deep draft vessels. Berth 31, adjacent to the Port Sutton turning basin, was deepened to 13.1 meters (43 feet). The berth accommodates larger vessels carrying more cargo to use the port. The berth was used to "top-off" phosphate rock cargoes.

In Tennessee and the Western States, phosphate rock was moved by both railroad and truck to either beneficiation plant or electric furnace facilities. Phosphate concentrates were transported by pipeline by two companies producing in Idaho and Utah.

TABLE 10

TENNESSEE AND WESTERN STATES[1] PHOSPHATE ROCK SOLD OR USED BY PRODUCERS

Year	Rock (thousand metric tons)	P_2O_5 content (thousand metric tons)	Value	
			Total[2] (thousands)	Average per ton f.o.b. mine
1986	5,443	1,515	$119,192	$21.90
1987	4,981	1,395	80,751	16.21
1988	6,047	1,723	117,758	19.47
1989	6,151	r1,752	120,459	19.58
1990	5,878	1,695	120,992	20.58

r Revised.
[1] Includes Idaho, Montana, and Utah.
[2] The total value is based on a weighted value.

Self-unloading barges were used in North Carolina to transport phosphate rock concentrates from the Aurora Mine to the Morehead City Port Terminal.

Foreign Trade

Large fertilizer plants, near the supply of phosphate rock and sulfur, generally have lower capital and operating costs compared with smaller plants and, by minimizing transportation costs, their competitive position is improved. Trade in high-analysis phosphate fertilizers has increased, and trade in low-analysis phosphate rock has declined as was exemplified by the reduction in world phosphate rock exports in the 1980's.

The United States was a net exporter of phosphate rock in 1990. Phosphate rock exports declined by about 20% compared with that of 1989. Exports of higher value phosphate fertilizers were similar to those of 1989. The export tons and values for ground and unground phosphate rock, superphosphates, ammonium phosphates, phosphoric acid, and elemental phosphorus are shown in tables 18 through 25.

The principal countries that have sources of phosphate that compete in international trade are Algeria, Israel, Jordan, Morocco, Senegal, Syria, the Republic of South Africa, Togo, Tunisia, and the United States. Countries with indigenous supplies of phosphate rock have recognized the advantages of exporting high-analysis phosphate fertilizers rather than phosphate rock. U.S. phosphate rock exports have declined, and exports of ammonium phosphates and superphosphates have increased during the past decade.

Phosphate rock was exported from

TABLE 11

MARKETABLE PHOSPHATE ROCK YEAREND STOCKS

(Million metric tons)

Year	Quantity
1981	19.6
1982	18.3
1983	14.5
1984	11.9
1985	15.5
1986	13.3
1987	10.9
1988	9.3
1989	11.0
1990	8.9

TABLE 12

TIME-PRICE RELATIONSHIPS FOR PHOSPHATE ROCK[1]

(Dollars per metric ton)

Year	Actual prices	Based on constant 1990 dollars
1970	5.80	18.16
1971	5.80	17.18
1972	5.62	15.89
1973	6.24	16.58
1974	12.10	29.47
1975	25.35	56.21
1976	21.26	44.31
1977	17.39	33.98
1978	18.56	33.80
1979	20.04	33.53
1980	22.78	34.95
1981	26.63	37.25
1982	25.52	33.56
1983	23.97	30.34
1984	23.99	29.29
1985	24.31	28.83
1986	22.25	25.71
1987	19.37	21.70
1988	19.56	21.20
1989	21.76	22.66
1990	23.20	23.20

[1] Average annual U.S. producer domestic and export price, f.o.b. mine.

TABLE 13

PHOSPHATE ROCK ESTIMATED EXPORT PRICES[1] PER METRIC TON, UNGROUND, F.O.B. VESSEL TAMPA RANGE OR JACKSONVILLE, FL, BY GRADE

Grade (percent BPL[2] content)	1987[3]	1988[4]	1989[5]	1990[6]
75	$32.00	$33.00	$38.00	$41.50
72	29.00	31.00	35.50	38.50
70	27.50	28.00	32.00	36.00
68	24.00	26.00	31.00	34.00

[1] Prices include severance taxes, rail freight costs from mine to port, and port loading and weighing charges.
[2] 1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.
[3] Estimated selling price, including a revised severance tax of $2.49.
[4] Estimated selling price, including a revised severance tax of $1.99.
[5] Estimated selling price, including a revised severance tax of $1.48.
[6] Estimated selling price, including $1.52 severance tax.

Note.—Estimated 1991 severance tax is $1.62.
Source: Florida State tax office.

central Florida mines through Tampa, FL; Occidental in North Florida exported through Jacksonville, FL; Texasgulf exported through Morehead City, NC; and Western States phosphate rock was exported into Canada.

Phosphate rock imports declined from 705,000 tons in 1989 to about 451,000 tons in 1990. In past years, phosphoric acid plants at Taft, LA, and Pascagoula, MS, imported Moroccan phosphate rock. Currently, a Geismar, LA, phosphoric acid plant is importing phosphate rock from the Moroccan Bou Craa phosphate rock mine to produce super phosphoric acid for liquid fertilizer. Weak fertilizer demand from the U.S. market has reduced the demand for imported phosphate rock.

World Review

The changes in the political systems in Eastern Europe and the war in the Middle East reduced the demand for phosphate fertilizers in these parts of the world and reduced phosphate rock exports from involved Middle East countries. Restricting Iraqi trade eliminated exports of sulfur, phosphate rock, and phosphate fertilizers and reduced exports of phosphate rock and phosphate fertilizers from Jordan. The Persian Gulf crisis has decreased the stability of several economies in the region that supply raw materials and finished fertilizers.

There were no significant changes in the function of the world phosphate rock industry with the exception of the impact of the Gulf war on Jordan. The Port of Aqaba operated at 80% of its capacity. Another contributing factor to the decline of phosphate rock shipments from Syria and Jordan was the drop in demand from Eastern European Countries.

The world phosphate rock capacity was estimated and is shown in table 27. An estimated capacity of about 200 million tons was unchanged from the 1989 estimate. In countries where mines have closed for reasons of depletion of reserves or high costs, world production was maintained by increasing the output from existing mines or by moving mining equipment to another deposit. The mining capacity was essentially maintained.

The U.S. Bureau of Mines has estimated world phosphate rock reserves and the reserve base. Reserves and re-

TABLE 14

MOROCCAN PHOSPHATE ROCK EXPORT PRICES, U.S. DOLLARS PER METRIC TON, F.A.S. CASABLANCA, JORF LASFAR, AND LAAYOUNE, BY GRADE[1]

Grade (percent BPL[2] content)	1985	1986	1987	1988	1989	1990[e]
Khouribga:						
72 to 73	40.50	40.50	35.00	40.50	45.00	48.00
70 to 71	39.50	39.00	34.00	38.50	42.00	45.00
Youssoufia:						
74 to 75	—	40.50	39.50	45.00	49.00	51.00
68 to 69	—	30.50	30.00	34.00	37.00	40.00
Phosboucraa:						
79 to 80	43.00	42.00	40.50	45.50	50.50	53.00

[e] Estimated.
[1] Revised.
[2] 1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

Source: Moroccan Office Cherifien des Phosphates.

TABLE 15

PRICE OR VALUE OF FLORIDA AND NORTH CAROLINA PHOSPHATE ROCK, BY GRADE

(Dollars per metric ton, f.o.b. mine)

Grade (percent BPL[1] content)	1989			1990		
	Domestic	Export	Average	Domestic	Export	Average
74 or more	27.70	38.63	29.87	31.84	40.77	39.25
72 to less than 74	25.73	30.57	29.29	27.83	32.17	30.78
70 to less than 72	25.04	29.47	28.90	26.12	30.95	30.56
66 to less than 70	19.68	26.73	20.31	21.39	29.25	21.88
60 to less than 66	22.83	20.82	22.76	22.91	13.19	22.65
Less than 60	—	—	—	30.18	—	30.18
Average	20.65	28.67	22.07	22.44	30.43	23.55

[1] 1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

TABLE 16

PRICE OR VALUE OF TENNESSEE AND WESTERN STATES[1] PHOSPHATE ROCK, BY GRADE

(Dollars per metric ton, f.o.b. mine)

Grade (percent BPL[2] content)	1989			1990		
	Domestic	Export	Average	Domestic	Export	Average
72 to less than 74	36.93	—	36.93	35.85	—	35.85
70 to less than 72	36.38	—	36.38	—	—	—
66 to less than 70	26.50	44.88	27.56	24.62	42.47	25.19
60 to less than 66	10.02	40.00	11.61	7.31	41.67	15.95
Less than 60	12.87	—	12.87	13.29	—	13.29
Average	18.91	42.87	19.58	18.44	42.05	20.58

[1] Includes Idaho, Montana, and Utah.
[2] 1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

TABLE 17

PRICE OR VALUE OF U.S PHOSPHATE ROCK, BY GRADE

(Dollars per metric ton, f.o.b. mine)

Grade (percent BPL[1] content)	1989			1990		
	Domestic	Export	Average	Domestic	Export	Average
74 or more	27.70	38.63	29.87	31.84	40.77	39.25
72 to less than 74	28.93	30.57	30.02	31.23	32.17	31.75
70 to less than 72	30.99	29.47	29.83	26.12	30.95	30.56
66 to less than 70	20.08	27.42	20.73	21.59	29.67	22.08
60 to less than 66	21.05	24.61	21.19	20.76	19.42	21.71
Less than 60	12.87	—	12.87	22.31	—	22.31
Average	20.40	28.98	21.76	21.91	30.66	23.20

[1] 1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

TABLE 18

U.S. EXPORTS OF GROUND PHOSPHATE ROCK, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 2510.20.0000)

Country	1989		1990	
	Quantity	Value	Quantity	Value
Australia	5	NA	5	NA
Canada	165		126	
France	586		473	
Germany, Federal Republic of	211		47	
India	10		25	
Italy	17		—	
Japan	1		—	
Korea, Republic of	1		1	
Mexico	46		65	
Netherlands	361		144	
New Zealand	163		130	
Romania	39		42	
Other	40		26	
Total	1,645	57,708	1,084	38,695

NA Not available.

Source: Bureau of the Census.

serve base estimates shown in tables 28 and 29 include those with costs less than $40 and $100 per ton, respectively. The reserve and reserve base estimates are largest in the continent of Africa and include the carbonatite deposit in the Republic of South Africa and the vast sedimentary deposits in northwest Africa. Significant reserves exist in the U.S.S.R and in Florida and North Carolina in the United States.

OUTLOOK

During the next 3 to 5 years, the supply of phosphate rock is forecast to be adequate to meet agriculture and industrial demands. World demand is forecast to increase at an annual rate of 1% to 2% to meet the demands of population increases.

Although the Bevill amendment excluded solid waste from regulatory control under the Resource Conservation and Recovery Act, the EPA, in 1989 and 1990, defined which processing wastes met high-volume, low-hazard criteria. The wastes that did not meet both criteria would be subject to subtitle C regulation. The final mineral processing report to Congress was made in July 1990, and the final mineral processing regulatory determination will be made in 1991.

Phosphate rock exports show a declining trend. Conversion of phosphate rock into higher analysis and value products has increased in the United States and the world to maximize the profitability of the commodity. Imports of high-grade and high-quality phosphate rock to manufacture phosphoric acid and liquid phosphoric fertilizers increased in the late 1980's, but, at this time, a growth trend does not appear to be developing.

It is probable that additional facilities will be constructed in the United States to purify wet-process phosphate acid to compete with products manufactured from the electric furnace, elemental phosphorus, and phosphoric acid route. Increasing power costs will encourage reduction in the number of electric furnaces and promote wet-process acid purification.

In recent years, about one-half of the phosphate rock mined was exported as phosphate rock, phosphate fertilizers, and phosphate chemicals. The importance of the export market to the U.S. phosphate industry cannot be overestimated. The ability of the U.S. phosphate rock industry to supply future domestic and export markets is of some concern when it is recognized that phosphate rock reserves are finite.

The survey of world phosphate rock producers performed by the International Fertilizer Industry Association (IFA) shows that world phosphate rock production has declined from 164 million tons in 1988 to 162 million tons in 1989 and, based on production reports from principal world producers, may decline in 1990 to about 154 million tons. The statistics showing declining production occurred during a period of increasing world demand. All of the world forecasting organizations, including IFA, the World Bank, and the Wharton Econometric Forecasting Association, predict a demand increase of

1% to 2% per year for phosphates.

The reasons for declining production during a period of increasing demand are not clear. It may be explained if it is assumed that production data were different from that reported or the annual supply of phosphate rock was much greater than demand, without drawing down inventories, to accommodate the increase in demand. Phosphate consumption in the recently liberated centrally planned economy countries in Eastern Europe may have been lower than expected, or production estimates from centrally planned economy countries may be overestimated.

U.S. phosphate rock production was 45.4 million tons in 1988, 49.8 million tons in 1989, and 46.3 million tons in 1990. Phosphate consumption by major importing countries such as China and India will maintain U.S. diammonium phosphate exports at their current level, and the demand created by U.S. farm programs will complicate the outlook for 1991. Domestic fertilizer use is projected to decline in 1991, exports of phosphate rock are projected to decline in 1991, and exports of phosphate rock are projected to improve.

OTHER SOURCES OF INFORMATION

Fertilizer International.

International Fertilizer Industry Association Ltd.

The British Sulphur Corp. Ltd., Phosphorus and Potassium.

The Fertilizer Institute, Dealer Progress.

The Moroccan Office Cherifien des Phosphates.

The Phosphate Rock Export Association.

TABLE 19

U.S. EXPORTS OF UNGROUND PHOSPHATE ROCK, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 2510.10.0000)

Country	1989		1990	
	Quantity	Value	Quantity	Value
Australia	282		64	
Austria	32		104	
Belgium-Luxembourg	294		412	
Brazil	—		57	
Canada	766		341	
Finland	37		21	
France	92		147	
Germany, Federal Republic of	353		291	
India	420		378	
Italy	88		102	
Japan	790	NA	688	NA
Korea, Republic of	1,267		1,275	
Mexico	610		798	
Netherlands	662		763	
New Zealand	42		46	
Philippines	—		—	
Poland	631		29	
Romania	—		42	
Sweden	196		209	
Other	117		108	
Total	[1]6,678	231,282	5,875	215,409

NA Not available.

[1] Data do not add to total because of independent rounding.

Source: Bureau of the Census.

TABLE 20

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	1989		1990	
	Quantity	Value[1]	Quantity	Value[1]
Argentina	8		9	
Australia	56		155	
Bangladesh	102		50	
Brazil	2		41	
Canada	—		14	
Chile	110		131	
Colombia	8		8	
Costa Rica	11	NA	9	NA
Czechoslovakia	—		6	
Dominican Republic	2		2	
Germany, Federal Republic of	67		51	
Japan	48		48	
Peru	21		—	
Uruguay	6		13	
Other	76		177	
Total	517	149,377	714	95,786

NA Not available.
[1] All values f.a.s.

Source: Bureau of the Census.

TABLE 21

U.S. EXPORTS OF SUPERPHOSPHATES, LESS THAN 40% P_2O_5, BY COUNTRY

(HTS No. 3103.10.0010)

Country	1989		1990	
	(Quantity metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Argentina	—		3,390	
Canada	3,312		17,322	
Ecuador	2,983		5,498	
Spain	6,026	NA	2,598	NA
Uruguay	4,012		—	
Other	776		3,864	
Total	17,109	$2,484	32,672	$4,844

NA Not available.
[1] All values f.a.s.

Source: Bureau of the Census.

TABLE 22

U.S. EXPORTS OF DIAMMONIUM PHOSPHATES, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 3105.30.0000)

Country	1989		1990	
	Quantity	Value[1]	Quantity	Value[1]
Argentina	80		74	
Australia	246		318	
Belgium-Luxembourg	463		361	
Brazil	12		32	
Canada	614		185	
Chile	78		63	
China	2,337		2,778	
Colombia	104		131	
Costa Rica	19		23	
Dominican Republic	43		34	
Ecuador	26		16	
France	54		25	
Germany, Federal Republic of	34		89	
Guatemala	6		2	
India	2,255	NA	1,345	NA
Iran	128		248	
Ireland	45		19	
Italy	116		20	
Japan	367		457	
Kenya	74		81	
Mexico	51		25	
New Zealand	30		48	
Pakistan	33		544	
Peru	30		11	
Spain	90		91	
Thailand	88		38	
Turkey	268		401	
Uruguay	31		—	
Venezuela	100		47	
Yugoslavia	52		10	
Other	419		240	
Total	8,293	1,465,749	7,756	1,278,559

NA Not available.

[1] All values f.a.s.

Source: Bureau of the Census.

TABLE 23

U.S. EXPORTS OF MONOAMMONIUM PHOSPHATES, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 3105.40.0000)

Country	1989		1990	
	Quantity	Value[1]	Quantity	Value[1]
Argentina	6		8	
Australia	88		130	
Belgium-Luxembourg	10		—	
Brazil	3		53	
Canada	240		248	
Chile	5		15	
China	56		—	
Colombia	35		49	
Costa Rica	—		(2)	
Dominican Republic	—		(2)	
Ecuador	3		1	
Guatemala	12		29	
Hungary	29	NA	—	NA
Ireland	—		5	
Italy	61		20	
Japan	121		93	
Mexico	1		5	
New Zealand	5		9	
Peru	—		(2)	
Saudi Arabia	62		26	
Spain	—		3	
Thailand	27		9	
Uruguay	2		—	
Venezuela	31		21	
Other	12		13	
Total	809	142,515	737	135,660

NA Not available.

[1] All values f.a.s.

[2] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 24

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	1989		1990	
	Quantity	Value[1]	Quantity	Value[1]
Australia	49		43	
Canada	12		3	
Colombia	34		5	
India	455	NA	330	NA
Indonesia	—		69	
Japan	19		—	
Venezuela	110		58	
Other	24		47	
Total	703	124,074	555	95,881

NA Not available.
[1] All values f.a.s.

Source: Bureau of the Census.

TABLE 25

U.S. EXPORTS OF ELEMENTAL PHOSPHORUS, BY COUNTRY

(HTS No. 2804.70.0000)

Country	1989		1990	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Brazil	434	$933	450	$985
Canada	38	60	1,470	1,850
Japan	9,758	15,118	9,802	17,269
Korea, Republic of	1,746	2,863	400	636
Mexico	7,280	8,856	5,441	8,300
Taiwan	9	21	16	21
Other	669	443	337	559
Total	19,934	28,294	17,916	29,620

[1] All values f.a.s.

Source: Bureau of the Census.

TABLE 26

U.S. IMPORTS FOR CONSUMPTION OF PHOSPHATE ROCK AND PHOSPHATIC MATERIALS

(Thousand metric tons and thousand dollars)

Phosphatic materials	HTS No.[1]	1989		1990	
		Quantity	Value[2]	Quantity	Value[2]
Natural calcium[3] phosphates unground	2510.10.0000	705	29,878	451	21,905
Natural calcium[3] phosphates ground	2510.20.0000	(4)	254	(4)	163
Dicalcium phosphate	2835.25.0000	76	43,184	2	2,744
Phosphorus	2804.70.0000	—	—	10	17,532
Normal superphosphate	3103.10.0010	1	286	1	361
Triple superphosphate	3103.10.0020	(4)	22	(4)	14
Diammonium phosphate	3105.30.0000	14	3,903	11	3,271
Fertilizer containing nitrates and phosphates	3105.51.0000	18	2,736	2	322
Phosphoric acid	2809.20.0010	(4)	21	(4)	53

[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 27

WORLD PHOSPHATE ROCK ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990, RATED CAPACITY[1]

(Million metric tons per year)

Country	Capacity
North America:	
Mexico	1.0
United States	55.0
Total	56.0
South America	10.0
Europe:	
U.S.S.R.	36.0
Other	1.0
Total	37.0
Africa:	
Algeria	2.3
Morocco/Sahara	32.0
Senegal	2.1
South Africa, Republic of	4.7
Togo	3.2
Tunisia	10.0
Other	1.2
Total	55.5
Asia:	
China	19.0
Israel	4.0
Jordan	8.0
North Korea	1.0
Vietnam	1.0
Other	1.0
Total	34.0
Oceania:	
Australia	1.0
Nauru	2.0
Total	3.0
World total	195.5

[1] Includes capacities of operating plants as well as plants on standby basis.

TABLE 28

U.S. PHOSPHATE ROCK RESERVE AND RESERVE BASE ESTIMATES

(Million metric tons)

State	Reserves[1]	Reserve base[2]
Florida	750	2,540
Idaho	90	160
Montana	1	1
North Carolina	390	790
Tennessee	6	10
Utah	—	730
Wyoming	—	210
Total[3]	1,230	4,440

[1] Phosphate rock reserves at a cost less than $40 per ton f.o.b. mine. Costs include capital, operating expenses, taxes, royalties (if applicable), miscellaneous costs, and a 15% rate of return on investments. Costs and resources are as of Jan. 1990, f.o.b. mine.
[2] Reserve base at a cost less than $100 per ton f.o.b. mine. Costs are as defined in footnote 1.
[3] Data may not add to totals shown because of independent rounding.

TABLE 29

WORLD PHOSPHATE ROCK RESERVE AND RESERVE BASE

(Million metric tons)

	Number of deposits	Reserves[1]	Reserve base[2]
North America:			
Canada	1	50	50
Mexico	2	10	110
United States	94	1,230	4,440
Total	97	1,290	4,600
South America:			
Brazil	11	330	370
Colombia	1	—	100
Peru	1	310	310
Venezuela	1	—	10
Total	14	640	790
Europe:			
Finland	1	—	70
Turkey	1	30	30
U.S.S.R.	11	1,330	1,330
Total	13	1,360	1,430
Africa:			
Algeria	1	240	240
Egypt	5	—	760
Morocco	10	4,950	20,490
Western Sahara	1	950	950
Senegal	2	—	160
South Africa, Republic of	1	2,530	2,530
Togo	12	—	60
Tunisia	11	—	270
Total	43	8,670	25,460
Asia:			
China	6	210	210
Christmas Island	1	10	10
Israel	4	—	180
Jordan	3	90	480
Syria	2	190	190
Other	6	30	330
Total	22	530	1,400
Oceania:			
Australia	5	90	590
Nauru	1	5	5
Total	6	95	595
World total	195	12,585	34,275

[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. 1990, f.o.b. mine.
[2] Reserve base at a cost less than $100 per ton. Costs are as defined in footnote 1.

TABLE 30

PHOSPHATE ROCK, BASIC SLAG, AND GUANO: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Commodity and country[2]	Gross weight					P_2O_5 content				
	1986	1987	1988	1989	1990[e]	1986	1987	1988	1989	1990[e]
Phosphate rock:										
Algeria	1,203	1,073	1,332	1,223	[3]1,102	[e]380	[e]336	[e]404	[e]371	325
Australia	34	11	13	8	14	7	2	2	1	3
Brazil	4,509	4,777	4,672	[r]3,655	[3]2,968	1,620	1,694	[r]1,653	[r]1,293	[3]1,051
Chile	7	10	9	[r]14	12	1	[e]1	[e]1	[e]1	1
China[e]	6,700	9,000	[r]16,600	[r]17,000	17,300	1,810	2,700	[r]4,500	[r]4,600	4,700
Christmas Island (Indian Ocean)	880	842	—	—	—	310	[e]295	—	—	—
Colombia	27	34	35	[r]31	[3]37	7	8	9	8	8
Egypt	1,271	1,167	[e]1,146	[r]1,347	1,300	[e]315	[e]312	[e]293	[r e]337	325
Finland	527	[e]553	584	[r]580	[3]546	195	[e]195	215	[r]211	201
India	667	679	[r]739	[r]704	659	222	226	[r]246	[r]235	220
Indonesia	1	3	1	11	2	([4])	1	([4])	4	1
Iraq[e]	1,000	1,500	1,273	1,300	1,100	218	330	382	385	325
Israel	3,673	3,798	3,479	3,922	[3]3,516	1,110	[e]1,214	[e]1,092	[e]1,231	1,104
Jordan	6,249	6,800	6,611	[r]6,900	[3]5,925	[e]2,072	[e]2,260	[r e]2,182	[r e]2,277	[3]1,945
Korea, North[e]	500	500	500	500	500	160	160	160	160	160
Mali	3	8	10	10	10	[e]1	[e]2	[e]2	[e]2	2
Mexico[5]	747	689	[r]835	[r]655	[3]604	224	207	[r]251	[r]197	170
Morocco[6]	21,178	[r]21,300	25,015	[r]18,067	[3]21,396	[e]6,714	[r e]6,816	[e]8,061	[r e]5,781	6,906
Nauru	1,494	1,376	1,540	[r]1,181	[3]926	[e]575	[e]530	[e]593	[r e]455	355
Pakistan[e]	50	32	35	[r]40	30	16	10	[r]11	[r]13	10
Peru	5	61	13	[r e]21	5	2	20	[e]4	[r e]7	2
Philippines	2	[e]8	[r]8	[r]4	4	1	[e]2	[e]2	[e]2	[r]1
Senegal[7]	1,850	1,874	2,326	2,273	[3]2,147	[r e]671	[e]680	[r]831	[r]823	[3]777
South Africa, Republic of	2,920	2,623	2,850	[r]2,963	[3]3,165	[e]1,060	[e]950	[r]1,079	[r]1,111	[3]1,190
Sri Lanka	15	21	23	[r]24	[3]33	5	[e]7	[e]7	[e]8	11
Sweden	192	[e]221	142	[r]71	7	72	[e]82	52	[r]26	3
Syria	1,606	1,986	2,342	[e]2,250	1,670	485	606	715	[e]690	511
Tanzania	[e]10	18	[r]15	[r]18	20	[e]3	[e]5	[r]4	[r]5	6
Thailand	5	5	8	[r]7	[3]10	1	2	[e]2	[r]2	3
Togo	2,314	2,644	3,464	3,355	[3]2,314	840	[e]960	[e]1,257	[e]1,208	840
Tunisia	5,951	[e]6,390	6,103	[r]6,610	[3]6,259	1,712	[e]1,836	1,813	[r e]1,897	1,815
Turkey	3	19	74	[r]85	[3]87	[e]1	[e]6	23	26	[3]27
U.S.S.R.[e]	33,900	34,100	34,400	34,400	33,500	10,700	10,750	10,850	10,850	10,200
United States	38,710	40,954	45,389	48,866	[3]46,343	11,857	12,491	13,833	14,893	14,124
Venezuela	174	99	—	237	[3]165	45	28	—	57	[3]34
Vietnam[e]	530	300	330	[r]500	274	175	105	115	[r]175	96
Zimbabwe, concentrate	136	155	125	[r]134	[3]156	[e]47	[e]54	44	47	[3]56
Total	[r]141,029	[r]147,617	[r]162,041	[r]158,966	154,106	[r]45,620	[r]47,870	50,688	[r]49,389	47,508

See footnotes at end of table.

TABLE 30—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				
	1986	1987	1988	1989	1990[e]	1986	1987	1988	1989	1990[e]
Basic (Thomas converter) slag:										
Argentina	([4])	([4])	[e]([4])	([4])	([4])	[e]([4])	[e]([4])	[e]([4])	[e]([4])	([4])
Belgium[e]	180	175	170	165	160	32	32	31	30	30
Egypt[e]	8	8	8	8	8	2	2	2	2	2
France	855	[r]768	[r]775	[r]701	700	154	[r]138	[r]140	[r]126	125
Germany, Federal Republic of:										
Western states	374	[r e]300	[r e]250	[r e]250	220	54	[e]50	[e]45	[e]45	40
Luxembourg	620	542	[r]664	[r]680	600	112	98	[r]120	[r]122	108
Total	2,037	[r]1,793	[r]1,867	[r]1,804	1,688	354	[r]320	[r]338	[r]325	305
Guano:										
Chile	8	6	4	[r]3	2	1	[e]1	[e]([4])	[e]([4])	([4])
Philippines	3	[e]1	1	[r]48	40	1	[e]([4])	[e]([4])	[r]16	13
Seychelles Islands[e]	5	5	5	5	5	2	2	2	2	2
Total	16	12	10	[r]56	47	4	3	2	[r]18	15

[e] Estimated. [r] Revised.

[1] Table includes data available through May 31, 1991. 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 and Uganda may have produced small quantities of phosphate rock and Namibia may have produced small quantities of guano, but output is not officially reported, and available information is inadequate for formulation of reliable estimates of output levels.

[3] Reported figure.

[4] Less than 1/2 unit.

[5] Includes only output used to manufacture fertilizers.

[6] Production from Western Sahara area included with Morocco.

[7] Does not include aluminum phosphate production, gross weight, in thousand tons: 1986—131; 1987—191; 1988—119; 1989—115 (estimated, revised); and 1990—111 (estimated).

PLATINUM-GROUP METALS

By J. Roger Loebenstein

Mr. Loebenstein, a physical scientist with 16 years industry and U.S. Bureau of Mines experience, has been the commodity specialist for platinum-group metals for 10 years. Domestic survey data were prepared by Evangeline Hemphill, mineral data assistant; and international data tables were prepared by Harold Willis, international data coordinator.

The platinum-group metals (PGM) are composed of six closely related metals: platinum, palladium, rhodium, ruthenium, iridium, and osmium. They commonly occur together in nature and are among the scarcest of the metallic elements. In terms of commercial importance, platinum and palladium are the two most important metals of the group. All of the metals are valued for their corrosion resistance and catalytic activity.

The Clean Air Act of 1990 was passed by the Congress and signed by the President. Provisions of the new law require a 35% reduction in hydrocarbons and a 60% cut in nitrogen oxides beginning in 1994. In addition, automotive catalytic converters must be guaranteed by manufacturers to last double the current 50,000 miles.

The price of rhodium soared to a record high of more than $7,000 per troy ounce briefly in June before settling down to the $4,000 to $5,000 range. The supply of rhodium is a problem of increasing concern to automotive manufacturers who use it to control nitrogen oxide emissions from cars and trucks. There are no substitutes for rhodium for this application.

DOMESTIC DATA COVERAGE

Domestic production data for PGM are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. refiners. Of the 18 refiners to which a survey request was sent, 11 responded. These represent 85% of the total refined metal production shown in tables 5 and 6. Production for nonrespondents was estimated using prior-year levels adjusted for general industry trends.

BACKGROUND

Products for Trade and Industry

The basic forms of PGM are sponge or powder, which may be converted to other forms such as bars, pastes, or chemicals. The catalyst industry employs an extensive number of chemical compounds containing PGM. A typical PGM catalyst may consist of a platinum-rhodium gauze woven from wire. The electronics industry purchases PGM pastes, and the dental industry uses wire and a variety of alloys.

Geology-Resources

PGM deposits are associated with magmatic intrusions of mafic and ultramafic rocks. They also occur to a lesser extent as placer deposits. Layered deposits associated with stratiform complexes are the only ones mined principally for the PGM, with nickel, copper, and cobalt sometimes produced as byproducts. These are found in the Bushveld Complex, Republic of South Africa, and the Stillwater Complex, United States.

In other PGM deposits, such as those found in the Sudbury Complex, Canada, and Noril'sk, U.S.S.R., the PGM are produced as byproducts of nickel and copper mining.[1]

In the Republic of South Africa, it is interesting to note that base metals such as nickel and copper are important in generating revenues from the Merensky and Platreef ores. This is not the case at the Stillwater Mine in the United States, where platinum and palladium contribute about 100% of revenues.

Technology

Processing.—The processing of PGM ore entails four general steps: mining, concentrating, smelting, and refining. In the concentrating step, platinum ore is crushed and treated by froth flotation. The concentrates are dried, sometimes roasted, and then fused in a smelter furnace, producing a sulfide matte containing the PGM. The matte is treated in a refinery using solvent-extraction techniques to separate and purify the six PGM.

Recycling.—In North America, PGM are recovered by a small number of scrap refiners, as shown in table 1. Other companies collect scrap materials such as catalysts and PGM-bearing solutions and process them to increase the grade. These upgraded secondary materials are then sold to refiners. For example, Multi-Metco Inc., Anniston, AL, produces about a 90% concentrate of PGM from scrapped autocatalysts, which in turn is refined by another company. World Resources Co., McLean, VA, collects electroplating solutions, upgrades them, and sells the concentrate to another refiner. Most companies specialize in refining or upgrading a particular type of scrap, such as petroleum catalysts, autocatalysts, or electronic scrap.

Refiners often charge a fee or toll to "toll refine" scrap, ownership of the PGM content of the scrap remaining with the customer. For example, a refiner and/or fabricator would replace worn out catalyst with fresh catalyst and charge the customer for the refining and fabrication costs. In other cases, refiners purchase scrap, process it, and sell the refined metal. When scrap changes ownership in this way, it is referred to as nontoll scrap.

For statistical purposes, nontoll refined scrap is considered as old scrap and is added to supply, along with newly mined metal.

Because of their high value, PGM are routinely recovered from petroleum catalysts, chemical catalysts, automobile catalysts, glass fiber bushings, electronic

scrap, laboratory equipment, dental materials, and jewelry.

Major collectors and refiners of autocatalysts are shown in table 2. In the United States, only Multi-Metco refined any substantial quantities of autocatalyst PGM. Multi-Metco's output required further processing by other companies to produce commercial-grade metal. The other major refiners of scrapped automobile catalysts are in Canada, Belgium, and Japan.

Because used precious-metal scrap varies widely in value and grade, proper sampling and assaying is important to the industry. Fire assay techniques have long been used to determine the presence of precious metals. In addition to fire assays, PGM can be determined by chemical methods and instrumental methods such as X-ray fluorescence and spectrochemical methods.[2]

A list of independent PGM assayers is shown in table 3. The list is meant to be a sample rather than a complete list of assayers.

Economic Factors

Futures contracts are traded on the New York Mercantile Exchange (NYMEX) and the Tokyo Commodity Exchange for Industry (TOCOM), and to a lesser extent on the MidAmerica Exchange.[3] Futures contracts help producers and consumers of platinum and palladium lock in prices and allow speculators an opportunity to make profits. By comparing the current price with the price for future delivery, one can surmise whether market participants expect prices to rise or fall.

Platinum and palladium futures contracts, specifying 99.95% metal content, were traded on the NYMEX in units of 50 and 100 troy ounces, respectively. Table 4 shows the number of contracts traded on the last trading day of the year for 1987–90.

Trading of platinum futures contracts on the TOCOM began in 1984. The contract unit is 500 grams, the quality specifications are 99.9% purity, and prices are quoted in Japanese yen per gram.

In London, prices of physical platinum and palladium bullion are set each day in the morning and afternoon for the wholesale market. The eight companies participating in establishing prices are members of the London-Zurich Good Delivery Agreement, which sets standards for platinum and palladium trading in

TABLE 1

SELECTED NORTH AMERICAN PLATINUM-GROUP METALS REFINERS AND FABRICATORS

Company	Type	Plant location	Specialty
AT&T/Nassau Metals	Refiner	Gaston, SC	Electronics.
Do.	do.	Staten Island, NY	Do.
Degussa/Metz	Refiner, fabricator	South Plainfield, NJ	All.
Do.	Fabricator	Burlington, Ontario	Autocatalysts.
Du Pont Corp.	do.	Wilmington, DE	Electronics.
Engelhard Corp.	Refiner, fabricator	Carteret, NJ	All.
Do.	Fabricator	Seneca, SC	Catalysts.
Gemini Industries	Refiner	Santa Ana, CA	Do.
Handy & Harman	Refiner, fabricator	South Windsor, CT	Electronics.
Do.	do.	South Plainfield, NJ	Do.
Johnson Matthey Inc.	do.	West Deptford, NJ	All.
Martin Metals Inc.	Refiner	Los Angeles, CA	Electronics.
Multi-Metco Inc.	do.	Anniston, AL	Autocatalysts.
Noranda Ltd.	do.	Montreal, Quebec	Electronics.
PGP Industries Inc.	Refiner, fabricator	Santa Fe Springs, CA	Do.

TABLE 2

COLLECTORS AND REFINERS OF AUTOCATALYSTS

Company	Type	Plant location
A-1 Specialized Services & Supplies Inc.	Collector	South River, NJ.
Bowden Industries Inc.	do.	Covington, TN.
Brown Recycling & Manufacturing	do.	Somerville, AL.
Catalytic Converter Refining Co.	do.	Northlake, IL.
INCO Ltd.	Refiner	Sudbury, Canada.
Metallurgie Hoboken Overpelt/SGM	do.	Hoboken, Belgium.
Multi-Metco Inc.	do.	Anniston, AL.
Nissan Group/Ikeda	do.	Japan.
Parkans International Inc.	Collector	Houston, TX.
Sumitomo Metal Mining Co.	Refiner	Japan.
U.S. Scrap Co.	Collector	Los Angeles, CA.

TABLE 3

INDEPENDENT PLATINUM-GROUP METALS ASSAYERS

Company	Location
Accredited Laboratories Inc.	Carteret, NJ.
Alex Stewart (Assayers) Ltd.	Merryside, England.
Alfred H. Knight Laboratories Ltd.	Pompton Lakes, NJ.
Bondar-Clegg	Ottawa, Canada.
International Testing Laboratories	Newark, NJ.
Ledoux & Co.	Teaneck, NJ.
Umpire & Control Services Inc.	West Babylon, NY.

Europe. London and Zurich are the two most important European trading centers for platinum and palladium.

A time series of historical prices for each of the six PGM and a brief discussion of factors influencing prices are given in a U.S. Bureau of Mines publication entitled "Nonferrous Metal Prices in the United States Through 1988."[4]

ANNUAL REVIEW

Legislation and Government Programs

The Clean Air Act amendments of 1990 were passed, representing the fifth major effort by Congress to address clean air legislation. Provisions of this law deal with mobile sources and clean fuels, air toxics, acid rain, and ozone protection.

The amendments establish stricter standards for nonmethane hydrocarbons (NMHC), carbon monoxide (CO) and oxides of nitrogen (NO_x). Tier I standards for cars and light trucks call for 0.25 gram per mile (gpm) for NMHC, 3.4 gpm for CO, and 0.4 gpm for NO_x. These standards will be phased in between 1994 and 1998. Tier II standards are one-half of the Tier I standards and may go into effect between the years 2003 and 2006. In addition, catalytic converters must be guaranteed to operate for 100,000 miles, double the current limit.[5]

Strategic Considerations

Although production of platinum and palladium increased at the only PGM mine in the United States, the Stillwater Mine, the majority of PGM consumed in the United States was still derived from imported sources.

There were no changes in inventories of platinum, palladium, and iridium in the National Defense Stockpile in 1990. No purchases of rhodium or ruthenium were made, even though there is a stockpile goal for these two metals.

Production

The Stillwater Mine, southwest of Billings, MT, was operated by the Stillwater Mining Co. (SMC), owned 50% by Chevron Corp. and 50% by Manville Corp. Estimates from published sources showed that production of both platinum and palladium at the mine increased again in 1990. Small amounts of PGM

TABLE 4

NYMEX TRADING VOLUME FOR FUTURES CONTRACTS, DECEMBER 31

(Number of contracts)

	1987	1988	1989	1990
Platinum[1]	1,361,546	1,460,455	1,190,529	820,934
Palladium[2]	160,284	139,883	200,892	95,642

[1]50 troy ounces per contract.
[2]100 troy ounces per contract.

TABLE 5

SALIENT PLATINUM-GROUP METALS[1] STATISTICS

(Kilograms)

	1986	1987	1988	1989	1990
United States:					
Mine production:[2]					
Platinum	--	780	1,240	1,430	1,810
Palladium	--	2,330	3,730	4,850	5,930
Value[3] thousand dollars	--	r$23,606	r$35,601	r$45,764	$48,212
Refinery production:					
Primary refined	135	191	297	339	64
Secondary:					
Nontoll-refined	r11,015	r5,118	r4,788	r3,933	5,800
Toll-refined	35,924	44,935	46,403	46,253	46,447
Total refined metal	r47,074	50,243	51,488	r50,525	52,311
Stocks, yearend:					
Industry (refined)	40,187	38,412	r35,514	32,543	30,324
National Defense Stockpile:					
Platinum	14,079	14,079	14,079	14,079	14,079
Palladium	39,334	39,334	39,334	39,334	39,334
Iridium	920	920	920	920	920
Exports:					
Refined[4]	r11,880	13,423	20,301	23,082	20,148
Total	23,349	22,031	28,787	r38,301	55,044
Imports for consumption:					
Refined[4]	r115,925	r98,878	r110,947	111,107	120,631
Total	139,256	118,397	124,324	113,278	125,354
Imports, general	136,824	118,397	124,324	113,278	125,354
Consumption (reported sales to industry)	64,705	60,280	70,998	r78,483	77,487
Consumption, apparent[5]	r109,904	r95,458	103,302	r101,209	116,242
Net import reliance[6] as a percent of apparent consumption	90	91	91	90	88
Price, dealer, average, per ounce:					
Platinum	$461	$553	$523	$507	$455
Palladium	$116	$130	$123	$144	$114
World: Mine production[7]	r260,193	r273,581	r281,853	r283,158	e286,704

eEstimated. rRevised.
[1]The platinum-group comprises six metals: platinum, palladium, iridium, osmium, rhodium, and ruthenium. Multiply by 32.1507 to convert from kilgrams to troy ounces.
[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]Excludes ores, scrap, and platinum grains and nuggets.
[5]1986 mine production excluded to avoid disclosing company proprietary data. 1987–90 includes mine production plus nontoll-refined production of secondary metal plus refined imports for consumption minus refined exports plus or minus changes in Government and industry stocks.
[6]Refined imports for consumption minus refined exports plus or minus changes in Government and industry stocks.
[7]1986 total excludes U.S. mine production in order to avoid disclosing company proprietary data.

TABLE 6

PLATINUM-GROUP METALS REFINED IN THE UNITED STATES

(Kilograms)

	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total[1]
PRIMARY METAL[2]							
Nontoll-refined:							
1986	19	116	—	—	—	—	135
1987	32	158	—	—	—	—	191
1988	46	248	2	—	(3)	—	297
1989	47	289	2	—	—	2	339
1990	2	62	—	—	—	—	64
SECONDARY METAL							
Nontoll-refined:							
1986	2,204	8,627	9	—	134	41	r11,015
1987	1,180	3,743	4	19	123	49	r5,118
1988	1,133	3,545	4	—	104	2	r4,788
1989	r1,134	r2,664	6	—	94	35	r3,933
1990	1,913	3,671	7	—	175	34	5,800
Toll-refined:							
1986	20,977	12,388	111	44	1,792	613	35,924
1987	22,580	19,169	102	25	1,895	1,164	44,935
1988	22,884	20,923	252	19	1,826	499	46,403
1989	24,058	20,037	219	1	1,565	373	46,253
1990	27,548	16,408	65	—	2,200	225	46,447
1989 TOTALS[1]							
Total primary	47	289	2	—	—	2	339
Total secondary	r25,192	r22,701	225	1	1,659	408	r50,186
Total refined metal	r25,239	r22,990	227	1	1,659	410	r50,525
1990 TOTALS[1]							
Total primary	2	62	—	—	—	—	64
Total secondary	29,461	20,079	72	—	2,375	259	52,247
Total refined metal	29,463	20,141	72	—	2,375	259	52,311

rRevised.
[1]Data may not add to totals shown because of independent rounding.
[2]"Toll-refined" data were not reported for years 1986–90.
[3]Less than 1/2 unit.

were recovered by other companies as byproducts of domestic copper refining.

SMC opened a new smelter in Columbus, MT, to process PGM concentrates from the mine. PGM matte containing precious metals was airfreighted to Belgium for final refining and separation of the individual PGM. SMC had no plans to open its own PGM refinery or to have its concentrates refined domestically.

Sumitomo Corp. of America purchased Catalyst Collectors Corp. (CCC), Union, NJ, and CCC's network of autocatalyst collectors. Sumitomo, an international trading company, planned to offer scrap collectors financing capabilities, hedging capabilities, and precious-metal refining services.

Consumption and Uses

Reported sales of PGM by refiners is shown in table 7. For comparison purposes, the calculated apparent consumption for the individual PGM is also shown.

A summary of the typical uses for each PGM is shown in tables 8 and 9. Platinum, palladium, and rhodium were used in emission catalysts for light trucks (trucks weighing 14,000 pounds or less, gross weight) and automobiles. An informal survey of automobile catalyst manufacturers indicated that a typical emission catalyst in 1990 contained a total of about 2.7 grams PGM (approximately 2.18 grams platinum, 0.31 gram palladium, and 0.31 gram rhodium). These loadings were higher than in 1989, reflecting more stringent emission regulations.

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.

TABLE 7

PLATINUM-GROUP METALS[1] SOLD TO CONSUMING INDUSTRIES IN THE UNITED STATES

(Kilograms)

Year and industry	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total[2]
1986:							
Reported	30,513	27,681	382	21	2,906	3,203	64,705
Apparent consumption[3]	51,304	45,721	940	247	5,695	5,998	109,905
1987:							
Reported	25,471	30,956	250	29	2,692	882	60,280
Apparent consumption[3]	34,703	49,967	569	184	7,205	2,830	95,458
1988:							
Reported	31,125	34,241	495	23	3,292	1,821	70,998
Apparent consumption[3]	39,208	52,342	721	76	7,294	3,661	103,302
1989:							
Automotive[4]	18,774	4,886	—	—	1,982	—	25,643
Chemical	2,424	1,923	95	—	r177	26	r4,645
Dental and medical	632	8,424	105	57	1	15	9,233
Electrical	3,894	17,352	112	—	r177	r1,929	r23,464
Glass	1,130	181	—	—	177	1	1,489
Jewelry and decorative	418	179	7	—	205	6	814
Petroleum	2,859	2,543	—	—	27	—	5,429
Miscellaneous	3,566	3,786	81	—	273	61	7,766
Total[2]	33,698	39,273	400	57	r3,019	r2,037	r78,483
Apparent consumption[3]	47,035	45,299	604	30	6,112	2,129	101,209
1990:							
Automotive[4]	20,967	2,995	—	—	2,995	—	26,957
Chemical	2,080	2,369	22	—	169	16	4,654
Dental and medical	687	6,133	104	40	2	7	6,974
Electrical	3,907	17,997	111	—	274	1,406	23,698
Glass	431	346	1	—	31	1	810
Jewelry and decorative	431	177	11	—	195	8	818
Petroleum	3,274	1,488	—	—	—	—	4,762
Miscellaneous	4,280	3,612	199	1	520	202	8,814
Total[2]	36,055	35,116	448	40	4,187	1,641	77,487
Apparent consumption[3]	49,860	51,463	649	56	12,311	1,903	116,242

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 imports minus exports plus beginning stocks minus ending stocks. Between 1986 and 1988, unspecified PGM imports and exports were divided evenly between platinum and palladium. Iridium and osmium exports included with ruthenium, in 1989 and 1990.
[4]1986–90 platinum, palladium, and rhodium sales to the automotive industry are estimated based on U.S. light truck sales and U.S. automobile production.

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

TABLE 8

TYPICAL USES OF PLATINUM, PALLADIUM, AND RHODIUM

Platinum	Palladium	Rhodium
Automobile catalyst	Automobile catalyst	Acetic acid catalyst.
Cancer drugs	Dental alloys	Automobile catalyst.
Coins	Hydrocracking catalyst	Glass bushings.
Cracking catalyst	Hydrogen peroxide catalyst	Nitric acid catalyst.
Crucibles	Multilayered capacitors	Thermocouples.
Fuel cell electrode	Thick films pastes	
Glass bushings	Vinyl acetate catalyst	
Hydrogen cyanide catalyst		
Isomerization catalyst		
Jewelry		
Nitric acid catalyst		
Reforming catalyst		
Targets for thin films		
Thermocouples		

TABLE 9

TYPICAL USES OF RUTHENIUM, IRIDIUM, AND OSMIUM

Ruthenium	Iridium	Osmium
Caustic soda electrode	Caustic soda electrode	Biological staining.
Chlorine electrode	Chlorine electrode	Pharmaceutical catalyst.
Resistor circuits	High-temperature crucibles	
	Reforming catalyst	

TABLE 10

REFINER, IMPORTER, AND DEALER STOCKS OF REFINED PLATINUM-GROUP METALS[1] IN THE UNITED STATES, DECEMBER 31

(Kilograms)

Year	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total
1986	20,426	16,958	611	12	1,475	705	40,187
1987	19,004	17,356	506	1	996	549	38,412
1988	18,438	14,837	432	8	1,165	634	r35,514
1989	14,791	15,182	522	36	1,096	916	32,543
1990	13,421	14,425	483	55	1,089	851	30,324

rRevised.

[1]Includes metal in depositories of the New York Mercantile Exchange (NYMEX); on Dec. 31, 1990, this comprised 4,272 kilograms of platinum and 2,034 kilograms of palladium.

peroxide. A wide variety of organic chemicals and pharmaceuticals were produced using PGM catalysts.

Stocks

In addition to the reported stocks held by refiners, importers, and dealers, end users of PGM held sizable quantities of PGM that were not reported to the U.S. Bureau of Mines.

Markets and Prices

The price of rhodium began increasing near the end of 1989, setting record highs along the way, until the price reached more than $7,000 per ounce briefly in June. During the remainder of the year, rhodium sold between $4,000 and $5,000 per ounce.

There were two primary reasons for the escalation in rhodium prices. The first had to do with production problems at an important South African refinery. The other reason for high prices was a lack of any substantial spot sales of rhodium from the U.S.S.R.

In October, the NYMEX introduced the trading of options on platinum futures contracts. In the past, the platinum futures market at NYMEX as well as other foreign futures markets have helped companies protect themselves from price volatility. Platinum options were designed to provide additional hedging and trading opportunities.

Foreign Trade

Imports of rhodium increased substantially, probably because of stockpiling by automobile companies, from 7 metric tons in 1989 to 13 metric tons in 1990.

World Review

Capacity.—Capacity for PGM production is generally cited in terms of platinum capacity. The data in table 14 represent rated capacity, defined as the maximum quantity that can be produced on a normally sustainable long-term operating rate, based on the physical equipment of the plant and routine operating procedures for labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

TABLE 11

AVERAGE PRODUCER AND DEALER PRICES[1] OF PLATINUM-GROUP METALS

(Dollars per troy ounce)

	Platinum		Palladium		Rhodium		Iridium		Ruthenium	Osmium
	Producer	Dealer	Producer	Dealer	Producer	Dealer	Producer	Dealer	Dealer	Dealer
1986	519	461	131	116	1,196	1,157	600	414	73	704
1987	600	553	150	130	1,239	1,222	532	363	70	633
1988	600	523	150	123	1,275	1,218	420	306	61	592
1989:										
January	600	528	150	135	1,275	1,247	420	295	64	580
February	600	530	150	141	1,275	1,254	420	293	62	580
March	600	534	150	145	1,275	1,271	(2)	295	62	580
April	600	538	150	166	1,275	1,274	(2)	300	62	570
May	600	515	150	152	1,275	1,280	(2)	303	62	550
June	600	494	150	152	1,275	1,275	(2)	305	61	550
July	600	500	150	150	1,275	1,269	(2)	305	61	550
August	600	483	150	134	1,275	1,247	(2)	305	61	550
September	600	476	150	137	1,275	1,265	(2)	305	62	550
October	600	483	150	137	1,275	1,269	(2)	305	63	529
November	600	504	150	138	1,275	1,302	(2)	307	63	500
December	600	502	150	137	1,275	1,644	(2)	313	63	500
Average	600	507	150	144	1,275	1,300	NA	303	62	549
1990:										
January	600	492	150	134	1,275	2,031	(2)	315	63	505
February	600	516	150	135	1,275	2,098	(2)	310	61	444
March	600	494	150	130	1,275	2,058	(2)	310	61	425
April	600	475	150	127	1,275	2,108	(2)	310	61	421
May	600	484	150	118	1,275	2,308	(2)	305	61	400
June	600	479	150	115	1,275	2,960	(2)	305	61	400
July	600	475	150	116	1,275	5,040	(2)	305	61	400
August	600	486	150	115	1,275	5,014	(2)	305	61	400
September	600	319	150	103	1,275	5,271	(2)	305	61	400
October	600	415	150	94	1,275	4,720	(2)	305	59	400
November	600	416	150	93	1,275	4,405	(2)	304	60	400
December	600	414	150	87	1,275	4,769	(2)	309	61	400
Average	600	455	150	114	1,275	3,565	NA	307	61	416

NA Not available.
[1]Average prices calculated at the low end of the range and rounded to the nearest dollar.
[2]Producer prices discontinued Mar. 22, 1989.

Source: Metals Week.

The sudden and probably lasting rise in rhodium prices in 1990 has stirred speculation that despite rhodium's scarcity, it may become the chief revenue producer for South African mines, at least partly replacing platinum.[6] These conclusions are predicated on the assumption, shared by most experts, that rhodium will remain in short supply in the near term because of the lack of substitutes in automobile catalyst applications.

South Africa, Republic of.—Rustenburg Platinum Mines Ltd. announced its intent to develop a new PGM mine in Lebowa, to begin producing in 1994. The mine is part of the Platreef area, with in situ grades of 8.5 grams per metric ton of combined PGM and gold. The ore's platinum to palladium ratio is 1:1.

Lonrho PLC acquired the Karee Mine, owned by Impala Platinum Holding (Pty.) Ltd. (See table 14, footnote 4).

Johnson Matthey PLC announced plans to build a new autocatalyst plant in the Republic of South Africa with a capacity of 2 million units per year. The plant will cost $13.22 million and is to be in Germiston, near Johannesburg. Production is scheduled to begin next year and will supply primarily German auto manufacturers.

U.S.S.R.—General Motors Corp. (GMC) won a 5-year contract to supply

TABLE 12

U.S. EXPORTS OF PLATINUM-GROUP METALS, BY YEAR AND COUNTRY

(Kilograms)

Year and country	Platinum	Palladium	Rhodium	Iridium, osmium, ruthenium	Ores and concentrates	Waste and scrap	Total	
							Quantity	Value (thousands)
1989	8,414	13,005	1,156	507	173	15,046	r38,301	r$398,760
1990:								
Australia	102	63	—	31	—	—	196	1,640
Austria	14	57	—	—	—	—	71	341
Belgium	559	749	151	5	—	2,643	4,107	52,417
Brazil	12	22	8	—	—	—	42	297
Canada	728	824	326	14	300	290	2,482	31,307
China	—	1,303	—	1	—	—	1,304	5,434
France	1	63	—	1	—	71	136	656
Germany, Federal Republic of	800	644	1	84	59	3,052	4,640	54,269
Hong Kong	143	11	—	3	—	—	157	1,583
Italy	68	157	7	—	—	2,484	2,716	41,669
Japan	2,899	3,007	287	204	—	18,430	24,827	85,194
Korea, Republic of	495	141	106	9	—	3	754	19,792
Netherlands	2	1,496	—	—	—	—	1,498	6,919
Singapore	8	156	—	1	—	—	165	1,261
Sweden	10	31	—	175	—	191	407	1,586
Switzerland	196	309	35	—	22	—	562	6,450
Taiwan	631	356	—	16	27	—	1,030	10,666
U.S.S.R.	—	—	—	60	—	—	60	613
United Kingdom	733	1,127	46	54	—	7,322	9,282	90,119
Other	109	371	2	124	1	1	608	3,392
Total	7,510	10,887	969	782	409	34,487	55,044	415,605

rRevised.

Source: Bureau of the Census.

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF PLATINUM-GROUP METALS, BY YEAR AND COUNTRY

(Kilograms)

Year and country	Platinum	Palladium	Rhodium	Ruthenium	Iridium	Osmium	Waste and scrap	Ores	Total	
									Quantity	Value (thousands)
1989	49,238	51,135	7,105	2,883	688	58	2,159	12	113,278	$1,381,693
1990:										
Belgium	1,465	5,329	164	—	—	—	9	—	6,967	53,837
Canada	98	1,035	25	8	2	—	652	76	1,896	16,396
France	437	6	307	—	—	—	—	—	750	10,737
Germany, Federal Republic of	3,457	745	331	37	25	11	95	—	4,701	100,074
Hong Kong	4	—	11	—	—	—	601	—	616	8,340
Italy	22	—	—	—	—	—	—	—	22	297

See note at end of table.

TABLE 13—Continued

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)
Japan	632	1,846	—	—	—	—	43	—	2,521	$25,557
Mexico	3	—	—	—	—	—	578	—	581	1,470
Netherlands	30	240	536	—	—	—	6	—	812	14,339
Norway	672	988	11	—	—	—	14	—	1,685	13,532
South Africa, Republic of	38,926	19,782	5,494	2,328	512	64	—	1	67,107	1,021,710
Switzerland	482	350	131	2	—	—	—	—	965	17,337
Taiwan	4	529	—	—	—	—	—	—	533	2,480
U.S.S.R.	455	12,023	3,073	15	—	—	—	—	15,566	335,697
United Kingdom	5,030	9,015	2,717	184	55	—	2,161	—	19,162	269,578
Other	560	104	298	12	9	—	455	32	1,470	14,449
Total	52,277	51,992	13,098	2,586	603	75	4,614	109	125,354	1,905,830

Source: Bureau of the Census.

TABLE 14

PLATINUM ANNUAL MINE CAPACITY OF MAJOR PRODUCING COMPANIES, AS OF DECEMBER 31, 1990

(Kilograms)

	Capacity
North America:	
INCO Ltd.	3,800
Falconbridge Ltd.	1,300
Stillwater Mining Co.[1]	1,810
Total	6,910
Africa:	
Rustenburg Platinum Mines Ltd.[2]	44,000
Impala Platinum Holdings (Pty.) Ltd.[3]	34,000
Western Platinum Ltd. (Lonrho)[4]	7,800
Barplats and Rand Mines[5]	1,000
Total	86,800
World total (rounded)	93,700

[1]Jointly owned by Chevron Corp. and Manville Corp.
[2]Owns Lebowa Platinum Ltd.
[3]Owns the Messina Mine.
[4]Owns the Karee Mine.
[5]Owns the Crocodile River Mine.

pollution-control and engine-control parts to Volga Auto Works, (VAZ), the U.S.S.R.'s largest automaker. GMC plans to begin shipping autocatalysts to VAZ's factory beginning in 1992.

The format of table 15 was changed in 1990 to show production of platinum, palladium, and other platinum-group metals.

Current Research

Scientists at AEA Industrial Technology Ltd. at Harwell, United Kingdom, investigated the use of tin oxide in combination with oxides of copper, aluminum, and chromium as a substitute for PGM in automobile catalysts.[7]

Rhodium is one of a number of products produced from the radioactive disintegration of plutonium. Scientists at IBC Advanced Technologies in Orem, UT, worked on separating rhodium from nuclear waste material. The separation process is based on a principle called molecular recognition. Chemical compounds called "hosts" are used to recognize the shapes of positively charged particles called "guests" and bind to them.[8]

OUTLOOK

Supply

Most of the major expansion programs for South African mines are still progressing, despite relatively low prices for platinum and palladium in 1990. High rhodium prices in 1990, averaging about $3,565 per ounce, partly compensated for lower revenue from platinum and palladium sales. A South African source showed the revenue (dollars per metric ton) of ore as shown in table 16.[9]

Rhodium plays an important role in providing revenue from the UG2 reef. In fact, almost one-half of the $66 in revenue is derived from rhodium, and approximately one-half is derived from platinum. Nickel, copper, gold, and the minor PGM provide limited revenue for South African deposits. In the United States, most of the $187 in revenue comes from platinum and palladium.

TABLE 15

PLATINUM-GROUP METALS: WORLD PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1986	1987	1988	1989	1990[e]
Australia, metal content, from domestic nickel ore:[e 3]					
Platinum	[4]115	130	105	100	100
Palladium	[4]428	490	410	400	400
Canada: Platinum-group metals from nickel ore:					
Platinum	5,242	4,700	5,393	4,244	4,829
Palladium	5,486	4,919	5,643	4,442	5,044
Other	1,462	1,311	1,505	1,184	1,336
Colombia: Placer platinum	447	638	810	964	950
Ethiopia: Placer platinum[5]	2	1	1	[e]2	2
Finland:					
Platinum	120	120	54	[e]60	60
Palladium	96	89	106	[e]100	100
Japan, metal recovered from nickel-copper ores:[6]					
Platinum	663	753	647	[r]1,031	1,358
Palladium	1,453	1,417	1,170	[r]821	1,061
South Africa, Republic of: Platinum-group metals from platinum ore:[e 7]					
Platinum	73,100	78,400	80,200	81,500	88,000
Palladium	32,300	33,900	34,400	35,800	38,900
Other	17,800	19,000	18,700	18,500	11,600
U.S.S.R.: Placer platinum and platinum-group metals recovered from nickel-copper ores:[e]					
Platinum	30,000	31,000	32,000	32,000	31,000
Palladium	81,000	83,000	85,000	85,000	84,000
Other	10,300	10,400	10,500	10,500	10,000
United States: Platinum-group metals from palladium ores:[e 8]					
Platinum	--	780	1,240	1,430	1,810
Palladium	--	2,330	3,730	4,850	5,930
Yugoslavia:					
Platinum	33	24	23	[e]22	29
Palladium	85	132	142	[e]140	135
Zimbabwe:					
Platinum	26	18	28	[r]25	20
Palladium	35	29	46	[r]43	40
Total	[r]260,193	[r]273,581	281,853	[r]283,158	286,704
Of which:					
Platinum	109,748	116,564	120,501	[r]121,378	128,158
Palladium	120,883	126,306	130,647	[r]131,596	135,610
Other	29,562	30,711	30,705	[r]30,184	22,936

[e]Estimated. [r]Revised.

[1]Table includes data available through Apr. 26, 1991. Platinum-group metal production by the Federal Republic of Germany, 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 may also do so, but output is not reported quantitatively, and there is no reliable basis for the formulation of estimates of output levels. However, a part of this output not specifically reported by country is presumably included in this table credited to Japan. (See footnote 6).

[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 6).

[4]Reported figure.

[5]Data are for years ending June 30 of that stated.

[6]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.

[7]Includes osmiridium produced in gold mines.

[8]Estimates for the Stillwater Mine, from published sources. A very small quantity of byproduct platinum and palladium produced from gold-copper ores was excluded.

TABLE 16

REVENUE FROM PLATINUM-GROUP METALS DEPOSITS

(Dollars per metric ton)

UG2, Republic of South Africa	66
Merensky, Republic of South Africa	78
Platreef, Republic of South Africa	93
Great Dyke, Zimbabwe	57
Stillwater, United States	187

Demand

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, Republic of Korea, Taiwan, United States, and many Western European nations. Brazil, Hong Kong, and Mexico are expected to start using catalytic converters in the very near future. The potential market for the catalytic converter is huge given the fact that there are 500 million motor vehicles worldwide.

In the United States, California has for years had the most stringent automobile emission regulations, setting the tone for Federal standards. The California Air Resources Board is seeking to introduce zero emissions for 2% of vehicles by the year 2000. Other States, such as New York and Massachusetts, are opting for California standards instead of the more lenient Federal standards.

In addition to controlling emissions from motor vehicles, the Clean Air Act of 1990 controls emissions of air toxics and chlorofluorocarbons. More than 189 air toxics emitted from bakeries, dry cleaning operations, chemical plants, paint plants, paper plants, and other industrial sources are regulated. Catalysts containing PGM are expected to play some part in controlling air toxic emissions.

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[2]Kallmann, S. A Survey of the Determination of the Platinum Group Elements. Talanta, v. 34, No. 8, 1987, pp. 677–698.

[3]Findlay, G. Trading in Platinum. Woodhead-Faulkner Ltd., 1988, 170 pp.

[4]U.S. Bureau of Mines, Branch of Metals. Nonferrous Metal Prices in the United States Through 1988. 135 pp.

[5]Quarles, J., and W. H. Lewis, Jr. The New Clean Air Act, a Guide to the Clean Air Program as Amended in 1990. Morgan, Lewis & Bockius, Washington, DC, 1990, 102 pp.

[6]Cunningham, C. Rhodium: Prospective Valuation Elements and Implications. Pres. at Metal Bulletin's PGMs 90, Platinum: Future Options III, New York, NY, Sept. 26, 1990, 9 pp. Available from C. Cunningham, A-1 Specialized Services and Supplies Inc., South River, NJ.

[7]Metal Bulletin Monthly. Tin Challenges PGM Catalysts. Jan. 1991, p. 64.

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[9]Russell, D. South Africa's Sharpest Cutting Edge. Met. Bull., No. 7486, May 31, 1990, p. 14.

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POTASH

By James P. Searls

Mr. Searls, a physical scientist, has been the commodity specialist for potash for 11 years. Domestic survey data were prepared by Carleen Militello, mineral data assistant; and international data were prepared by Virginia P. Woodson, international data coordinator.

U.S. potash production in terms of potassium oxide (K_2O) equivalent increased more than 7% relative to that of 1989, and apparent consumption increased 3%. The average price, f.o.b. mine, was unchanged from that of 1989 on the basis of K_2O equivalent. Yearend stocks were unchanged from those of 1989 due to parallel increases in production and sales. The New Mexico producers operated at 78% capacity by reducing their work week to help control North American product stocks.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines developed potash domestic data from voluntary semiannual surveys of U.S. operations. Of the 12 survey requests sent to operations, 11 responded, representing 98% of total production shown in table 1.

ANNUAL REVIEW

Strategic Considerations

Strategic considerations for potash in the United States are relatively minor. Although the capacities of U.S. potash mines have not expanded to meet the expanding U.S. demand for potash, large, high-grade potash ore reserves are across the Canadian border in the Province of Saskatchewan. The United States has a long history of cooperation, friendship, and mutual investments with Canada. It, therefore, is unlikely that the United States would experience a potash cutoff by the Canadian producers. There are multiple pathways between the two countries that preclude the interdiction of trade by natural disaster or sabotage of railroad bridges or ports. The Canadian potash mine capacities were built with the expectations of sales to the U.S. market, especially the Corn Belt. A cessation of trade with the United States would close at least 60% of the Canadian capacity until the offshore markets for potash grow to replace the U.S. demand.

Production

Domestic potash production, in K_2O equivalents, increased more than 7% in 1990 over that of 1989. Producers in all four States, California, Michigan, New Mexico, and Utah, increased their production; New Mexico showed the smallest percentage increase. Of the total production for the year, 74% was standard, coarse, or granular muriate of potash, also known as potassium chloride, and 13% was sulfate of potash, also known as potassium sulfate. The remaining production included manure salts, soluble and chemical grades of muriate of potash, and sulfate of potash-magnesia, also known as potassium magnesium sulfate. The terms "standard," "coarse," and "granular" muriate of potash comprise the "three muriates," a term that ignores the soluble and chemical grades of muriate of potash. "Standard" and "soluble" grades of muriate of potash and sulfate of potash also have industrial end uses. The "sulfates" category combines the sulfate of potash-magnesia data and the sulfate of potash data. "Manure salts" formerly referred to high-grade "run-of-mine" ore; 25% K_2O potash ore is approximately 40% KCl that can be used on sugar beets. The term now refers to a mixture of white muriate of potash and common table salt for industrial uses.

The New Mexico potash producers accounted for 85% of total marketable potash salts production. Production of crude salts (ore) in New Mexico was unchanged at 14.9 million tons[1] with an average K_2O content of 13.8%. The producers were AMAX Potash Corp. of AMAX Inc., Eddy Potash Inc. of Trans-Resources Inc., IMC Fertilizers Inc. (IMCF), Mississippi Chemical Corp., New Mexico Potash Corp. of Trans-Resources Inc., and Western Ag-Minerals Co. of Rayrock Resources of Canada. All the New Mexico producers, except Western Ag-Minerals, mined sylvinite ore (the mixture of sylvite and halite from which most muriate of potash originates) and beneficiated the ore into muriate of potash. Several forms of beneficiation were used: The flotation of sylvite (potassium chloride) away from halite (sodium chloride) occurred at AMAX Potash, Eddy Potash, and Mississippi Chemical. The IMCF plant used heavy-media separation, and New Mexico Potash used selective crystallization in their plant. Western Ag-Minerals and IMCF mined langbeinite ore and beneficiated the ore 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.

AMAX Potash was put up for sale by its parent company near the beginning of the year. For part of the year Kali und Salz of the Federal Republic of Germany considered buying the mine through an intermediary, operating the mine to depletion, and then using the site for waste disposal. Apparently, depleted potash mines are used for waste disposal in the Federal Republic of Germany. The agreement was not signed due to funding problems. At the end of the year, a Denver, CO, gold-mining company was considering buying the mine to operate it to depletion. At the beginning of the year, a muriate of potash exporting association was established by the New Mexico producers under the auspices of the Webb-Pomerane Act. The New Mexico Potash Export Association (NewPotex)

TABLE 1

SALIENT POTASH[1] STATISTICS

(Thousand metric tons and thousand dollars, unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Production	2,381	2,464	2,999	3,132	3,360
K_2O equivalent	1,202	1,262	1,521	1,595	1,713
Sales by producers	2,291	2,904	2,802	3,008	3,391
K_2O equivalent	1,147	1,485	1,427	1,536	1,716
Value[2]	$144,900	e$197,700	$240,300	$271,500	$303,300
Average value per ton of product dollars	$63.24	$67.98	$85.75	$90.28	$89.46
Average value per ton of K_2O equivalent do.	$126.28	$131.73	$168.37	$176.74	$176.80
Exports[3]	1,025	926	783	945	1,016
K_2O equivalent	547	470	380	446	470
Value[4]	NA	NA	NA	NA	$136,100
Imports for consumption[3 5]	6,934	6,706	6,964	5,618	6,952
K_2O equivalent	4,212	4,073	4,217	3,410	4,164
Customs value	$385,100	$433,000	$623,000	$501,300	$545,700
Consumption, apparent[6]	8,200	8,683	8,983	7,680	8,990
K_2O equivalent	4,843	5,088	5,264	4,500	5,453
Yearend producers' stocks, K_2O equivalent	[7]378	155	248	307	303
World: Production, marketable K_2O equivalent	r28,763	r30,459	r31,892	r29,210	e28,290

e Estimated. r Revised. 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] Calculated from production plus imports minus exports plus or minus industry and Government stock changes.

[7] Inventory adjustment of minus 12,900 tons.

was created to increase sales to Latin America, but this year's sales to Latin America were disappointing, and the Association was disbanded at the end of October. At midyear, IMC Fertilizer Group Inc.'s parent company changed its name to IMCERA Group Inc. and sold off 62% of its stockholding in IMC Fertilizers Group Inc. to concentrate in animal-health products, specialty chemicals, and medical imaging media.

In Utah, Moab Salt Inc. produced muriate of potash for Texasgulf Chemical Co. from underground bedded deposits by solution mining and solar evaporation. The sylvinite salts from the solar ponds were beneficiated by flotation to separate the sylvite from the halite. Climax Chemical Co. converted some of Moab Salt's potassium chloride to potassium sulfate for sale during the first half of the year. In the first quarter of 1989, Great Salt Lake Minerals & Chemicals Corp. (GSLMC) was purchased from Gulf Resources and Chemical Corp. by a group of investors lead by D. George Harris & Associates and GSLMC management. GSLMC continued to produce sulfate of potash from the brines of the North Arm of the Great Salt Lake by solar evaporation and a proprietary process of beneficiation. GSLMC sometimes purchases muriate of potash from other sources for conversion to sulfate of potash owing to an excess of sulfate ions in the lake brine concentrate. For 1990, GSLMC imported a small amount of muriate of potash; this amount was subtracted from the import data to prevent double counting in the U.S. apparent consumption calculation. The Reilly-Wendover operation of Reilly Industries Inc. plant produced muriate of potash and manure salts by solar evaporation and flotation from near-surface brines at the west end of the Bonneville Salt Flats.

One plant in Utah manufactured sulfate of potash from muriate of potash and sulfuric acid. They reported production of about 22,000 tons K_2O equivalent for the year. The amount is not included in table 4 because the company does not mine any ore. One plant in Texas manufactured sulfate of potash in the same manner until the end of October and dismantled the plant. This production is included in table 4; the plant is operated by AMAX Potash.

In California, the muriate and sulfate of potash (and other products) operation at Searles Lake was sold by Kerr-McGee Chemical Corp. to an investment group composed of Chase Manhattan Investment Holdings Inc., Prudential Insurance Co., and Oriental Chemical Industries of Seoul, South Korea. The New York investor group D. George Harris & Associates, which previously sponsored the buyout of GSLMC, sponsored this buyout and will provide management to the new company, North American Chemical Corp. The managements of the North American Chemical Co. and GSLMC

TABLE 2

PRODUCTION, SALES, AND INVENTORY OF U.S. PRODUCED POTASH, BY TYPE AND GRADE

(Thousand metric tons and thousand dollars)

Type and grade	Production				Sold or used						Stocks, end of 6-month period			
	Gross weight		K_2O equivalent		Gross weight		K_2O equivalent		Value[e 1]		Gross weight		K_2O equivalent	
	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990
January–June:														
Muriate of potash, 60% K_2O minimum:														
Standard	342	342	209	209	387	317	236	194	30,600	25,200	118	166	72	101
Coarse	130	110	79	67	130	119	79	73	11,300	9,600	33	24	20	15
Granular	513	583	310	354	504	536	305	325	45,400	44,000	106	226	64	137
Chemical	5	9	3	5	6	8	4	5	W	W	2	2	1	1
Potassium sulfate	172	207	88	105	142	226	73	115	24,500	37,600	76	63	38	32
Other potassium salts[2]	405	445	104	119	446	508	115	134	W	W	143	147	34	34
Total[3]	1,569	1,695	793	860	1,616	1,716	812	847	r147,000	156,800	478	628	229	320
July–December:														
Muriate of potash, 60% K_2O minimum:														
Standard	371	334	227	203	348	392	212	238	26,200	28,702	142	108	86	66
Coarse	114	113	69	69	113	122	69	74	9,700	9,600	33	15	20	9
Granular	551	604	334	366	478	589	290	358	40,100	47,100	178	240	108	145
Chemical	8	5	5	3	8	7	5	4	W	W	2	(4)	1	(4)
Potassium sulfate	153	222	78	114	146	207	74	106	28,800	32,600	83	78	42	40
Other potassium salts[2]	366	387	89	98	299	358	74	88	W	W	211	176	49	43
Total[3]	1,563	1,665	802	853	1,392	1,675	724	868	124,300	146,500	649	618	307	303
Grand total[3]	3,132	3,360	1,595	1,713	3,008	3,391	1,536	1,716	271,500	303,300	XX	XX	XX	XX

[e] Estimated. [r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total." XX Not applicable.
[1] F.o.b. mine.
[2] Includes soluble muriate, manure salts, and potassium magnesium sulfate.
[3] Data may not add to totals shown because of independent rounding.
[4] Less than 1/2 unit.

are separate and distinct, but there will be some overlap in marketing.

In Michigan, Kalium Chemical Ltd. continued pilot plant development of a deep ore body and the technology to extract potash from that ore body.

Greensand, also known as glauconite, a natural silicate of potassium, aluminum, iron, and magnesium, was produced by Inversand Co., a subsidiary of Hungerford and Terry Inc., near Clayton, NJ. Production and sales information are withheld to avoid disclosing company proprietary data. Processed greensand was sold as a filter media for the removal of manganese, iron, and hydrogen sulfide from drinking water supply systems. Classified raw greensand was resold by Zook and Ranck Inc. as a soil conditioner and as a slowly released potash, with a K_2O equivalent between 5% and 10%, to the organic farmers of North America.

TABLE 3

PRODUCTION AND SALES OF POTASH IN NEW MEXICO

(Thousand metric tons and thousand dollars)

Period	Crude salts[1] (mine production)		Marketable potassium salts				
			Production		Sold or used		
	Gross weight	K_2O equivalent	Gross weight	K_2O equivalent	Gross weight	K_2O equivalent	Value[e 2]
1989:							
January–June	7,029	987	1,401	700	1,476	730	133,200
July–December	7,138	985	1,434	729	1,235	635	109,400
Total	14,167	1,972	2,835	1,429	2,711	1,365	242,600
1990:							
January–June	7,348	1,019	1,462	729	1,450	698	123,174
July–December	7,583	1,034	1,429	721	1,468	753	122,397
Total	14,931	2,053	2,891	1,450	2,918	1,451	245,571

[e] Estimated.
[1] Sylvinite and langbeinite.
[2] F.o.b. mine.

Consumption and Uses

Apparent domestic consumption of all forms of potash in 1990 increased 3% compared with that of 1989 if after correction for an error in Bureau of the Census import data. The Bureau of the Census has not issued a correction to the artificially low import figure for 1989.

The year went well for the farmers. There were no significant droughts or floods, nor were there new Government programs to restrict planting or fertilizer application. The production of grains for the year was excellent due to remarkably good weather during June, July, and August. Futures prices for grains dropped during the year.

According to the Potash & Phosphate Institute, the shipments of agricultural potash from Canadian and United States producers declined 4% from 1989 to 1990. The shipments of nonagricultural potash rose 5% for a total (agricultural plus nonagricultural) decline of 3%. The major States receiving agricultural potash from Canadian and United States producers, in decreasing order, were Illinois, Iowa, Ohio, Minnesota, Indiana, Wisconsin, and Missouri. These seven States received 56% of the total. Domestic producers accounted for 12% of the shipments to Illinois, 11% of the shipments to Iowa, 4% of the shipments to Ohio, 2% of the shipments to Minnesota, 15% of the shipments to Indiana, 2% of the shipments to Wisconsin, and 71% of the shipments to Missouri. The major receivers of domestically produced potash, in decreasing order, were Missouri, Texas, California, Illinois, Louisiana, Iowa, Indiana, Arkansas, Kansas, and Florida. These 10 States accounted for 73% of the total. The major consumers of sulfates of potash, in decreasing order, were Florida, Georgia, and California. These three States accounted for 42% of the total.

The major States for shipments of nonagricultural potash from Canadian and United States producers, in decreasing order, were Alabama, Ohio, Mississippi, and Delaware. These four States accounted for 61% of the total. In 1990, approximately 8% of total North American potash shipments were industrial (nonagricultural) potash.

Stocks

Yearend producers' stocks of potash were about 1% lower than that of 1989.

TABLE 4

SALIENT U.S. SULFATE OF POTASH[1] STATISTICS

(Thousand metric tons of K_2O equivalent and thousand dollars)

	1987	1988	1989	1990
Production	100	117	166	219
Sales by producers	109	109	147	221
Value[2]	$33,059	$36,854	$47,355	$70,226
Exports[3 4]	118	91	78	124
Value[5]	NA	NA	NA	$43
Imports[3]	26	46	r32	26
Value[6]	$10,500	$19,300	$11,700	$11,000
Consumption, apparent[4 7]	16	65	79	82
Yearend producers' stocks	16	23	42	39

r Revised. NA Not available.
[1] Excluding potassium magnesium sulfate.
[2] F.o.b. mine.
[3] Bureau of the Census.
[4] Preliminary export data pending verification by the Bureau of the Census.
[5] F.a.s. U.S. port.
[6] C.i.f. to U.S. port.
[7] Calculated from production plus imports minus exports plus or minus industry stock changes.

TABLE 5

SALES OF NORTH AMERICAN POTASH, BY STATE OF DESTINATION

(Metric tons of K_2O equivalent)

State	Agricultural potash		Nonagricultural potash	
	1989	1990	1989	1990
Alabama	57,895	75,611	111,870	140,233
Alaska	1,574	1,756	—	26
Arizona	2,807	2,920	1,749	1,297
Arkansas	57,467	49,045	103	363
California	71,063	79,540	6,839	10,376
Colorado	9,902	12,519	1,065	844
Connecticut	6,084	1,288	114	363
Delaware	16,995	23,312	39,945	42,243
Florida	154,752	127,453	749	1,214
Georgia	116,795	116,680	2,216	1,901
Hawaii	8,475	10,213	—	—
Idaho	23,787	30,273	883	2,823
Illinois	593,744	514,331	1,932	2,686
Indiana	333,268	297,302	1,630	2,895
Iowa	478,596	435,537	2,165	3,966
Kansas	46,676	44,129	1,526	2,497
Kentucky	114,280	99,660	584	619
Louisiana	131,146	180,342	3,021	2,527
Maine	3,519	6,173	549	710
Maryland	28,077	28,343	375	422
Massachusetts	2,502	4,666	679	293
Michigan	209,779	150,641	5,994	8,261
Minnesota	341,110	315,495	4,920	2,443
Mississippi	32,773	43,714	40,591	42,806
Missouri	273,227	238,467	3,270	3,035
Montana	11,492	13,075	215	191

TABLE 5—Continued

SALES OF NORTH AMERICAN POTASH, BY STATE OF DESTINATION

(Metric tons of K_2O equivalent)

State	Agricultural potash		Nonagricultural potash	
	1989	1990	1989	1990
Nebraska	32,613	33,114	1,073	1,626
Nevada	18	749	104	26
New Hampshire	780	682	24	116
New Jersey	5,270	5,576	2,500	1,126
New Mexico	9,074	5,517	21,008	15,076
New York	48,138	59,510	23,250	19,888
North Carolina	72,107	78,043	689	1,198
North Dakota	27,539	21,566	15	15
Ohio	362,297	344,509	47,116	51,174
Oklahoma	23,027	20,400	3,617	4,041
Oregon	26,454	30,627	2,181	1,500
Pennsylvania	53,886	56,747	3,101	2,851
Rhode Island	1,962	1,604	22	63
South Carolina	64,003	59,773	96	122
South Dakota	15,678	18,464	122	89
Tennessee	81,193	102,684	2,134	1,015
Texas	131,011	139,697	27,671	31,765
Utah	15,912	18,607	9,804	9,115
Vermont	3,635	5,987	—	49
Virginia	75,454	88,649	201	345
Washington	40,201	48,329	2,855	3,091
West Virginia	9,857	8,162	544	564
Wisconsin	267,447	256,432	24,345	29,018
Wyoming	2,012	3,008	21,153	851
Total	4,497,353	4,310,921	426,609	449,758

Source: Potash & Phosphate Institute.

TABLE 6

SALES OF NORTH AMERICAN MURIATE OF POTASH TO U.S. CUSTOMERS, BY GRADE

(Thousand metric tons of K_2O equivalent)

Grade	1987	1988	1989	1990
Agricultural:				
Standard	328	259	310	263
Coarse	2,078	2,095	2,036	1,882
Granular	1,866	1,530	1,658	1,658
Soluble	360	339	342	334
Total	4,632	4,223	4,346	4,137
Nonagricultural:				
Soluble	88	104	116	131
Other	269	283	305	314
Total	357	387	421	445
Grand total	4,989	4,610	4,767	4,582

Source: Potash & Phosphate Institute.

Yearend stocks represented 18% of annual production or 9 weeks of average production.

Prices

The average annual price, $176.80 f.o.b. mine, of U.S. potash sales of all types and grades, was unchanged from that of 1989. The average price was $168.64 per ton for the first half of the year and $185.18 for the second half of the year. The average annual price of the three grades of muriate was $130.13, down 5% from last year. Standard-grade muriate of potash averaged $124.75 per ton; coarse grade, $130.81; and granular grade, $133.39. The average annual price for all grades of sulfate of potash averaged $317.30 per ton.

Foreign Trade

Total potash exports as reported by the Bureau of the Census increased 5% by ton K_2O. Muriate of potash exports decreased 10%, while sulfate of potash increased 59%. The major destination for potash exports was to Latin America, which received 52%, by product tonnage. The individual countries were, in decreasing order, Brazil, Mexico, Costa Rica, Colombia, and the Dominican Republic. These five countries accounted for 72% of exports to Latin America. Three countries accounted for 75% of the non-Latin American market: in decreasing order these were Japan, China, and Canada. The U.S. Bureau of Mines determined, using prices, that the exported product in Harmonized Code category 3104.100000 was langbeinite, and these values were placed in the 3104.900000 category of sulfate of potash-magnesia.

Potash imports for consumption as reported by the Bureau of the Census increased 22% by ton product compared to that of 1989. Muriate of potash increased 19%, while sulfate of potash declined 18%. Both Eastern and Western Germany increased their exports to the United States. Canada provided 92% of all muriate of potash imports and 91% of all imports by K_2O. Israel was the second largest source of U.S. imports, with 5% of the muriate of potash imports and 6%, by K_2O content, of the total imports. The U.S. Bureau of Mines determined, using prices, that the imported product in Harmonized Code category 3104.100000 was sylvite, and these values were placed in the 3104.200000

TABLE 7

PRICES[1] OF U.S. POTASH, BY TYPE AND GRADE

(Dollars per metric ton of K_2O equivalent)

Type and grade	1988		1989		1990	
	January–June	July–December	January–June	July–December	January–June	July–December
Muriate, 60% K_2O minimum:						
Standard	119.73	122.29	129.54	123.45	129.84	120.52
Coarse	137.28	133.95	142.77	140.92	137.32	129.07
Granular	136.62	140.12	149.01	138.05	135.36	131.60
All muriate[2]	130.84	132.65	140.80	132.98	133.25	124.38
Sulfate, 50% K_2O minimum	326.98	335.76	336.48	306.96	326.34	307.47

[1] Average prices, f.o.b. mine, based on sales.
[2] Excluding soluble and chemical muriates.

TABLE 8

AVERAGE ANNUAL U.S. PRODUCER PRICE

(Dollars per metric ton, K_2O equivalent)

Year	Nominal prices						Based on constant 1990 dollars, 1982 = 100[1]					
	All types and grades	Muriate			Sulfate	Other[2]	All types and grades	Muriate			Sulfate	Other[2]
		Standard	Coarse	Granular				Standard	Coarse	Granular		
1968	30.64	23.53	27.61	29.29	—	56.18	98.91	75.96	89.13	94.55	—	181.36
1969	28.92	20.88	r24.07	25.61	—	52.37	88.43	63.85	r73.60	78.31	—	160.14
1970	39.64	29.52	35.47	r37.09	—	60.87	114.86	85.54	102.78	r107.47	—	176.38
1971	42.84	34.83	38.78	41.47	78.32	54.43	117.42	95.47	106.30	113.67	214.67	149.19
1972	44.22	36.52	38.87	39.99	89.19	56.82	115.73	95.58	101.73	104.66	233.43	148.71
1973	47.69	38.14	r41.08	42.78	91.14	71.64	117.25	93.77	r101.00	105.18	224.08	176.13
1974	r38.07	58.04	58.83	56.52	122.12	100.42	r85.80	130.80	132.59	127.38	275.22	226.32
1975	99.69	84.45	83.33	81.69	188.95	130.74	204.59	173.31	171.02	167.65	387.78	268.31
1976	92.97	69.54	73.33	76.69	219.61	137.09	179.31	134.12	141.43	147.91	423.56	264.40
1977	92.66	63.56	79.37	79.72	191.36	150.63	167.56	114.94	143.53	144.16	346.04	272.39
1978	98.17	67.97	81.81	83.66	203.68	161.83	165.47	114.57	137.90	141.02	343.32	272.78
1979	116.91	87.34	100.97	101.84	226.67	189.79	181.02	135.23	156.34	157.68	350.96	293.86
1980	159.63	r127.02	139.36	138.63	261.79	227.88	226.69	r180.38	197.90	196.86	371.76	323.61
1981	r172.04	136.55	141.61	136.86	349.23	262.78	r222.74	176.79	183.34	177.19	452.14	340.22
1982	148.87	106.36	r115.09	109.53	352.35	248.56	181.17	129.44	r140.06	133.30	428.81	302.50
1983	145.97	95.45	106.72	102.05	341.64	228.71	170.98	111.80	125.00	119.53	400.17	267.89
1984	147.53	106.33	110.22	110.79	375.45	243.84	166.71	120.16	124.55	125.19	424.26	275.54
1985	140.89	100.07	96.21	92.60	353.28	246.54	154.19	109.52	105.30	101.34	386.64	269.82
1986	r126.28	80.99	87.49	81.17	312.82	298.40	141.32	86.38	93.32	86.58	333.65	318.27
1987	r131.73	93.68	99.80	r124.09	303.43	271.73	137.65	97.03	103.37	r97.03	314.27	281.45
1988	168.37	121.05	135.69	138.28	335.74	282.25	168.37	121.05	135.69	138.28	335.74	282.25
1989	176.74	126.67	141.91	143.67	321.90	307.77	184.02	131.88	147.75	149.58	335.15	320.44
1990	176.80	124.75	130.81	133.39	317.30	296.56	176.80	124.75	130.81	133.39	317.30	296.56

r Revised.
[1] GNP Implicit Price Deflator used.
[2] Includes chemical and soluble muriates, manure salts, potassium magnesium sulfate, and before 1971, potassium sulfate.

category of muriate of potash.

World Review

World production declined 3% from that of 1989. World prices, as exemplified by the per ton price of standard muriate of potash, f.o.b. Vancouver, Canada, rose from approximately $162.50 per ton ($97.50 per short ton of product) level in October to approximately $170 per ton ($101 per short ton of product) through the end of the year. On the same basis, granular potash, which usually moves in parallel with the price of standard potash, finished the year at approximately $183 per ton ($110 per short ton of product). These prices were reported by the British Sulphur Corp. Ltd. This upward movement in price comes from a concerted effort by the Canadian (and United States) potash producers to restrict production, reduce stocks, and increase profitability.

TABLE 9

U.S. EXPORTS OF POTASH, BY TYPE

	Approximate average K_2O content (percent)	Quantity (metric tons)		Value (thousands)
		Product	K_2O equivalent	
1989:				
Potassium chloride, all grades	61	496,575	302,911	NA
Potassium sulfate	51	153,271	78,168	NA
Potassium magnesium sulfate	22	295,609	65,034	NA
Total	XX	945,455	446,113	NA
1990:				
Potassium chloride, all grades	61	445,810	271,944	$46,450
Potassium sulfate	51	243,738	124,306	43,271
Potassium magnesium sulfate	22	318,176	69,998	41,399
Potassium nitrate	45	7,841	3,528	4,998
Total	XX	1,015,565	469,776	136,118

NA Not available. XX Not applicable.

Source: Bureau of the Census.

Brazil.—There are reports that the Tarquari-Vassouras Mine was closed during the year due to the newly elected Government's refusal to further subsidize production.

Canada.—Saskatchewan producers, other than Potash Corp. of Saskatchewan (PCS), operated at an average 80% capacity factor, while PCS operated at an average 40% capacity factor, to keep North American stock levels below 2 million tons. The average capacity factor for the Province was 60%. The proposed sale of the Saskterra Fertilizers Ltd. 40% share of the Allan Mine to the Dead Sea Works was halted due to financial disagreements. This share of the mine was eventually sold to PCS, the operator, who owned the other 60% of the mine. Groupe Entreprise Minière et Chimique (EMC) of France purchased Canamax Resource Inc.'s 51% share in the proposed Russell-Binscarth Mine, which is east of Esterhazy and a few miles across the Provincial border into Manitoba. The remaining 49% of the property is owned by the Provincial Government of Manitoba. It would operate in the rich Esterhazy member of the Elk Point Basin if put into production. With Saskatchewan potash producers operating at only 60% of capacity, an immediate need for new potash capacity does not seem to exist. At midyear, Denison Mines Ltd. put its 60% ownership of Denison-Potacan Potash Co. on the market to reduce long-term indebtedness. The leak in the International Minerals & Chemicals (Canada) Ltd.'s Esterhazy K-2 Mine, which began in 1986, has been throttled but not stopped. The company has started to consider sinking another shaft into an unconnected portion of its reserves to start a new mine and maintain operations.

Chile.—AMAX Inc. was reported to be withdrawing from the Minsal Project in the Salar de Atacama.[2] The Yolanda Project, to be operated by the North Lily Mining Co.[3] of California, United States, will mine sodium nitrate and iodine, converting the sodium nitrate to potassium nitrate using imported muriate of potash. It is not clear how far the price of potassium nitrate would fall if more material from new production capacity was to be introduced into the world market.

China.—China has raised its estimate of the reserves at the Qaidam Basin salt flats from 200 million tons to 222 million tons and considers that basin to contain 70% of the country's total of 320 million tons.[4]

European Commission.—The European Commission opened antidumping investigations following the filing by the European Potash Producers Association of dumping charges against the U.S.S.R.

France.—Groupe Entreprise Minière et Chimique (EMC) became involved in the French chemical reorganization when it was considered for merger, which was later dropped, with Société Nationale Elf Aquitaine under Entreprise de Recherche et d'Activité Pétrolières (ERAP). Another state owned chemical company, Orkem, has been split into two parts with its fertilizer divisions going to EMC and its chemical divisions going to Elf Aquitaine's Atochem in 1995. Entreprise Minière et Chimique's Alsatian Mines will run out of minable ore in the year 2004 (exactly 100 years since discovery). Entreprise Minière et Chimique will have its 50% portion of the New Brunswick, Canada, mine and potentials in both Manitoba, Canada, and the People's Republic of the Congo. Entreprise Minière et Chimique is determined to stay in the fertilizer business even though they will no longer be mining potash in France. However, for the Alsatian Mines, the company started to consider storing hazardous (nonliquid, nonflammable, nonradioactive) waste as a possible use of the depleted mines and as a source of employment for the Mulhouse region.

TABLE 10

U.S. EXPORTS OF POTASH, BY COUNTRY[1]

(Metric tons of product)

Country	Potassium chloride		Potassium sulfates, all grades[2]		Potassium nitrate		Total[3]	
	1989	1990	1989	1990	1989	1990	1989	1990
Algeria	1,200	—	—	—	—	—	1,200	—
Argentina	7,200	10,370	1	5,230	—	—	7,200	15,600
Australia	830	20	9,280	6,960	—	—	10,110	6,980
Bahamas	—	—	640	80	—	—	640	80
Bangladesh	—	—	—	2,200	—	—	—	2,200
Belize	2,790	2,580	430	190	—	—	3,220	2,770
Bolivia	530	290	580	18	—	19	1,110	327
Brazil	229,820	162,320	21,470	4,000	—	—	251,290	166,320
Canada	1,710	6,300	54,310	87,200	—	4,660	56,020	98,160
Chile	6,800	12,980	20,270	18,120	—	—	27,070	31,100
China	—	—	73,940	105,670	—	—	73,940	105,670
Colombia	53,870	38,160	25,020	15,460	—	—	78,890	53,620
Costa Rica	26,550	31,730	23,110	22,310	—	—	49,660	54,040
Dominican Republic	35,820	45,570	3,930	3,160	—	—	39,750	48,730
Ecuador	6,130	17,350	13,020	13,380	—	10	19,150	30,740
Egypt	130	—	—	1,000	—	—	130	1,000
El Salvador	4,080	1,080	500	1,000	—	—	4,580	2,080
Fiji	—	—	—	2,090	—	—	—	2,090
France	7	—	—	—	—	—	7	—
Greece	—	—	—	1	—	—	—	1
Guatemala	5,200	—	3,700	4,400	—	—	8,900	4,400
Guyana	—	500	400	—	—	—	400	500
Honduras	1,900	9,690	6,990	90	—	—	8,890	9,780
Hong Kong	—	—	—	400	—	—	—	400
India	—	—	—	18,400	—	—	—	18,400
Indonesia	—	—	—	7,970	—	—	—	7,970
Italy	800	14,850	—	16,550	—	—	800	31,400
Japan	16,520	19,140	116,300	135,060	—	3,060	132,820	157,260
Korea, Republic of	11,430	—	80	6	—	3	11,510	9
Malaysia	—	—	—	14,700	—	—	—	14,700
Martinique	—	8,820	—	4,550	—	—		13,370
Mexico	61,330	26,960	37,140	34,600	—	78	98,470	61,638
New Zealand	120	—	460	250	—	—	580	250
Pakistan	—	—	—	29,570	—	—		29,570
Panama	2,140	7,250	860	1,870	—	—	3,000	9,120
Peru	12,140	2,000	21,070	—	—	—	33,210	2,000
Philippines	9	3	—	37	—	1	9	41
Saudi Arabia	—	—	—	1	—	—	—	1
Sweden	950	950	—	—	—	—	950	950
Taiwan	—	—	350	37	—	—	350	37
Thailand	—	—	4,000	5,300	—	3	4,000	5,303
Trinidad	2,610	2,540	490	35	—	—	3,100	2,575
United Kingdom	3,530	340	2	—	—	—	3,532	340
Uruguay	—	2,801	—	—	—	—	—	2,801
Venezuela	42	20,950	10,500	—	—	2	10,542	20,952
Other	390	266	36	19	—	4	426	289
Total[3]	496,575	445,810	448,880	561,914	—	7,840	945,455	1,015,565

[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 11

U.S. IMPORTS FOR CONSUMPTION OF POTASH, BY COUNTRY

Country	Metric tons of product										Total value (thousands)			
	Potassium chloride		Potassium sulfate		Potassium nitrate		Potassium sodium nitrate		Total[1]		Customs		C.i.f.	
	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990
Belgium-Luxembourg	21	2,500	5,800	11,900	—	139	—	—	5,800	14,500	$1,100	$2,400	$1,200	$3,000
Canada	5,089,800	6,286,500	900	500	—	5	—	18,300	5,090,700	6,305,300	440,100	481,900	509,200	601,300
Chile	—	—	—	—	19,000	13,800	11,500	29,300	30,500	43,100	5,100	6,200	6,000	7,300
France	—	—	10,200	4,000	—	—	—	—	10,200	4,000	1,800	700	2,200	800
Germany, Federal Republic of:														
Western states	400	18,800	45,600	35,400	—	—	—	—	46,000	54,200	7,200	8,000	8,100	9,100
Eastern states	56,300	122,900	—	—	—	24	—	—	56,300	122,900	5,000	8,100	5,700	9,200
Israel	248,200	363,300	—	—	14,700	22,000	—	—	262,900	385,300	30,400	36,500	34,300	40,000
Italy	—	—	400	5	—	—	—	—	400	5	40	2	40	3
Japan	40	—	—	73	6	7	100	200	150	280	90	180	100	200
Jordan	22,000	—	—	—	—	—	—	—	22,000	—	2,000	—	2,400	—
Mexico	—	—	—	—	—	1	—	—	—	1	—	1	—	1
Netherlands	3,000	—	73	—	—	—	—	—	3,100	—	343	—	400	—
Poland	—	—	—	—	36	80	—	—	36	80	20	30	20	40
U.S.S.R.	87,200	21,800	—	—	—	—	—	—	87,200	21,800	7,900	1,500	9,600	1,800
United Kingdom	3,000	223	—	—	—	20	—	—	3,000	243	180	173	220	204
Yugoslavia	—	—	—	—	—	23	—	—	—	23	—	20	—	20
Total[1]	5,510,000	6,816,000	63,000	51,900	33,700	36,100	11,600	47,800	5,618,300	6,951,700	501,300	545,700	579,500	673,000

[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.

Germany, Federal Republic of.— Early in the year Kali und Salz closed two mines, Hattorf and Wintershall, for a short period to maintain stocks at reasonable levels. As the reunification with East Germany approached, the concern was about reducing the salt pollution in the Werra River by replacing East German production with West German production and modifying East German technology in other plants. It was felt that 16 million tons of salt per year could be withheld from the Werra and Weser Rivers.

With the simultaneous dissolution of the centrally planned economic operation and combination with the Federal Republic of Germany in the middle of the year, VEB Kalikombinat founded Mitteldeutsche Kali AG and three potash mining companies, Zielitz Kali AG (Zielitz), Kali Werra AG (Ernst Thälman or Merkers, Wilhelm Pieck, Marx-Engels), and Kali Südharz AG (Glückauf or Sondershausen, Volkenroda or Menteroda, Karl Marx or Sollstedt, Heinrich Rau or Rossleben). Volkenroda was

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.
1989:					
Potassium chloride	61	5,510,000	3,361,000	$481,200	$556,200
Potassium sulfate	51	63,000	32,100	10,200	11,700
Potassium nitrate	45	33,700	15,200	8,600	10,000
Potassium sodium nitrate mixtures	14	11,600	1,600	1,300	1,600
Total	XX	5,618,300	3,409,900	501,300	579,500
1990:					
Potassium chloride	61	6,816,000	4,114,600	520,600	644,200
Potassium sulfate	51	51,900	26,400	9,500	11,000
Potassium nitrate	45	36,100	16,200	10,100	11,400
Potassium sodium nitrate mixtures	14	47,800	6,700	5,500	6,300
Total	XX	[1]6,951,700	4,163,900	545,700	[1]673,000

[e] Estimated. XX Not applicable.

[1] Data do not add to total shown because of independent rounding.

Source: Bureau of the Census, as adjusted by the U.S. Bureau of Mines.

closed during 1990. Earlier in the year a conveyer belt was completed between the Wilhelm Pieck Mine and the Ernst Thälman Mine to circumvent the damage of the 1989 collapse in the Ernst Thälman Mine and keep the production at that mine at four-fifths of previous production. Kali Bergbau/Handelsgesellschaft mbH continues to handle sales to long-standing contracts and former Comecon countries. Some potash will be handled through Kali Export Gesellschaft.

Israel.—The concept of privatization was withering on the vine as several Government officials expressed reservations concerning extra-Israel control over the second most important Israeli source of exports. By the end of the year, the differences in valuation of the 50% share of the company, which would not be controlling in major decisions, put the sale beyond expectations. The tensions in the Gulf of Arabia had little effect on shipments and no effect on production for the year.

Italy.—A drought in Sicily halted Italkali SpA's production of sulfate of potash between July and end of the year due to lack of water for the beneficiation plant.

Japan.—The Co-op Chemical Co. Ltd. commenced construction of its sulfate of potash plant in Niigata-Higasiko. Plant capacity has been put at 10,000 tons per year using imported muriate of potash.

Jordan.—The tensions in the Persian Gulf region had no effect on production and little effect on shipments of potash. The Arab Potash Co. decided to increase its capacity from 1.4 million to 1.8 million tons per year using either the cold-crystallization technology or flotation technology. The new capacity, probably cold-crystallization, is expected to be on-line in 1994.

Korea, North.—The Sariwon Potassic Fertilizer Complex tested its kiln for the first time this year. It is questionable that the energy required to separate potassic feldspar into sulfate of potash, alumina, and cement aggregate will allow a profitable operation considering the world price of potash.

Poland.—Poland reports that it produced 137,000 tons of potassic fertilizer in 1990. Because there is now nitrate of potash being imported into the United States from Poland, this production would appear to be nitrate of potash manufactured from muriate of potash. This muriate of potash could be purchased from either the U.S.S.R. or the Federal Republic of Germany and combined with indigenous nitrogen fixation product.

Spain.—The fertilizer components of Explosivos Rio Tinto, S.A. (ERT) and S.A. Cros combined in 1988 to form Fertilizantes Espanoles, S.A. (FESA). The remaining segments of ERT and S.A. Cros merged to form ERCROS, S.A., which purchased 80% of Empresa Nacional de Fertilizantes, S.A., (Enfersa) in 1989. Kuwait Investment Office (KIO) purchased 51% of ERCROS in 1988. In 1990, FESA, now controlled by ERCROS, merged with Enfersa. In 1990, ERCROS, through FESA, shut down the

TABLE 13

WORLD POTASH ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990, RATED CAPACITY[1]

(Thousand metric tons of K_2O equivalent)

North America:	
Canada	11,520
Mexico	NA
United States	1,920
Total	13,440
South America:	
Brazil	150
Chile	45
Total	195
Europe:	
France	1,680
Germany, Federal Republic of:	
Western states	2,700
Eastern states	2,900
Italy	400
Spain	750
U.S.S.R.	13,700
United Kingdom	490
Total	22,620
Asia:	
China	120
Israel	1,350
Total	1,470
World total[2]	37,725

NA Not available.
[1] Includes capacity at operating plants as well as at plants on standby basis.
[2] Data do not add to total shown because of independent rounding.

TABLE 14

WORLD POTASH RESERVES AND RESERVE BASE

(Million metric tons, K_2O equivalent)

	Reserves	Reserve base[1 2]
North America:		
Canada	4,400	9,700
Mexico	NA	NA
United States	85	360
Total[3]	4,500	10,000
South America:		
Brazil	50	400
Chile	10	50
Total	60	450
Europe:		
France[2]	16	45
Germany, Federal Republic of:		600
Western states	500	—
Eastern states	300	—
Italy[2]	20	40
Spain[2]	30	50
U.S.S.R.[4]	3,600	22,600
United Kingdom[2]	25	30
Total[3]	4,500	24,400
Africa:		
Congo	—	20
Ethiopia	NA	NA
Tunisia	NA	NA
Total	—	20
Asia:		
China	320	NA
Israel	54	150
Jordan	54	150
Laos	NA	20
Thailand	NA	100
Total[3]	400	400
World total[3]	9,500	35,300

NA Not available.
[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] Based on recent studies by U.S. Bureau of Mines, Division of Minerals Availability.
[3] Data may not add to totals shown because of independent rounding.
[4] The U.S.S.R. has increased the reserve base of the Upper Kama Basin to 19 billon tons. Apparently, the carnallite ores can be mined.

TABLE 15

SALIENT CANADIAN POTASH STATISTICS

(Thousand metric tons of K_2O equivalent)

	1987	1988	1989	1990
Production[1]	7,267	8,327	7,360	7,002
Domestic sales by domestic producers[1]	499	416	315	393
Exports:				
United States[1]	4,223	4,248	3,886	3,630
Overseas[1]	3,133	3,792	2,924	3,164
Imports for consumption[2]	19	11	16	31
Domestic consumption[3]	518	427	331	424
Yearend producers' stocks[1]	1,135	1,356	1,596	1,272

[1] Data supplied by the Potash & Phosphate Institute.
[2] From Bureau of the Census export data. Sulfate of potash and nitrate of potash were landed on the Canadian east coast from European sources.
[3] Domestic sales by domestic producers plus imports.

TABLE 16

MARKETABLE POTASH: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons of K_2O equivalent)

Country	1986	1987	1988	1989	1990[e]
Brazil	r11	r37	r54	r97	60
Canada[2]	6,753	7,668	r8,154	r7,074	3,7,372
Chile[4]	20	23	25	e25	25
China[e]	40	40	40	40	40
France	1,617	1,539	1,502	r1,195	1,300
Germany, Federal Republic of:					
Western states	2,161	2,199	r2,290	r2,182	2,200
Eastern states	3,485	3,510	3,510	3,200	2,700
Israel	1,255	1,253	1,244	r1,338	1,350
Italy	r119	r134	r148	r156	60
Jordan	660	734	785	r793	790
Spain	795	741	r855	r850	3,690
U.S.S.R.	10,228	10,888	11,301	r10,200	9,500
United Kingdom	r417	r431	r463	465	490
United States	1,202	1,262	1,521	1,595	3,1,713
Total	r28,763	r30,459	r31,892	r29,210	29,290

[e] Estimated. [r] Revised.
[1] Table includes data available through Apr. 19, 1991.
[2] Official Government figures. Potash & Phosphate Institute production data are given in table 15.
[3] Reported figure.
[4] Data represent officially reported output of potassium nitrate product (gross weight basis) converted assuming 14% K_2O equivalent.

Cardona Mine because of ore depletion. The nearby Vittoria deposit will not be opened due to geologic problems even though the ore grade runs as high as 24% K_2O. ERCROS' Sallent Mine will be expanded from 270,000 to 350,000 tons per year K_2O.

Thailand.—The six member countries of the Association of Southeast Asian Nations (ASEAN) approved a potash mine and mill as a joint Industrial Project in Thailand. This is the Bamnet Narong Project of the early 1980's, where an incline to the 180-meter-deep ore zone was flooded in 1984.

U.S.S.R.—Free market entrepreneurship has emerged from the U.S.S.R. with "perestroika potash." This refers to potash that is sold by other than Soyuzpromexport, such as various enterprises that were allocated potash for upgrading to complete fertilizers. These enterprises are allowed to sell the potash on the world market rather than use the product internally. The potash mines in the U.S.S.R. are reported to be shifting to profit orientation. To become competitive in the world market, they will need hard currency to upgrade to equipment from hard currency countries, which can only be achieved by selling potash to the hard currency countries. The other side of the coin is that potash consumption in the U.S.S.R. is declining as the farmers have to pay unsubsidized prices for their seed, machinery, fuel, and fertilizers. The farmers may decide to delay fertilizer application until they have money from selling their crops at free market prices. Even then they may choose to invest in machinery instead of fertilizer.

A paper, published in the proceedings of the Ninth Industrial Minerals International Congress (1990) in Sydney, Australia,[5] by B. Y. Golovkov, reported that the U.S.S.R. contains 22,600 million tons of K_2O of geological reserves of minable deposits. Eighty-four percent of this is in the Upper Kama (Ural mountain) deposits or 19 billion tons of K_2O. Much of this must be carnallite.

OUTLOOK

Demand for Potash

It is interesting to read that writers are forecasting fertilizer demand growth because of the momentum of population growth around the world. One writer pointed out a world population gain forecast of 1 billion humans, the equivalent of four U.S. populations, is going to be added in the next 10 years; therefore, the world will need more potash. It is not necessarily so. Food, and the fertilizer to grow the food, have to be paid for. The transportation of the foodstuffs from the fields to the new humans has to be paid for. Many of the families with these 1 billion new children will not be able to pay for more food. The growth of potash consumption requires that there is additional money to pay for both the potash and the required transportation costs. Analysis of the consumption patterns of several of the economic regions of the world tend to demonstrate that in some parts of the world, private consumption

tends to crowd out the consumption of potash. An example of this might be energy imports.

For 1987, the average calories per day consumed in the developed countries of the world is 3,345 calories. The average population growth rate for these countries is 0.6% per year. Their average gross national product (GNP) per capita in U.S. dollars is $11,350 per capita. The average daily caloric intake for Latin America is 2,560 calories. Its population growth rate is 2% per year. Its average GNP per capita in U.S. dollars is $1,910 per capita. The average daily caloric intake for the Sub-Saharan portion of Africa is 2,225 calories, some of which is likely gathered from indigenous plants. Its population growth rate is 3% per year. Its average GNP per capita in U.S. dollars is $640 per capita (with a median of $335). Not all countries can achieve or even strive to feed their people in the near future at the same level of caloric intake as the developed countries. It is not predetermined that they will do so in the future. Of course, not all countries have the governmental policies in place to have a large effect on the average daily caloric intake of its population. Further, it seems clear that large population growth, at present, is joined to a low average daily caloric intake. Generally, population growth indicators such as "crude birth rate" and "total fertility rate" showed neither positive nor negative significance.

An assortment of macroeconomic and other variables published by the World Bank for a single year (1987) were investigated that might describe the financial health, investment attitudes, and a few sociological indicators for many of the countries for their predictive relationship to potash consumption. The world was divided into economic groups following the lead of the World Bank: the Developed Countries, the Sub-Saharan African Developing Countries, Latin America and Caribbean, Asian, etc. Parallel to this data, the United Nations Food and Agricultural Organization (FAO) provides potash consumption by country and by kilograms per hectare of (a) agricultural land, (b) arable land and permanent crops, and (c) per capita for approximately all countries of the world.

The Developed Countries.—The developed countries respond to a pair of factors and to one of these in a surprising manner. The economic system of the developed countries makes a clear calculation of the food demand per person, the food producible per area, and the potash needed to grow that amount of food per area. For the developed countries, the two variables were "arable hectares per capita," which would describe the amount of land available for grains, vegetables, oils, and fibers, and "agricultural hectares per capita," which would includes arable hectares plus the hectares for tree crops and grazing lands. These countries have a high enough GNP per capita to fertilize their grazing lands and tree crops. Curiously, the "agricultural hectares per capita" is negatively correlated to the total potash per hectare. The R^2 of this regression is 0.838, which means that the two variables explain about 90% (the approximate square root of 0.838) of the variation within the countries in the grouping. For predictive purposes, the excess production of food (for exports and stocks) in both North America and Western Europe, the declining potash consumption in the United States (since 1980), plus the slow or zero growth in potash consumption in Western Europe would indicate zero or declining potash consumption growth in this group of countries. The average population growth rate for the developed countries was 0.5% per year between 1980 and 1988. The average daily caloric intake for the developed countries is 3,345 calories. This grouping of countries consumed about 44% of the world's total potash production for 1990.

For the reader's information, Andorra, Faeroe Islands, Gibraltar, Vatican City, Liechtenstein, Malta, Monaco, and San Marino were not used in the analysis. Israel, Japan, and the Republic of South Africa were in the grouping.

Latin America and Caribbean.—Latin America responds to four of the variables that were tested by regression. They responded positively only to "gross domestic investment: contribution to gross domestic product" in percentage. This could mean that countries that are making investments for growth are also sophisticated enough to make investments in potash.

This region responded negatively to the ratio of "arable hectares per capita." The countries with large arable hectares per capita apparently do not fertilize the soil as much as the countries with fewer hectares per capita. It must be that the large countries are still cropping the natural fertility of the land, while the small countries and islands must fertilize. This region also responds negatively to "private consumption: contribution to gross domestic product." This may mean that private consumption crowds out some of the investment, including fertilizers. Finally, this region responds negatively to the "crude birth rate," which is simply the number of births per year divided by the total population. This is certainly counterindicative of potash growth because of population growth. The R^2 was 0.386, meaning that the four variables explained only about 60% of the variation. The average daily caloric intake per capita was 2,563 calories. The average population growth was about 2% per year. This region received about 8% of the world's potash production for 1990.

The African Sub-Saharan.—The World Bank divided Africa into two groups, the Sub-Saharan, which was grouped together, and the Mediterranean Africa, which was grouped with the Near East. Both "K_2Oarable" (kilograms of K_2O per arable hectare) and "K_2Oagric" (kilograms of K_2O per agricultural hectare) were investigated but only "K_2Oarable" was chosen for analysis because it was not believed that this part of the world has GNP per capita to fertilize the orchards and the meadows. Even for the countries that were available, the data were incomplete. It was found that when significance was investigated using stepwise forward or backward variable choice, a reduced number of "degrees-of-freedom" occurred because some countries were dropped out of the regression for not having data in all the variables. Dropping these countries would result in a medium (0.3 to 0.5) level of R^2. When the data were subjected to multiple regressions with the few variables that showed relationships with the dependant variable, a different, lower value of R^2 would be obtained. This was because the simpler regressions were on data that were complete for all countries. Then the R^2's were lower or zero,

from which it was concluded that the 10 additional, poorer countries did not have any pattern, within the variables that were studied, of choosing how much potash they used per hectare. It would appear that the countries of Africa that do not have the wealth to compute and answer all the questions that are asked by the World Bank do not have a pattern of response within the variables that were searched. The more advanced countries in this group (27 out of 37 countries) responded negatively to "private consumption as a percentage of gross domestic product" and negatively to "agricultural area per capita" with an $R^2 = 0.296$. For all 37 countries in the group, the response to only "private consumption as a percentage of gross domestic product" was significant and that was only $R^2 = 0.10$. "Agricultural area per capita" added very little significance. For 36 of the 37 countries, "population growth rate" (a positive relationship) and "private consumption as a percentage of gross domestic product" (a negative relationship) combined for a $R^2 = 0.16$. It seems clear that in this relatively poor area there will be some separation of the countries with higher GNP per capita from the countries with lower GNP per capita. The countries with higher GNP per capita will move toward more potash consumption, while the countries with lower GNP per capita will vary around some low level of potash consumption in a random fashion. This area consumed about one-half of 1% of the world total potash produced for 1990.

South Asia, East Asia, and Pacific.—This region responds positively to GNP per capita (or gross national product per capita) and negatively to population growth. There is a weaker, negative correlation to "average daily calories per capita." These three variables have an $R^2 = 0.83$, which means that these three variables explain about 90% of the variation between the countries. It would appear that this region will be a growth area for the consumption of potash because the region contains the "Four Tigers" of the Pacific, and other countries will attempt to emulate them as a paradigm of movement to healthy nationhood. The problem for some of the countries will be to contain their population growth. This region of the world consumed about 13% of the total potash production in 1990.

Conclusions

This is a cursory report of the study because there was not enough time to study "Rest of Europe and Mediterranean," and "Middle East and North Africa." The Middle East and North Africa is not an important potash consuming area at this time (0.4%) but will grow at a rate above the world norm. The "Rest of Europe and Mediterranean" are the European countries that are not included in the "developed countries." These are the former centrally planned economies who will probably decrease their consumption for 10 years. For the forecasts in figure 1, data from the International Fertilizer Industry Association (IFA) concerning production and imports for the past 3 years was used where it was available. When IFA data were not available, FAO data were used, and 1986–87 consumption data went into the 1987 column and 1987–88 went into the 1988 column.

From the analysis of most of the countries' macroeconomic data and

FIGURE 1

FORECAST OF WORLD POTASH CONSUMPTION

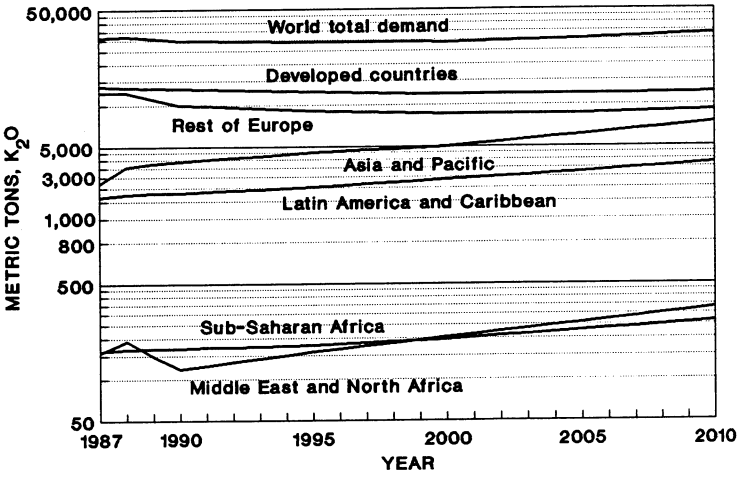
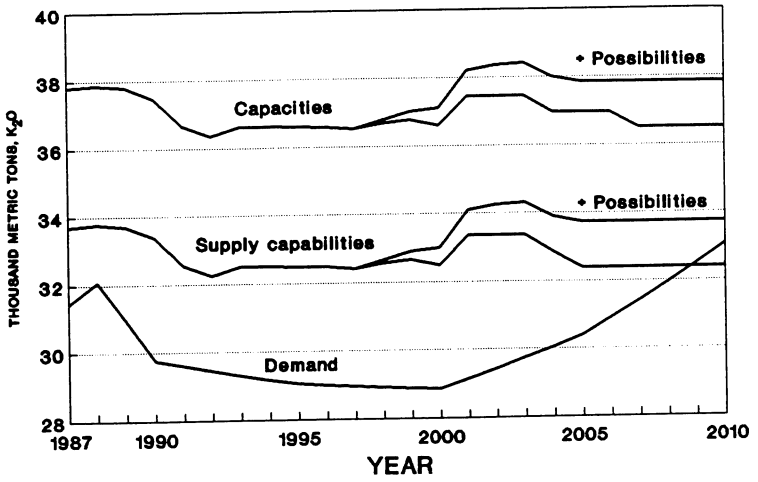


FIGURE 2

FORECAST OF WORLD SUPPLY-DEMAND



potash consumption, and from rudimentary economic analysis, the forecast in figure 2 shows declining or level potash consumption for the world for approximately 10 years. After the year 2000, one might foresee an increase that will be above 1988 levels by the year 2010. Several factors point toward level or declining consumption of potash in the midterm. First, there is the history of declining potash consumption in the United States for several reasons. Second, there is the likelihood of western Europe (European and United Kingdom demand for fertilizers was forecast to fall between 10% to 20% during the 1990's;. . .[6]) slowly dropping its subsidies to the farmers. These factors point to declining potash consumption in the largest consuming group of countries in this study. The former Comecon countries will toil through their conversion to capitalism, or modified capitalism, with much time and money devoted to creating new institutions. The former Comecon countries will consume less potash for 5 to 10 years as they modify their thinking from subsidized potash consumption under central planning to individual farmers computing their marginal investment in potash for the marginal profit.

The possible new capacities that might start production after the year 2000 are in Brazil, Egypt, Israel, and Saudi Arabia. Israel and Saudi Arabia have or can hire the technical expertise to develop underground resources in their countries that are now being investigated. Egypt, if the resource turns out to be minable, will be able to borrow the money to initiate the project, and it will pursue the project with interest. All three locations are close to water for shipping anywhere in the world. The potash resources in Manaus, Brazil, will be near water deep enough for barging to deepwater ports, but are likely to be consumed within Brazil if either of the two resources are economically viable. It is not clear what the U.S.S.R. will do with the new resources that it has identified. This country will be busy with other problems for many years.

[1] All tonnages are reported in metric tons, K_2O equivalent, unless otherwise noted.

[2] Mining Journal (London). AMAX'S Lithium Withdrawal. V. 315, No. 8096, Nov. 9, 1990, p. 353.

[3] ———. Yolanda Debate. V. 315, No. 8102, Dec. 21 28, 1990, p. 472.

[4] Green Markets. China Shifts Attention to Phosphate and Potash Production. Sept. 17, 1990, pp. 5–6.

[5] Golovkov, B. Y. Development of Potash and Salt in the U.S.S.R. to Enter Pacific Rim Markets. Paper in Ninth Industrial Minerals International Congress (Sydney, Australia, 25–28 Mar. 1990) Met. Bull. PLC, Mar. 1990, pp. 159–164.

[6] Fertilizer International. Kemira Picks Up the Pieces. No. 288, Aug. 1990, pp. 30–31.

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PUMICE AND PUMICITE

By Wallace P. Bolen

Mr. Bolen, a physical scientist, is a graduate of the University of Virginia and has been the acting commodity specialist for pumice since September 1989. Domestic survey data were prepared by Blanche S. Hughes, mineral data assistant; and the international production table was prepared by Audrey Wilkes, international data coordinator.

Domestic production of pumice and pumicite sold or used increased about 4% compared with that of 1989. Apparent consumption decreased about 1%. Greece was the principal source of pumice imports, with 82% of total imports compared with 71% in 1989.

DOMESTIC DATA COVERAGE

Domestic production data for pumice and pumicite were developed by the U.S. Bureau of Mines from one voluntary survey of U.S. operations. All 16 operations that received a survey form responded. Thirteen active operations contributed 100% of the quantity and value of pumice and pumicite sold and used as shown in table 1.

PRODUCTION

Production of pumice and pumicite sold or used increased to 443,000 metric tons with a value of $10.7 million. The States of Oregon, California, New Mexico, Arizona, and Idaho, in order of decreasing production, accounted for approximately all of the pumice sold or used in the United States.

Principal domestic producers were Arizona Tuff Lite, Flagstaff, AZ; Glass Mountain Pumice Inc., Tulelake, CA; Hess Pumice Products, Malad City, ID; Producers Pumice, Meridan, ID; Copar Pumice Co. Inc., Santa Fe, NM; General Pumice Corp., Santa Fe, NM; Cascade Pumice Co., Bend, OR; and Central Oregon Pumice Co., Bend, OR. These eight companies accounted for 97% of U.S. pumice and pumicite production.

CONSUMPTION AND USES

The most important market for pumice was building block, consuming 66% of the total. Pumice consumed by textile laundries accounted for 14% of the total sold or used in 1990. A "laundries" category is listed for the first time in this publication in table 3. Landscaping uses of pumice increased 50% compared with that of 1989. Other and unspecified uses of pumice and pumicite increased to more than 61,000 tons.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Mineral Commodity Summaries, annual.

TABLE 1

SALIENT PUMICE AND PUMICITE STATISTICS

(Thousand metric tons and thousand dollars)

	1986	1987	1988	1989	1990
United States: Sold and used by producers:					
Pumice and pumicite	503	356	353	424	443
Value (f.o.b. mine and/or mill)	$5,756	$4,493	$4,129	$8,213	$10,688
Average value per ton	$11.44	$12.62	$11.70	$19.38	$24.13
Exports[e]	1	1	1	7	20
Imports for consumption	349	247	306	297	280
Apparent consumption[1]	851	602	658	710	703
World: Production, pumice and related volcanic materials	r11,125	r11,671	r12,403	r10,913	e10,964

[e] Estimated. [r] Revised.

[1] Production plus imports, minus exports, plus adjustments for Government and industry stock changes.

TABLE 2

PUMICE AND PUMICITE SOLD AND USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1989		1990	
	Quantity	Value	Quantity	Value
California	79	4,612	72	5,088
Idaho	W	W	31	220
New Mexico	77	795	W	W
Other[1]	268	2,806	340	5,380
Total	424	8,213	443	10,688

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

[1] Includes Arizona, Hawaii, Idaho (1989), Kansas, New Mexico (1990), and Oregon.

Mineral Industry Surveys, annual.

Other Sources

Industrial Minerals Magazine (London).

TABLE 3

PUMICE AND PUMICITE SOLD AND USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons and thousand dollars)

Use	1989		1990	
	Quantity	Value	Quantity	Value
Abrasives[1]	37	2,953	23	2,978
Concrete admixture and aggregate	9	28	15	518
Decorative and building block	311	3,345	292	3,470
Landscaping	6	807	12	1,059
Laundries	(2)	(2)	39	1,773
Other[3]	61	1,080	62	890
Total	424	8,213	443	10,688

[1] Includes cleaning and scouring compounds and stone washing (1989).
[2] Included with "Abrasives."
[3] Includes agricultural (horticultural), filter aids, insulating medium, road construction material, roofing granules, miscellaneous uses, and other unspecified uses.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF PUMICE, BY CLASS AND COUNTRY

Country	Crude or unmanufactured		Wholly or partly manufactured	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989:				
Australia	3,952	$228	145	$6
Ecuador	17,197	1,775	14,410	1,416
Greece	[1]210,017	4,499	347	58
Guatemala	3,909	586	433	40
Indonesia	5,583	665	383	27
Italy	259	115	1,208	509
Mexico	20,432	3,011	(2)	1
Turkey	11,722	1,539	6,068	929
Other[3]	393	65	697	663
Total	273,464	12,483	23,691	3,649
1990:				
Ecuador	8,507	738	7,210	636
Greece	[1]229,975	3,340	792	137
Guatemala	2,220	394	204	38
Indonesia	3,235	274	3,359	296
Italy	55	18	1,200	505
Mexico	16,231	2,108	—	—
Turkey	5,889	851	389	57
Other[4]	493	135	550	352
Total	266,605	7,858	13,704	2,021

[1] The Journal of Commerce Port Import/Export Reporting Service data.
[2] Less than 1/2 unit.
[3] Includes Austria, Canada, China, the Dominican Republic, France, Federal Republic of Germany, India, Japan, the Republic of Korea, the Netherlands, and the United Kingdom.
[4] Includes Austria, Canada, China, the Federal Republic of Germany, Japan, the Republic of Korea, the Netherlands, Norway, Singapore, Sweden, Thailand, and the United Kingdom.

Source: Bureau of the Census.

TABLE 5

PUMICE AND RELATED VOLCANIC MATERIALS: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989	1990[e]
Argentina[3]	22,957	99,093	[r]164,300	[r]127,853	125,000
Austria: Trass	5,808	6,922	7,359	[e]7,000	7,000
Cameroon: Pozzolan	168,425	[e]170,000	130,490	[e]130,000	130,000
Cape Verde Islands: Pozzolan[e]	[r]33,000	[r]43,000	[r]53,000	[r]53,000	53,000
Chile: Pozzolan	222,080	242,453	277,179	[r]299,874	290,000
Costa Rica	[e]1,500	6,000	6,000	[r]6,430	6,500
Dominica: Pumice and volcanic ash[e]	110,000	100,000	100,000	100,000	100,000
Ethiopia	35,481	26,042	143,442	[r]23,000	25,000
France: Pozzolan and lapilli	409,600	[r]420,000	[e]450,000	[e]450,000	400,000
Germany, Federal Republic of: Western states: Pumice (marketable)	215,000	205,000	[r]95,000	[r]115,000	105,000
Greece:					
Pumice	860,047	779,885	750,000	[r]640,152	700,000
Pozzolan	1,005,000	814,000	900,000	[e]900,000	900,000
Guadeloupe: Pumice[e]	[4]221,157	220,000	220,000	220,000	220,000
Guatemala: Pumice	11,442	15,191	[e]15,000	[e]15,000	15,000
Iceland	52,500	58,792	65,444	[r]56,815	65,000
Italy:[e]					
Pumice and pumiceous lapilli	700,000	725,000	730,000	700,000	725,000
Pozzolan	4,500,000	5,000,000	5,000,000	4,500,000	4,500,000
Martinique: Pumice[e]	140,000	130,000	130,000	130,000	130,000
New Zealand[e]	20,000	15,000	[4]25,003	25,000	25,000
Spain[5]	968,116	1,053,914	[r]909,625	[r e]925,000	900,000
Turkey[e]	[r]534,900	[r]760,700	[r]1,470,700	[r]665,500	700,000
United States (sold and used by producers)	502,600	355,600	352,900	423,800	[4]442,848
Yugoslavia: Volcanic tuff	385,844	423,917	407,988	[e]400,000	400,000
Total	[r]11,125,457	[r]11,670,509	[r]12,403,430	[r]10,913,424	10,964,348

[e] Estimated. [r] Revised.

[1] Table includes data available through May 9, 1991.

[2] Pumice and related volcanic materials are also produced in a number of other countries, including (but not limited to) Iran, Japan, Mexico, and the U.S.S.R., but output is not reported quantitatively, and available information is inadequate for the formulation of reliable estimates of output levels.

[3] Unspecified volcanic materials produced mainly for use in construction products.

[4] Reported figure.

[5] Includes Canary Islands.

QUARTZ CRYSTAL

By Joyce A. Ober

Mrs. Ober, a physical scientist with 13 years industry and U.S. Bureau of Mines experience, has been the commodity specialist for quartz crystal since 1986. Domestic survey data were prepared by Maureen Nash Riley, mineral data assistant.

Cultured quartz crystal production and consumption decreased slightly in 1990 after 3 years of growth. Consumption of domestic lascas as feedstock for cultured quartz crystal decreased also. The single domestic producer of lascas, the raw material from which cultured quartz crystal is produced, operated its mine to supply material to domestic consumers. Demand for specimen-quality natural quartz continued; quartz crystal for this application is discussed in the Gem Stones chapter.

Electronic-grade quartz crystal is single-crystal silica that is free from all visible defects and has piezoelectric properties that permit its use in electronic circuits for accurate frequency control, timing, and filtration. These uses generate about all the demand for electronic-grade quartz crystal. A smaller amount of optical-grade quartz crystal is used as windows and lenses in specialized devices, including some lasers.

More natural quartz crystal was consumed in electronic and optical applications until 1971, when cultured quartz crystal took the lead. Since that time, cultured (synthetic) quartz has replaced practically all natural crystal in these applications. In 1990, synthetic quartz crystal producers consumed about 527,000 kilograms of lascas in their production, and less than 400 kilograms of natural quartz crystal found application in electronic devices.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines collected domestic production and consumption data for quartz crystal through a voluntary survey of U.S. operations. Six companies responded to the canvass for the production of cultured quartz crystal, and the five active operations represented 100% of total production shown in table 1. Of the 34 operations canvassed concerning consumption of quartz crystal, 32 responded, 7 of which did not consume quartz crystal in 1990. These companies represented approximately 100% of total consumption, also shown in table 1. Consumption for the nonrespondents was estimated using reported prior-year consumption levels.

ANNUAL REVIEW

Legislation and Government Programs

The National Defense Stockpile contained about 686,000 kilograms of natural quartz crystal, valued at about $9 million at yearend. This quantity represented an excess of about 577,000 kilograms above the goal set for the stockpile.

TABLE 1

SALIENT U.S. ELECTRONIC- AND OPTICAL-GRADE QUARTZ CRYSTAL STATISTICS

(Metric tons unless otherwise specified)

		1986	1987	1988	1989	1990
Production:						
Mine[e 1]		544	—	272	454	423
Cultured		238	381	389	464	441
Exports:						
Natural:[2]						
Quantity		34	63	43	NA	NA
Value	thousand dollars	$411	$708	$431	NA	NA
Cultured:[2]						
Quantity		147	203	189	57	39
Value	thousand dollars	$5,686	$6,954	$7,162	$2,600	$1,745
Lascas:						
Quantity		—	—	—	—	—
Imports of lascas:[3]						
Quantity		24	66	98	NA	NA
Value	thousand dollars	$51	$157	$180	NA	NA
Consumption:						
Natural (electronic- and optical-grade)		1	(4)	2	(4)	(4)
Cultured (lumbered)		20	25	28	17	14
Cultured (as grown)		194	250	293	344	326
Total		215	275	323	361	340

[e]Estimated. NA Not available.
[1]Excludes lascas produced for specimen and jewelry material uses.
[2]Bureau of the Census as adjusted by the U.S. Bureau of Mines.
[3]Bureau of the Census.
[4]Less than 1/2 unit.

During the year, quartz crystal stockpile sales amounted to about 172,000 kilograms at about $444,000. About one-quarter of the disposals was to support the stockpile ferroalloys upgrading project. The excess stockpile material, which primarily consists of large natural crystals, could be absorbed by the specimen and gem material industry. Very little, if any, of the material would be consumed in the same applications as synthetic quartz crystal.

Strategic Considerations

Natural electronic-grade quartz crystal was initially designated as a strategic and critical material after World War II. Cultured quartz crystal was not commercially available at the time of U.S. stockpile acquisition. With the changing patterns of quartz consumption, the Federal Emergency Management Agency asked the National Materials Advisory Board to assess the requirements and related trends for stockpiling quartz. The final report was published in early 1985 and recommended changes in stockpile goals to reflect the declining dependence on natural quartz crystal.[1] The President has set the quartz crystal goal for the stockpile at 110,000 kilograms.

The National Defense Stockpile contains natural quartz in several weight classes and grades, including about 13,000 kilograms of material consisting of individual crystals weighing more than 10,000 grams each. Some of the individual quartz pieces in this weight class are suitable for generating mother seeds for cultured quartz crystal production. These large pieces were acquired from Brazil because similar materials were not available domestically.[2]

Production

Coleman Quartz Inc., Jessieville, AR, the only domestic company known to produce lascas, supplied the feed material for cultured quartz crystal from mine production. Production in 1990 was about 7% lower than that in 1989. Coleman mined only during the summer months, but processed lascas year round. Lascas was mined, crushed, and sized. Crushed and sized material was transported to the processing plant where operators rinsed it in oxalic acid and then in deionized water to remove external contaminants. Hand sorting, drying, and examination on a light table completed the necessary processing. The material was then shipped to cultured quartz crystal producers in 45-kilogram (100-pound) bags.

Production of cultured quartz crystal decreased almost 5% in 1990. Five companies were active. The two largest producers, Sawyer Research Products Inc. of Eastlake, OH, and Thermo Dynamics Corp. of Merriam, KS, were independent growers that produced crystal bars for domestic and foreign consumers in the crystal device fabrication industry. Motorola Inc. of Chicago, IL, produced quartz crystal for both internal consumption and the domestic device fabrication industry. P. R. Hoffman Material Processing Co. of Carlisle, PA, also reported outside sales. Bliley Electric Co. of Erie, PA, produced only for internal consumption. Electro Dynamics Corp. of Overland Park, KS, formerly a producer, sold the quartz-crystal-growing portion of its operation to Thermo Dynamics in February 1989. Electro Dynamics continued to process synthetic quartz crystal.

These companies produced cultured quartz crystal using a hydrothermal process in large pressure vessels, known as autoclaves. Seed crystals, very thin crystals cut to exact dimensions, were mounted on racks and suspended in the upper growth region of the vessel. Lascas was loaded in an open-mesh wire basket that was placed in the bottom of the autoclave.

A solution of sodium hydroxide or sodium carbonate (the mineralizer), with additives such as lithium salts, and deionized or distilled water was used to fill the vessel to 75% to 85% of its volume. The bottom half of the growing vessel was heated to temperatures averaging between 350° to 400° C; the temperature of the top portion is maintained at 10° to 50° C less. At these temperatures, the solution expands and creates an internal pressure in the vessel of between 10,000 pounds per square inch and 30,000 pounds per square inch. Under these conditions, the lascas dissolves to create a solution saturated with silica.

Through convection, the saturated solution transports dissolved silica to the cooler upper half of the vessel where it becomes supersaturated, and the excess dissolved quartz deposits on the seed crystals in the top half of the autoclave. The process continues until the growing crystals reach desired size. The process may take 30 to 60 days and sometimes even longer.

The processing of quartz crystals for various end uses is the same whether natural or cultured crystal is used. Crystals are examined for physical defects before cutting. They are then cut, usually with diamond or slurry saws, along a predetermined crystallographic plane to a thickness slightly larger than that desired. Each wafer is inspected and diced into blanks of the desired dimensions. The blanks then progress through a series of lapping stages until they reach the final thickness; electrodes are attached, and the crystals are mounted in suitable holders. The final assembly, called a quartz crystal unit, is ready for insertion into an electronic circuit.

Consumption and Uses

Consumption of lascas by the five domestic quartz crystal producers decreased about 8%, from 572,000 kilograms in 1989 to 527,000 kilograms in 1990. The 25 active device-fabricating companies in 9 States consumed 8% less quartz crystal in 1990 than in 1989. Of these companies, 24 consumed only cultured quartz crystal. One company consumed only natural quartz crystal.

Lascas and quartz crystal were used in piezoelectric, optical, and glass industries. The piezoelectric effect is achieved when a suitable electrical signal is applied to a quartz wafer or blank with appropriate electroding, which causes the wafer to vibrate mechanically throughout the bulk of the material at a characteristic natural resonance frequency. The quartz resonators are uniquely suitable for military-aerospace and commercial bandpass filter applications that require very high selectivity or in oscillator applications that require very high stability. In addition, for many applications requiring only moderate stability, a quartz resonator offers a unique combination of high performance, small size, and low cost. Quartz resonators were used for many less demanding applications such as providing timing signals for watches, clocks, and microprocessors in a variety of industrial, automotive, and consumer products.

The quartz wafer becomes too thin for practical use for very high frequencies (above 100 megahertz). Quartz crystal structures that use surface vibrations, in which the frequency is determined by electrode dimensions rather than wafer thickness, have become more important at these high frequencies. These structures

are called surface acoustical wave (SAW) devices. Most optical applications used quartz in the fused form as silica glass. Relatively small quantities of cultured quartz crystal were used directly for special optical considerations. Quartz's crystal properties are responsible for its uses that deal with normally polarized laser beams. Quartz retardation plates (especially quartz wave plates), Brewster windows and prisms, birefringent filters, and tuning elements are used in laser optics.

Historically, quartz crystal has been a material of strategic importance. During World War II, quartz was used principally in analog communications (e.g., in telephone multiplexing and in mobile military radios). Today, because of military emphasis on command, control, communications, surveillance, and the growth of more sophisticated electronic systems, the importance of quartz crystal devices has grown. Many of the military applications are at the leading edge of technology. It has been U.S. Department of Defense policy to require all military systems to be hardened to nuclear radiation. To meet this special requirement, cultured quartz crystal must be radiation hardened by sweeping, a technique to remove certain impurities from the quartz.

Cultured quartz was used almost exclusively by the crystal device industry because of cost advantages. For resonator applications, raw quartz must be cut into thin wafers oriented precisely with the raw material crystal axes. The uniformity and convenience of cultured quartz have made its use almost universal. Unlike cultured quartz, natural electronic-grade quartz requires special orientation, cutting, grading, and sizing to produce a quartz wafer. As a result, most device manufacturers that cut natural quartz in the past have discontinued its use. One of the remaining uses of natural electronic-grade material was in pressure transducers used in deep wells.

Stocks

Crystal growers' stocks of as-grown cultured quartz crystal were reported as 76,000 kilograms at the beginning of 1990. At yearend, these stocks had increased to 97,000 kilograms.

Prices

The average value of as-grown cultured quartz, based on reported sales of about 324,000 kilograms, was $28.35 per kilogram ($12.86 per pound), a decrease of about 8% compared with that of 1990. Sales volume decreased about 5%. The average value of lumbered quartz, as-grown quartz that has been processed by sawing and grinding, decreased 24% to $107.48 per kilogram ($48.75 per pound), based on reported sales of 33,000 kilograms. Sales volume decreased 16%.

Foreign Trade

The Bureau of the Census began using the Harmonized Tariff Schedule in 1989 to identify material passing through U.S. customs. This system makes classification codes for imports and exports consistent internationally. With the adoption of the new codes, imports and export codes for quartz crystal changed, and some formerly listed details are no longer available. The import code for Brazilian crude pebble, which represented approximately all lascas imports recorded, was eliminated. Although this material probably continued to enter the United States, the new code system aggregated several categories, making information about specific materials unavailable. The export data for natural electronic-grade quartz crystal were no longer available.

Because of these changes, foreign trade information for quartz crystal is limited. While information remained concerning exports of synthetic quartz crystal, Census figures indicate a continuing downward trend for quartz crystal exports. Reports by domestic producers indicated that these data may not be accurate. Reports indicated that exports were higher than those reported by the Census Bureau.

World Review

Synthetic quartz crystal production is concentrated in the United States and Japan, with several companies producing crystal in each country. Smaller production capacity exists in Belgium, Brazil, Bulgaria, France, Germany, the Republic of South Africa, and the United Kingdom. Details concerning quartz operations in China, the U.S.S.R., and other Eastern European countries are unavailable.

Alfa Quartz C.A., a joint venture between Bulgarian and Venezuelan companies, was building a cultured quartz crystal plant near Caracas, Venezuela. On completion, the operation should have the capability of producing 36,000 kilograms of quartz crystal per year from 16 autoclaves. Sales are expected to be lumbered bars and blanks. Domestic lascas deposits will provide feed material.

OUTLOOK

Domestic production of cultured quartz crystal has grown or remained relatively stable since 1986. The slightly decreased production in 1990 is not expected to represent the beginning of a downward trend. Demand for crystal devices for electronic consumer products and microprocessor-controlled devices should continue to grow, and quartz crystal production should remain strong well into the future. Because crystal devices continued to be used in an increasing variety of applications from kitchen appliances to military hardware in addition to the traditional items such as watches, demand should continue to increase, and additional production capacity may be required worldwide.

[1]National Materials Advisory Board. Quartz for the National Defense Stockpile. Natl. Acad. Sci., Washington, DC, NMAB-424, Jan. 1985, 99 pp.

[2]Work cited in footnote 1.

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RARE EARTHS

The Lanthanides, Yttrium, and Scandium

By James B. Hedrick

Mr. Hedrick is a physical scientist in the Branch of Industrial Minerals. He has been the commodity specialist for rare earths since 1981. Domestic survey data were prepared by Kevin Bacon, mineral data technician. International data were prepared by Harold Willis, international data coordinator.

International competition dominated the global rare-earth market in 1990, continuing the trend of 1989. The United States was the world's principal producer of rare earths with mine production reaching its second highest level of alltime. Overall performance of the domestic industry was slightly higher than that in 1989, with significant growth only in the permanent magnet sector. Traditional major rare-earth markets, petroleum cracking catalysts and metallurgical applications, decreased from those of the previous year.

Average performance was seen in emerging applications. Demand increased slightly for erbium used in optical fibers and for cerium as a component in ultraviolet-absorbing glass and automotive catalytic converters. Demand for rare earths used in optical storage disks and in rechargeable batteries was expected to show strong growth in the future.

A probe that monitors liquid nitrogen levels in human tissue refrigeration units was announced as the first commercial application for yttrium-bearing high-temperature superconductors. Although demand for rare earths used in high-temperature superconductors was very small, scientific advances continued to increase the potential for significant long-term growth.

DOMESTIC DATA COVERAGE

Domestic mine production data for rare earths are developed by the U.S. Bureau of Mines from the voluntary survey, "Rare Earths, Thorium, and Scandium." The two mines to which a survey form was sent responded, representing 100% of known production. Production data were withheld to avoid disclosing company proprietary data.

BACKGROUND

Definitions, Grades, and Specifications

The rare earths are a group of 17 elements comprised of scandium, yttrium, and the lanthanides. Rare earths are classified chemically as members of the third subgroup of the periodic table.

Scandium, atomic number 21, is the lightest rare-earth element. 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 because it does not combine easily with the common ore-forming anions.

TABLE 1

SALIENT U.S. RARE-EARTH STATISTICS

(Metric tons of rare-earth oxides (REO) unless otherwise specified)

	1986	1987	1988	1989	1990
Production of rare-earth concentrates[1]	11,094	16,710	11,533	20,787	22,713
Exports:[e 2]					
Cerium compounds	NA	NA	NA	1,433	1,730
Rare-earth metals, scandium, and yttrium	NA	NA	NA	r425	201
Ores and concentrates	3,911	3,041	4,415	NA	NA
Rare-earth compounds, organic or inorganic	NA	NA	NA	NA	1,460
Ferrocerium and pyrophoric alloys	29	72	32	e31	(3)
Imports for consumption:[e 2]					
Monazite	1,628	617	1,058	426	440
Metals, alloys, oxides, compounds	751	724	912	6,125	4,489
Stocks, producers and processors, yearend	W	W	W	W	W
Consumption, apparent[e]	10,900	11,100	16,800	27,770	28,741
Prices, yearend, dollars per kilogram:					
Bastnasite concentrate, REO basis	r2.54	r2.54	r2.54	r2.76	2.87
Monazite concentrate, REO basis	1.06	.90	1.15	1.19	1.19
Mischmetal, metal basis	12.35	12.35	12.35	12.35	11.02
Employment, mine and mill[e 4]	283	301	320	381	397
Net import reliance[e 5] as a percent of apparent consumption	E	E	29	23	18

[e]Estimated. [r]Revised. E Net exporter. 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]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export categories for 1989 and 1990 are not necessarily comparable with those of previous years.

[3]Because of the implementation of the Harmonized Tariff System in Jan. 1989, data are no longer available for this export category.

[4]Employment at a rare-earth mine in California and at a mineral sands operation in Florida.The latter mine produced monazite concentrate as a byproduct of mining ilmenite, rutile, and zircon, and employees were not assigned to specific commodities.

[5]Imports minus exports plus adjustments for Government and industry stock changes.

Yttrium, atomic number 39, is chemically similar to the lanthanides and often occurs in the same minerals. Yttrium's average concentration in the Earth's crust is 33 parts per million and is the second most abundant rare earth in the Earth's crust.

The lanthanides comprise a group of 15 elements with atomic numbers 57 through 71, and include the following: lanthanum, cerium, praseodymium, neodymium promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. Cerium, the most abundant of the group at 60 parts per million, is more abundant than copper. Thulium, the least abundant of the lanthanides at 0.48 parts per million, occurs in the Earth's crust in higher concentrations than thallium, antimony, cadmium, and bismuth.

Due largely to differing ionic radii, the rare-earth elements are broadly classified into two groups: the light or cerium subgroup, comprised of the first seven lanthanides (atomic numbers 57 through 63), and the heavy or yttrium subgroup, comprised of the remaining lanthanides and yttrium (atomic numbers 64 through 71, and 39). Yttrium is classed with the heavy subgroup because of its occurrence, ionic radius, and other similar properties.

Bastnasite can theoretically contain 74.81% rare-earth oxide (REO).[1] Flotation concentrates of bastnasite average 60% REO, which can be upgraded to 70% REO by acid leaching, and to 85% REO by a combination of acid leaching and calcining.

Monazite can theoretically contain 69.73% REO. Monazite concentrate is usually sold at 55% minimum REO contained plus thorium, with most product grading 59% to 65% REO. Thorium contents are variable, but typically occur in the range of 4% to 10% equivalent thorium oxide. Monazite, with a low thorium content, commands a premium price.

Xenotime can theoretically contain 61.40% yttrium oxide. However, xenotime concentrates from southeast Asia and Australia typically contain 25% to 30% yttrium oxide. Xenotime is often upgraded by acid leaching to produce an yttrium concentrate grading 60% yttrium oxide and the balance primarily other rare earths.

Various metallic rare-earth materials 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 containing about one-third mischmetal, one-third iron, and one-third silicon. The rare-earth content of master alloys range from tenths of a percent in nodularizing alloys for ductile iron to 10% or more in inoculants for gray cast iron. Alloys containing about 100% rare-earth metals, such as mischmetal, are additives to certain steels.

The purity of separated rare-earth elements, produced primarily by solvent extraction or ion exchange, usually grade 96% or higher in purity. High-purity rare-earth compounds and metals are produced up to 99.9999% purity. Rare-earth products grading higher than 99.9% purity are often produced to specification. As a result of the wide range of products in which rare earths are consumed, many grades of rare-earth concentrates, compounds, alloys, and metals are produced. Analyses of the rare-earth contents of selected ores are shown in table 2.

Products for Trade and Industry

Products for trade and industry are varied and include concentrates, individual and mixed compounds, and individual and mixed metals.

Bastnasite concentrate, marketed by Molycorp, Inc., 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 by processors and trading firms as a concentrate containing 55% to 60% minimum REO plus contained thorium. Mixed compounds from monazite produced by companies such as Rhône-Poulenc Basic Chemical Co. or the Davison Div. of W.R. Grace include cerium chloride, ceric ammonium nitrate, ceric sulfate, cerium carbonate, cerium hydroxide, cerium nitrate, cerium octoate, rare-earth carbonate, lanthanum carbonate, lanthanum-neodymium carbonate, lanthanum-neodymium nitrate, neodymium carbonate, neodymium nitrate, praseodymium oxalate, rare-earth octoate, and yttrium nitrate.

Xenotime concentrate, with a minimum 25% yttrium oxide content, is a major source of yttrium. It is usually upgraded chemically to a 60% yttrium oxide product known as yttrium concentrate, the balance of the concentrate being mostly other rare earths.

Rare-earth ion adsorption ore is produced in southern China. It is also a major source of yttrium. The ore varies 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 contains more than 60% yttrium oxide. Although the europium concentrate grades from 0.5% to about 1% europium oxide and 12% yttrium oxide, it is predominantly enriched in lanthanum oxide, 33% to 43%. Both ion adsorption concentrates are low in cerium oxide, typically less than 2%.

Individual rare-earth oxides and other compounds, except promethium, are produced from bastnasite, monazite, xenotime, and ion adsorption ore. Purities from 96% up to 99.9999% are available for most oxides. Compounds for almost all of the rare earths are available as oxides, acetates, carbonates, chlorides, fluorides, nitrates, oxalates, and sulfates.

High-purity rare-earth metals are marketed in the form of sponge, lump, ingot, rod, wire, chips, powder, sheet, foil, plates, 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 in a variety of compositions to meet individual requirements. Magnet alloys are marketed in ingot form, crushed ribbon, or may be purchased as mixed oxides for powder metallurgical processes. Magnets are available in finished and semifinished shapes, bonded and unbonded, magnetized and unmagnetized, and either coated or uncoated.

Scandium concentrate was previously produced as a byproduct during uranium extraction and from tailings from a previously operated fluorite operation. Scandium

TABLE 2

RARE-EARTH CONTENTS OF MAJOR SOURCE MINERALS

(Percent of total rare-earth oxide)

Rare earth	Bastnasite Mountain Pass, California, United States[1]	Bastnasite Baiyunebo, Nei Monggol, China[2]	Monazite Capel, Western Australia[3]	Monazite North Stradbroke Island, Queensland, Australia[4]	Monazite Green Cove Springs, Florida United States[5]	Monazite Nangang, Guangdong, China[6]
Lanthanum	33.2000	23.0000	23.8938	21.5000	17.5000	23.0000
Cerium	49.1000	50.0000	46.0177	45.8000	43.7000	42.7000
Praseodymium	4.3400	6.2000	5.0442	5.3000	5.0000	4.1000
Neodymium	12.0000	18.5000	17.3805	18.6000	17.5000	17.0000
Samarium	7890	.8000	2.5310	3.1000	4.9000	3.0000
Europium	1180	.2000	.0531	.8000	.1600	.1000
Gadolinium	1660	.7000	1.4867	1.8000	6.6000	2.0000
Terbium	0159	.1000	.0354	.2900	.2600	.7000
Dysprosium	0312	.1000	.6903	.6400	.9000	.8000
Holmium	0051	trace	.0531	.1200	.1100	.1200
Erbium	0035	trace	.2124	.1800	trace	.3000
Thulium	0009	trace	.0177	.0300	trace	trace
Ytterbium	0006	trace	.1239	.1100	.2100	2.4000
Lutetium	0001	trace	.0354	.0100	trace	.1400
Yttrium	0913	.5000	2.4071	2.5000	3.2000	2.4000
Total[7]	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

	Apatite 40% RE Khibiny complex, U.S.S.R.[8]	Loparite Lovozero complex, U.S.S.R.[8]	Xenotime Lahat, Perak, Malaysia[1]	Xenotime southeast, Guangdong, China[9]	RE minerals in clay, Xunwu, Jiangxi Province[10]	RE minerals in clay, Longnan, Jiangxi Province[10]
Lanthanum	24.0000	25.0000	1.2400	1.2000	43.3700	1.8200
Cerium	52.0000	50.5000	3.1300	3.0000	2.3800	.3700
Praseodymium	5.5000	5.0000	.4930	.60009	.0200	.7400
Neodymium	14.0000	15.0000	1.5900	3.5000	31.6500	3.0000
Samarium	2.5000	.6500	1.1400	2.2000	3.9000	2.8200
Europium	5000	.0900	.0120	.2000	.5000	.1200
Gadolinium	1.4000	.5500	3.4700	5.0000	3.0000	6.8500
Terbium	1500	trace	.9060	1.2000	trace	1.2900
Dysprosium	2500	.5500	8.3200	9.1000	trace	6.6700
Holmium	0500	.7000	1.9800	2.6000	trace	1.6400
Erbium	1500	.8000	6.4300	5.6000	trace	4.8500
Thulium	0500	.1000	1.1200	1.3000	trace	.7000
Ytterbium	0500	.2000	6.7700	6.0000	.2600	2.4600
Lutetium	0500	.1500	.9880	1.8000	.1000	.3600
Yttrium	1.5000	1.2500	61.0000	59.3000	8.0000	65.0000
Total[7]	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

[1]Johnson, G. W., and T. E. Sisneros. Analysis of Rare-Earth Elements in Ore Concentrate Samples Using Direct Current Plasma Spectrometry. Proceedings of the 15th Rare-Earth Research Conference, Rolla, Mo, June 15-18, 1981. The Rare Earths in Modern Science and Technology, Plenum Press, NY, v. 3, 1982, pp. 525-529.

[2]Zang, Z., et al. Rare-Earth Industry in China. Hydrometallugy, v. 9, No. 2, 1982, pp. 205-210.

[3]Westralian Sands Ltd. Company Brochure. Product Specifications.

[4]Analysis from Consolidated Rutile Ltd.

[5]Analysis from Associated Minerals, Green Cove Springs, FL.

[6]Xi, Z.The Present Status of Nd-Fe-B Magnets in China. Paper presented at The Impact of Neodymium-Iron-Boron Materials on Permanent Magnet Users and Producer Conf. Gorham International Inc., Clearwater, FL, Mar. 2-4, 1986, 5 pp.

[7]Some analyses adjusted to 100%.

[8]Rabinovch, Y., et al. Main Modern Trends in Exploratory Development of Raw Materials and Magnets Production. Pres. at Inter Conf. "The Outlook for Magnetic Materials in Eastern Europe" Feb. 4-5, 1991, Berlin, Germany, 22 pp.

[9]Nakamura, S. China and Rare Metals-Rare Earth. Ch. in Industrial Rare Metals, No. 94, May 1988, pp. 23-28.

[10]Introduction to Jiangxi Rare-Earths and Applied Products. Jiangxi Province Brochure at the International Fair for Rare Earths, Beijing, China, Sept. 1985, 42 pp. (In English and Chinese).

is marketed primarily as a high-purity oxide from Boulder Scientific Co. and Sausville Chemical Co. Oxide purities from 98% to 99.995% are 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 powder, lump, and foil form, as listed by the Johnson Matthey Aesar group.

Industry Structure

Rare-earth ore minerals are sold by producers directly to processors, consumers, and commodity brokers, usually as a concentrate. Of the three principal ore minerals, bastnasite, monazite, and xenotime, only bastnasite concentrate may be used in certain industrial applications with little or no processing. Most rare-earth concentrates undergo extensive processing to produce mixed or separated compounds and metals. Few companies in the rare-earth industry are fully integrated. Most rare-earth mining companies sell their concentrates to processors that separate the rare earths by chemical processing, primarily solvent extraction (SX) and, to a lesser extent, ion exchange (IX).

Geology-Resources

Rare-earth minerals occur in a variety of geologic environments. Concentrations exist in igneous, sedimentary, and metamorphic rocks. The rare earths are mined primarily from igneous-metamorphic and sedimentary deposits.

The rare earths are constituents in more than 100 minerals, but only a few are recovered for economic gain. Bastnasite, monazite, xenotime, and rare-earth-bearing clay are the principal sources of the world's rare-earth supply. Other sources include the minerals loparite, rare-earth-bearing apatite, yttrium-rich synchysite (doverite), and byproduct solutions from processing uranium, which contain rare-earth enriched uraninite and brannerite. Future production may include rare earths recovered from the minerals gadolinite, dickgarrenite (proposed name of new mineral), and eudialyte.

Bastnasite.—Bastnasite is found in vein deposits, contact metamorphic zones, pegmatites, and carbonatites. In the two principal deposits where bastnasite is mined, Mountain Pass, CA, in the United States and Bayan Obo, Nei Monggol Autonomous Region, in China, bastnasite occurs in rare-earth-enriched carbonatite rock. Carbonatites are an unusual type of carbonate-silicate rock found almost exclusively in areas of alkalic igneous rock.[2] Formation of carbonatites is believed to occur by several processes. Most carbonatites are believed to have been formed by the introduction of carbonate-rich hydrothermal solutions, but a carbonate-rich lava flow was observed following the 1960 eruption of a volcano in Africa.[3]

United States.—In the United States, the Mountain Pass Mine bastnasite is recovered from the Sulphide Queen carbonatite. The ore body is a north-striking sill that dips 40° W. The original carbonatite surface exposure was 760 meters in length with a maximum width of 210 meters. The sill pinches out to the north where it narrows to less than 30 meters. The steeply dipping southern contact strikes northeast. The ore body averages 60 meters thick, although it narrows to less than 30 meters on the north end. The thickness in the area of active mining is about 60 meters. The intrusive complex and surrounding alkaline rocks are pre-Cambrian, dated at 1.4 billion years old. From oldest to youngest, the mineralogical sequence of intrusion was shonkinite, syenite, granite, shonkinitic dikes, carbonates, and andesitic dikes.[4] Emplacement of the rare-earth-bearing carbonatite took place in at least 13 recognized pulses. The two main groups of carbonatites are older barite sovites (calcite-rich carbonates) and younger barite dolomitic sovites and barite beforsites (dolomite-rich carbonates). The older sovites occupy the northern up-dip part of the sill and the younger dolomitic carbonates are located down-dip.

All of the carbonatite units contain ore-grade concentrations of rare-earth minerals. Reserves are 24 million tons at an average grade of 8.8% rare-earth oxide. Bastnasite, however, is the only ore material recovered. Other rare-earth minerals in the carbonatite are parisite, monazite, synchysite, sahamalite, and allanite.[5]

China.—In China, the Bayan Obo Mine bastnasite is recovered from the Bayan Obo Group carbonatite. The primary ore is iron minerals, with the rare-earth minerals, bastnasite and monazite, produced as byproducts. Niobium is also recovered as a byproduct. The Bayan Obo ore bodies are in a syncline that extends 18 kilometers along its axis and varies in width from 1 to 3 kilometers. Within the syncline are 2 large ore deposits, the Main and East ore bodies, and 16 medium ore bodies comprising the West mine.[6] Rare-earth minerals occur predominantly in the Main and East ore bodies at a grade of 6.19% and 5.71% REO, respectively. Overall reserves of the ore deposit are reported at 1.5 billion tons of ore (Main, East, and West mine ore bodies) grading 35% iron; rare-earth minerals in the 800 million tons of ore in the Main and East ore bodies contain an estimated 48 million tons of REO.[7]

Formation of the Bayan Obo deposit is related to a rift margin on the North China plate, estimated to have separated between 1.85 and 1.7 billion years ago.[8] As a rift basin formed, deep faulting occurred associated with deposition of the Bayan Obo Group sediments. The sequence of formation of the Bayan Obo Group, from oldest to youngest, was coarse sandstone and basal conglomerate, orthoquartzite, shale, quartzite, shale, arkosic sandstone, carbonates (dolomite in the ore-bearing syncline), shale, an unconformity, gray limestone, and a white and gray limestone. Emplacement of the Bayan Obo carbonatite is reported to have formed after deposition of the Bayan Obo Group by hydrothermal replacement of the dolomite unit.[9] The thick shale unit overlying the dolomite appears to have acted as a seal that trapped the rare-earth-enriched hydrothermal solutions. The origin of these solutions is possibly the upper mantle or lower crust, sourced through the syndepositional aults along the rift. Sedimentological and paleontological evidence indicates a sedimentary origin of the dolomite and other carbonate rocks. The bastnasite ore occurs in a tan dolomite in association with thin shale beds and scattered quartzite beds.

The age of the Bayan Obo Group, based on fossil evidence, is Middle Proterozoic (1.4 billion years ago). Interestingly, the age of the Bayan Obo Group coincides with emplacement of the Sulphide Queen carbonatite in the United States.

Monazite and Xenotime.—Monazite and xenotime originate as primary accessory minerals in many crustal rocks. Monazite occurs as an accessory mineral in granites, syenites, gneisses, schists, migmatites, quartz veins, and pegmatites. Xenotime, which is mineralogically similar to monazite, occurs in the same rock types as monazite. Placer deposits are the major source of these minerals.

In the formation of placers, erosion must

first breakdown the monazite- and xenotime-bearing rocks. Once released from the rocks, the minerals undergo natural separation and sorting by rain and wind and dissolution of the soluble minerals. Further separation and concentration of the heavy minerals, especially by specific gravity, is accomplished by river and sea currents. Only the more chemically and physically stable minerals, which include monazite and xenotime, survive transport to become concentrated in economic heavy-mineral sands deposits.

Heavy minerals that occur with monazite and the less abundant xenotime include the following: the titanium oxides, ilmenite, rutile, and leucoxene; the aluminum silicates, kyanite, sillimanite, and andalusite; the zirconium silicate, zircon; the aluminum oxides, corundum and spinel; the tin oxide, cassiterite; and other minerals such as gold, tourmaline, staurolite, epidote, garnet, and pyroxene.

Monazite is also mined as a vein mineral. Vein monazite was previously mined in the Republic of South Africa and is currently recovered from the Bayan Obo Mine in China.

Technology

Exploration.—Exploration for rare-earth minerals (primarily thorium) began in the 1880's for the purpose of locating thorium and cerium for incandescent gas mantles. After electric lighting came into general use, about 1912, demand for gas mantles fell; subsequently, most rare-earth deposits were located during the search for other minerals, especially ilmenite, rutile, zircon, uranium, and gold.

Exploration techniques employed to locate the rare earths include surface and airborne reconnaissance with magnetometric and radiometric equipment. Satellite imagery and aerial photographs are also used in exploration.

Because many of the rare-earth minerals are naturally radioactive or associated with radioactive minerals, many discoveries were made during exploration for uranium and thorium. Prospectors searching for radioactive minerals were responsible for discovering the Mountain Pass bastnasite deposit.

Most monazite-bearing heavy-mineral sands deposits were discovered by exploring for recent and ancient alluvial deposits. Buried alluvial deposits may be located based on geologic and climatic inference. Following visual identification of rare-earth minerals, a systematic sampling program and laboratory analysis is run to determine ore grades and individual rare-earth contents.

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 hard-rock carbonatite. The ore is recovered as a byproduct of iron ore mining by hard-rock, 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. After separation from the iron ore by flotation, a bastnasite concentrate and a mixed bastnasite-monazite concentrate are produced.

Heavy-mineral sands are the source of most monazite and xenotime mined in the world. Most of these minerals are recovered by surface placer methods from unconsolidated sands. Almost all mining of these sands is done by floating cutterhead- or bucketwheel-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 bulldozers, scrapers, and loaders. Sand recovered by these techniques is crushed and screened and then processed by the wet mill equipment described 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 1990 constant dollars, are shown in table 3. Bastnasite prices differ slightly from the previous year's table and figure based on a change from truckload and/or carload pricing to standard package pricing. Price trends for bastnasite and monazite concentrate are shown in figures 1 and 2, respectively.

Concentrates of bastnasite and monazite have traditionally been low-priced. Significant value is added when the concentrates are separated into the individual rare-earth oxides or other compounds. Mischmetal prices have also been historically low, with prices remaining in the $7 to $12 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 five times the separated rare-earth oxide price.

Initially available in 1954, bastnasite concentrate was priced at $3.31 per kilogram. By the early 1960's, the development of the first significant commercial applications for the rare earths caused its price to drop under $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, 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 ranged from $0.33 to $0.40 per kilogram of REO, decreasing to $0.22 to $0.33 per kilogram in the early 1960's. By the mid-1960's, monazite's price began to increase steadily, with a major increase

appearing in 1985, the result of a weak Australian economy and increased competition for monazite supplies. Balanced supply and demand is seen in monazite's relatively stable price during the past 5 years.

Costs.—Mine and mill operating costs to produce bastnasite and monazite in the United States are withheld to avoid disclosing company proprietary data. The cost to mine bastnasite is higher than that for monazite. Bastnasite, as a sole primary product, incurs all costs of production. Monazite, however, is produced as a byproduct, and the cost of its recovery is based primarily on costs associated with recovering the primary minerals.

Because both domestic mines have been in production for several years, mining costs are related to direct costs, which include the following: labor, mining equipment (trucks, drills, loaders, dredges, pumps, etc.), supplies (explosives, drill bits, etc.), and utilities (fuel, natural gas, and electricity).

Tariffs.—Tariff rates for various categories specific to the rare earths, including scandium and yttrium, are shown in table 4. The duties reflect results from the 1979 Tokyo Round of Multilateral Trade Negotiations under which the tariffs on many items were reduced in several stages over the period January 1, 1980, to January 1,

TABLE 3

YEAREND RARE-EARTH CONCENTRATE PRICES

(Dollars per kilogram of rare-earth oxide contained)

Year	Bastnasite concentrate, 60% REO[1]		Monazite concentrate, 55% REO plus thoria	
	Actual dollars	1990 dollars[2]	Actual dollars	1990 dollars[2]
1971	r$0.77	$2.28	$0.38	$1.13
1972	r.77	2.18	.35	.99
1973	r.77	2.05	.40	1.06
1974	r.84	2.05	.42	1.02
1975	r1.10	2.44	.41	.91
1976	r1.21	2.52	.36	.75
1977	r1.59	3.11	.35	.68
1978	r1.72	3.13	.58	1.06
1979	r2.09	3.50	.76	1.27
1980	r2.09	3.21	.81	1.24
1981	r2.25	3.15	.83	1.16
1982	r2.43	3.20	.75	.99
1983	r2.43	3.08	.71	.90
1984	r2.43	2.97	.64	.78
1985	r2.54	3.01	1.09	1.29
1986	r2.54	2.94	1.06	1.22
1987	r2.54	2.85	.90	1.01
1988	r2.54	2.75	1.15	1.25
1989	r2.76	2.87	1.19	1.24
1990	2.87	2.87	1.19	1.19

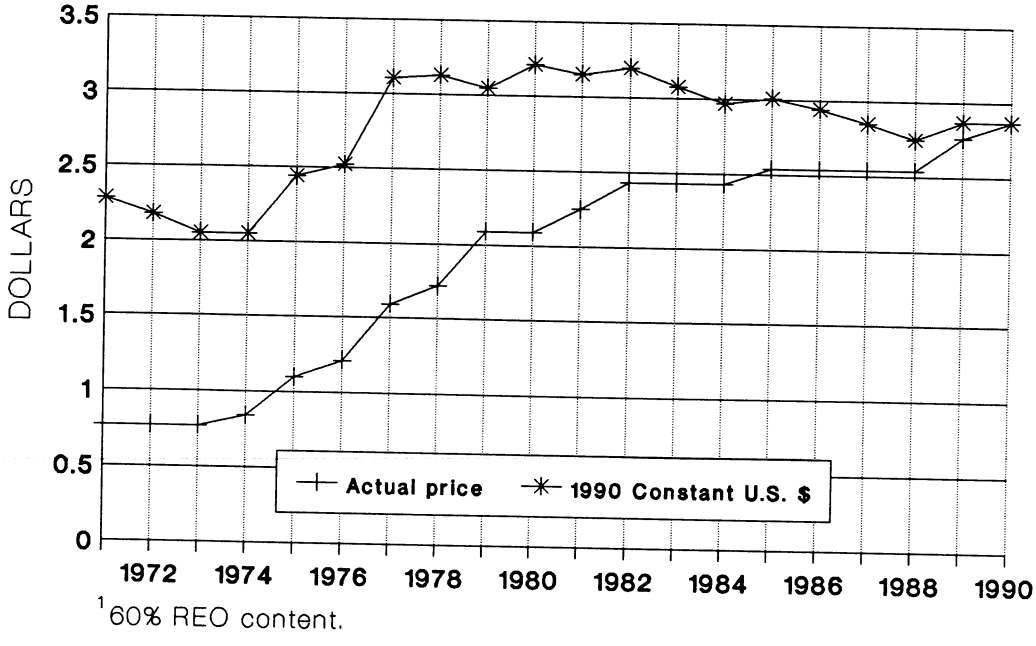
rRevised.

[1]Pricing for standard package quantities.

[2]From final 1990 implicit price deflators for gross national product, by the Council of Economic Advisors, based on 1982 = 100.

FIGURE 1

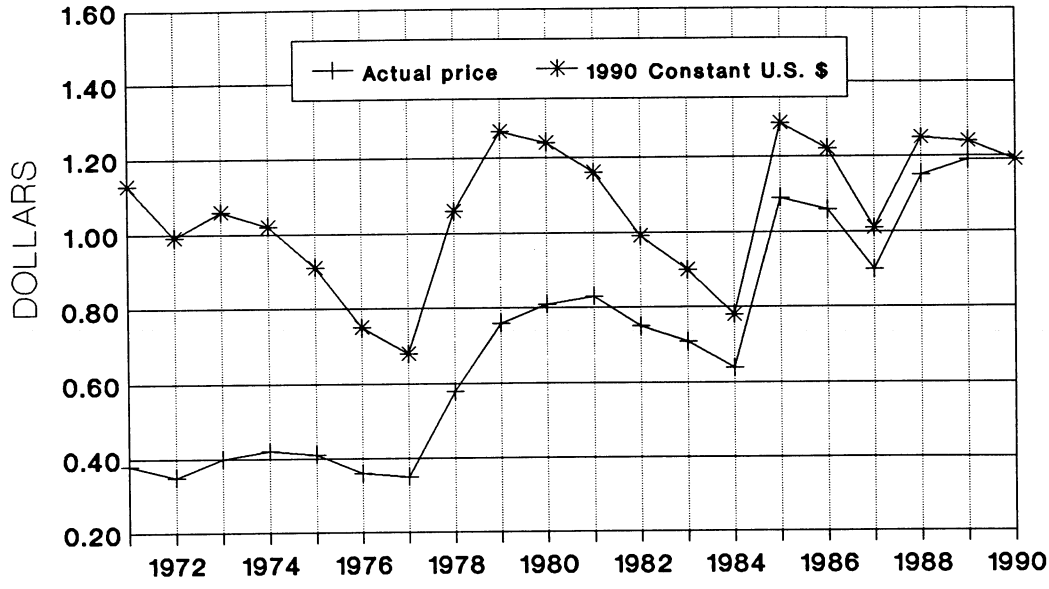
BASTNASITE CONCENTRATE PRICES



[1]60% REO content.

FIGURE 2

MONAZITE CONCENTRATE PRICES



[1] 55% REO content.

1987. Tariffs are expected to remain at the present rate until negotiations are completed.

Depletion Provisions.—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% from foreign deposits.

Bastnasite's depletion allowance is 14% on both domestic and foreign production.

Operating Factors

Toxicity.—The rare earths are considered only slightly toxic.[10] However, the production of skin and lung granulomas after exposure to oxides, fluorides, chlorides, and metals by prolonged breathing, intradermal injection, or subcutaneous implantation requires extensive protection to prevent exposure through cuts and abrasions of the skin and inhalation. Symptoms of toxicity include writhing, ataxia, labored respiration, walking on the toes with arched back, and sedation. Research has shown that males are less susceptible than females to the toxic effects of rare earths. Extreme care must also be taken when exposed to finely divided rare-earth metals and metallic powders to avoid pyrophoric burns from rapid and possibly instantaneous oxidation, especially if inhaled. Certain finely divided rare-earth metals, alloys, and powders may also present the additional hazard of oxidizing rapidly enough to explode.

Employment.—Rare-earth mine and mill employment statistics, based on the quarterly average number of employees on-site, are shown in figure 3. Data were furnished by the U.S. Department of Labor and compiled by the U.S. Bureau of Mines.

Productivity Trends.—The 11-year trend for U.S. rare-earth mine productivity, based on capacity utilization for bastnasite concentrate and monazite concentrate, is shown in figures 4 and 5.

Increased bastnasite production in 1990 changed its previous 11-year trend from a slight decrease to an increase.

The 11-year trend for monazite continued to show a slight increase, although a shorter trend without the low production year of 1980 exhibits a decrease in capacity utilization. However, monazite's decrease, since it is a byproduct of titanium and zirconium minerals, is primarily a function of demand for the primary products.

ANNUAL REVIEW

Legislation and Government Programs

The calendar year 1990 included the U.S. Government fiscal years for 1990 and 1991. Public Law 101-189, the National Defense Authorization Act for Fiscal Years 1990 and 1991, continued the authorization for disposal of all stocks of rare earths in the National Defense Stockpile.

The National Defense Authorization Act also legislated a limit of $180 million on the value of materials disposed of during each fiscal year.

Production

The United States was the world's largest producer of rare earths in 1990. Two domestic mines produced rare-earth concentrates. Producers were Molycorp, Inc. a wholly owned subsidiary of Unocal Corp., and Associated Minerals (USA) Inc., a wholly owned subsidiary of the Australian company, Renison Goldfields Consolidated Ltd. (RGC).

Bastnasite, a rare-earth fluocarbonate mineral, was mined by open pit methods by Molycorp at Mountain Pass, CA. Molycorp's mine was the leading producer of rare earths in the world. Mine production increased from that of the previous year to 22,713 metric tons of equivalent REO. Molycorp reported that 1990 sales were 6% less than those of the previous year, the result of increased global competition, a slowdown of the domestic economy, and less-than-expected growth in new uses.

The rare-earth phosphate mineral,

TABLE 4

TARIFF RATES

	HTS No.	Most favored nation (MFN)		Non-MFN	
		Jan. 1, 1990	Jan. 1, 1991	Jan. 1, 1990	Jan. 1, 1991
Mineral substances not elsewhere included. Rare-earth metal ores, e.g., xenotime (complex phosphate) and gadolinite, ytterbite, and cerite (complex silicates)	2530.90.0050	Free	Free	Free	Free
Thorium ores and concentrates. Rare-earth metal ores, e.g., monazite (phosphates of thorium and rare-earth metals)	2612.20.0000	Free	Free	Free	Free
Cerium coumpounds, including oxides, hydroxides, nitrate, sulfate, chloride, oxalate, etc.	2846.10.0000	7.2% ad valorem	7.2% ad valorem	35% ad valorem	35% ad valorem
Mixtures of rare-earth oxides except cerium oxide[1]	2846.90.2010	Free	Free	25% ad valorem	25% ad valorem
Mixtures of rare-earth chlorides, except cerium chloride	2846.90.2050	Free	Free	25% ad valorem	25% ad valorem
Rare-earth compounds, including individual rare-earth oxides, rare-earth hydroxide, rare-earth nitrate, and other compounds (excludes cerium compounds, mixtures of rare-earth oxides and mixtures of rare-earth chlorides)[1]	2846.90.5000	3.7% ad valorem	3.7% ad valorem	25% ad valorem	25% ad valorem
Promethium, salts and other compounds, organic and inorganic	2844.40.0020	Free	Free	Free	Free
Ferrocerium and other pyrophoric alloys	3606.90.3000	$.485 per kilogram + 2.6% ad valorem	$.485 per kilogram + 2.6% ad valorem	$4.41 per kilogram + 25% ad valorem	$4.41 per kilogram + 25% ad valorem
Yttrium bearing materials and compounds, containing by weight more than 19%, but less than 85% yttrium oxide equivalent	9902.26.2200	[2]Free	[2]Free	25% ad valorem	25% ad valorem

[1]Duty on certain yttrium bearing materials temporarily suspended. See HTS number 9902.26.2200.
[2]Duty temporarily suspended effective on or before Dec. 31, 1992.

FIGURE 3

U.S. RARE-EARTH MINE AND MILL EMPLOYMENT

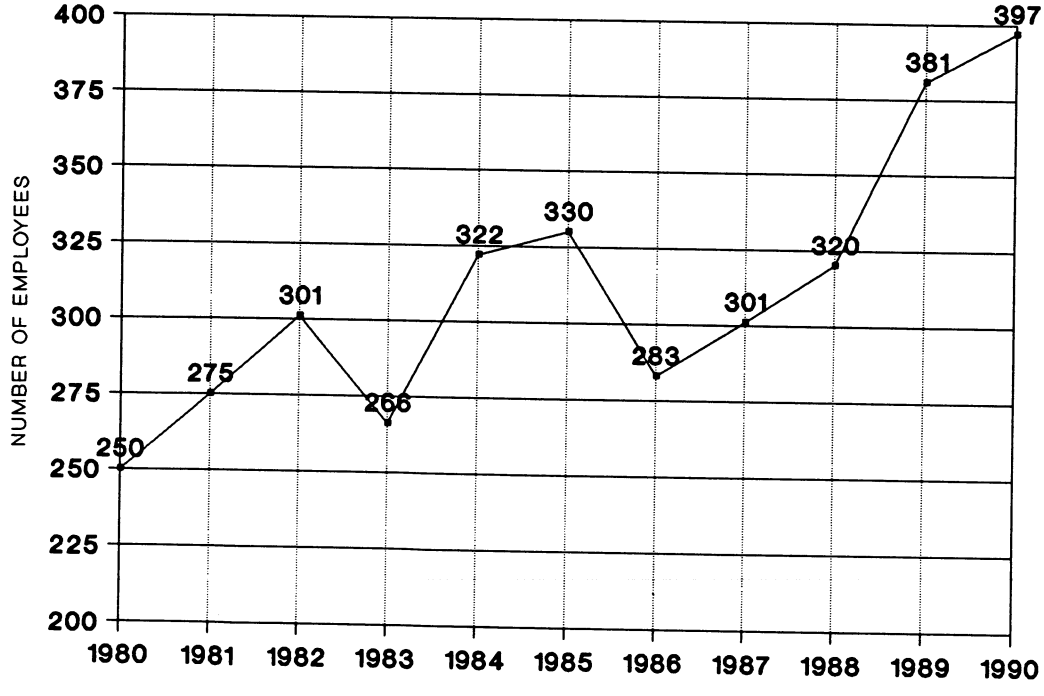


FIGURE 4

U.S. BASTNASITE CAPACITY UTILIZATION

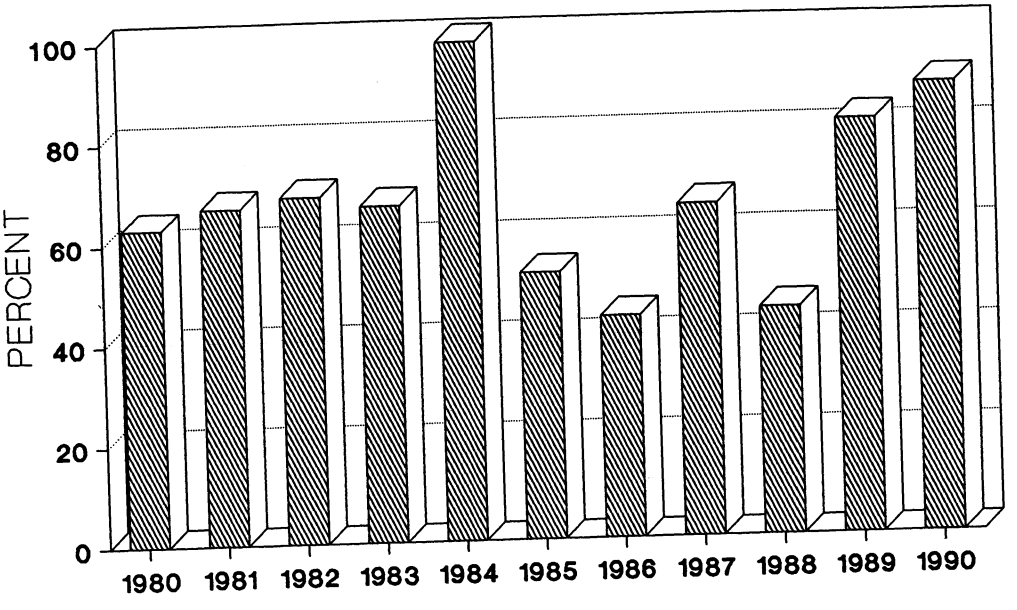
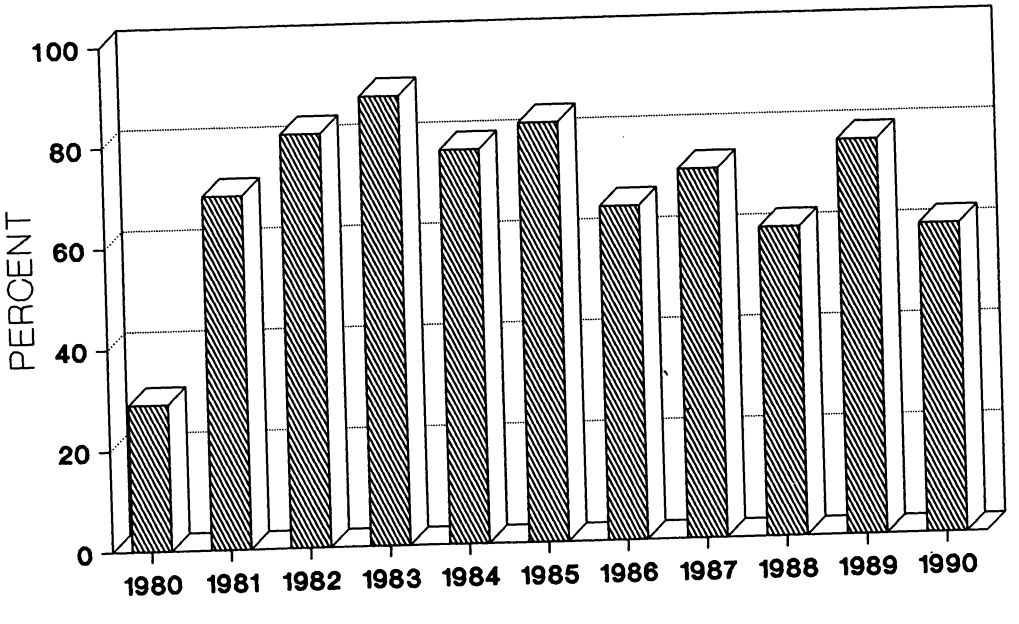


FIGURE 5

U.S. MONAZITE CAPACITY UTILIZATION



monazite, was a byproduct of titanium and zirconium minerals produced by Associated Minerals (USA) Inc. Associated Minerals operated a placer dredging operation at Green Cove Springs, FL.

Imperial Mining Co., a minor producer of byproduct monazite and xenotime, closed its operations at midyear. The Marion, NC, mine was primarily an industrial sand and gravel and gold producer. The operation closed reportedly as a result of Imperial's inability to obtain State permitting for a closed cyanide leach system for gold recovery.

After 75 years in the rare-earth business, Ronson Metals Corp., best known for its production of mischmetal and lighter flints, closed its production facility in Newark, NJ. Ronson was the only domestic lighter flint producer in the United States.

With the closing of Ronson Metals, Reactive Metals and Alloys Corp. (REMACOR), in West Pittsburg, PA, was the only remaining 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.

At yearend, Mitsubishi Materials Corp., a joint owner of Neomet Corp., acquired a 100% interest in the company.

Molycorp continued feasibility and beneficiation studies on the joint-venture Pajarito Project with the Mescalero Apache Tribe. The Pajarito deposit, on the tribe's reservation in southeastern New Mexico, contains the yttrium-bearing zirconium silicate mineral, eudialyte.

Associated Minerals completed a $12 million development project at its operations in Green Cove Springs, FL. The investment doubled the capacity and improved the efficiency of the floating concentrator.

Associated Minerals and its parent company, RGC, continued feasibility studies at three heavy-mineral sands deposits, two in North Carolina and one in Virginia. The principal deposit scheduled for development is the Old Hickory, near Stony Creek, VA. Approval to proceed with a $10 million feasibility study was granted by RGC. A pilot plant, close-spaced drilling, and an environmental testing program reportedly progressed favorably in 1990.

Consumption and Uses

Domestic rare-earth processors consumed slightly more rare earths in 1990 than in 1989. Bastnasite consumption was essentially unchanged, while monazite consumption was 23% lower. Shipments of rare-earth products from domestic processors of ore, concentrates, and intermediate concentrates were equivalent to 12,980 tons of REO, up 4% from the revised 12,425 tons shipped in 1989.

Consumption of mixed rare-earth compounds increased 6% from the 1989 level, while consumption of purified compounds increased 10%. Lower consumption of purified compounds by domestic processors was primarily the result of a slowdown in the domestic economy and the availability of low-cost foreign materials.

The producers of mischmetal, rare-earth silicide, and other rare-earth alloys consumed 51% less rare earths in 1990 than in 1989, while shipments of these goods fell 50% during the same period.

The approximate distribution of rare earths by use, based on information supplied by primary processors and some consumers, was estimated as follows: catalysts in petroleum, chemical, and pollution control, 41%; metallurgical uses as iron and steel additives and as alloys, 29%; ceramics, glass polishing compounds, and glass additives, 24%; and miscellaneous uses in phosphors, electronics, permanent magnets, lighting, and research, 6%.

The glass industry's principal use of rare earths, mainly cerium concentrate or cerium oxide, was as polishing compounds for mirrors, lenses, cut crystal, television and other cathode-ray tube (CRT) faceplates, gem stones, and plate glass. Rare-earth compounds were also used as additives to glass used in automobiles; food and beverage containers; television and CRT faceplates; radiation shielding windows; opthalmic lenses; lasers; incandescent and fluorescent lights; and optical, photochromic, filter, and photographic lenses. The rare-earth additives acted as colorants, color correctors, decolorizers, opacifiers, stabilizers against discoloration from ultraviolet light and against browning caused by high-energy radiation, as dopants in laser glass, as modifiers to increase the refractive indices and decrease dispersion, and as absorbers of ultraviolet and visible light.

Phosphors containing rare earths were used in color television tubes, radar screens, low- and high-pressure mercury vapor lights, electronic thermometers, trichromatic fluorescent lamps, and X-ray intensifying screens.

The ceramics industry used purified rare earths in pigments, heating elements, dielectric and conductive ceramics, thermal and/or flash protective devices, stereoviewing systems, data printers, image storage devices, opacifiers, paint, glasses, and as principal constituents and stabilizers in high-temperature refractories and structural ceramics, such as yttria-stabilized zirconia.

Rare-earth compounds had applications in petroleum fluid cracking catalysts, noncracking catalysts, oxygen-sensing electrolytes, dyes and softeners for textiles, electronic components, nuclear fuel reprocessing, microwave applications, incandescent gas mantles, laser crystals and glass, fiber optics, carbon arc lighting, synthetic gem stones, corrosion inhibitors, and superconductors.

Rare-earth permanent magnets were used in electric motors; alternators; generators; line printers; computer disk drive actuators and drives; proton linear accelerators; torque couples; and eddy current brakes. Magnets were also used in microwave transmission focusing; magnetrons; klystrons; medical and dental applications, including magnetic resonance imaging; traveling wave tubes; metallic separators; aerospace electric actuators for ailerons and rudders; and in speakers, headphones, microphones, and tape drives.

Metallurgical applications of rare earths included alloys and additives in high-strength, low-alloy steels; gray and ductile iron; stainless and carbon steels; high-temperature and corrosion resistant metals; and hydrogen-storage alloys for rechargeable batteries. Rare-earths alloys were also used in heat exchangers and fuel cells; lighter flints; armaments; permanent magnets; and neutron converter foils, special lead fuses, target materials for sealed-tube neutron generators, and in high-voltage transmission cable.

Stocks

U.S. Government stocks of rare earths in the National Defense Stockpile, all classified as excess to goal, remained at 457 tons throughout 1990. Rare-earth stocks held in the stockpile were contained in sodium sulfate and were inventoried on a contained-REO basis.

Industry stocks of rare-earth ores and concentrates held by 18 producing, processing, and consuming companies de-

creased 9%. Bastnasite concentrate stocks held by the principal producer and three other processors increased 10% from those of the 1989 level. Yearend stocks of monazite increased 4%.

Stocks of other rare-earth concentrates fell 6%. Stocks of mixed rare-earth compounds increased 263%, as stocks of purified compounds increased 92%. Yearend stocks of mischmetal, rare-earth silicide, and other alloys containing rare earths declined 95%, as inventories of high-purity metals were off 81%.

Prices

Published prices for the rare earths were generally nominal and subject to change without notice. Foreign competition continued in 1990, and competitive domestic 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), as quoted in Australian dollars (A$),[11] increased from A$780 - A$880 per ton at yearend 1989, to A$800 - A$900 per ton by yearend 1990. Changes in the United States-Australian foreign exchange rate in 1990, resulting from a slightly weaker Australian dollar, caused the corresponding U.S. dollar to be up $0.03 against the Australian dollar at yearend. The U.S. price range, converted from Australian dollars, increased slightly from US$616 - US$695[12] per ton in 1989 to US$618 - US$695[13] per ton in 1990. The average declared value of imported monazite increased in 1990 to $857 per ton, up $172 from the 1989 value.

The yearend price quoted in Industrial Minerals (London) for yttrium concentrate (60% Y_2O_3, f.o.b. Malaysia) was $32 - $33 per kilogram. Market prices for refined yttrium compounds were reportedly much lower, especially from China.

Prices quoted by Molycorp for unleached, leached, and calcined bastnasite in standard quantities, containing 60%, 70%, and 85% REO, were $1.30, $1.35, and $1.55 per pound of contained REO, respectively, at yearend 1990. The price for each grade of concentrate increased $0.15 per pound from last year's quote.

The price of cerium concentrate quoted by American Metal Market was $1.65 per pound of contained cerium oxide at yearend 1989, an increase of $0.10 from that of the previous year. The yearend price of lanthanum concentrate decreased $0.05 from the 1989 level to $1.35 per pound of REO contained.

The nominal price for typical neodymium-iron-boron alloy, compiled by the U.S. Bureau of Mines, was $14.25 per pound at yearend, f.o.b. shipping point, 1,000-pound minimum.

Molycorp quoted prices for lanthanide (rare earth) and yttrium oxides, net 30 days, f.o.b. Louviers, CO; Mountain Pass, CA; or York, PA; effective March 1, 1990, and through the end of the year, as shown in table 5.

Molycorp also quoted prices for lanthanide (rare earth) compounds, net 30 days, f.o.b. York, PA, or Louviers, CO, effective April 1, 1990, as shown in table 6.

Rhône-Poulenc quoted rare-earth prices, per kilogram, net 30 days, f.o.b. New Brunswick, NJ, or duty paid at point of entry, effective at yearend 1990 as shown in table 7.

No published prices for scandium oxide were available. Yearend nominal prices for scandium oxide per kilogram, compiled by the U.S. Bureau of Mines from information from several suppliers, were as follows: 99% purity, $3,500; 99.9% purity, $5,000; 99.99% purity, $8,000; 99.999% purity, $10,000. Scandium metal prices, as listed by the Johnson Matthey Aesar Group, were unchanged from yearend 1989 as follows: 99.99% purity, lump, sublimed dendritic, $248.20 per gram; 99.9% purity, 250 micron powder, $444.00 per 2 grams; and 99.9% purity, lump, vacuum remelted, $322.00 per gram.

Foreign Trade

Rare-earth imports decreased in 1990 from those of the previous year. Imports of ore and compounds are shown in tables 8 and 9. As in 1989, France dominated the import market in 1990, followed by Brazil as a distant second. The principal sources of U.S. imports are displayed in figure 6.

Domestic exports of rare earths are shown in table 10. Based on the available export data, Brazil, Canada, and Japan were the leading destinations of rare earths from the United States in 1990. This was a shift from 1989 data when Japan, Korea, and Dominica were the leaders. Principal destinations of U.S. exports are displayed in figure 7.

World Review

Industry Structure.—The world's principal source of rare earths, bastnasite, was mined as a primary product in the United States and as a byproduct of iron ore mining in China. Significant quantities of rare earths were also recovered from monazite, a byproduct of heavy-mineral sands mined for titanium and zirconium minerals or tin minerals in Australia, Brazil, China, India, Indonesia, Malaysia, the Republic of South Africa, Sri Lanka, Thailand, Taiwan, and the United States. Smaller amounts of rare earths, especially yttrium, were obtained from the mineral xenotime. Xenotime was recovered primarily as a byproduct of processing for tin minerals in Malaysia, Thailand, and Indonesia, but was also produced as a byproduct of processing titanium and zirconium minerals in Australia and China. Rare earths, including yttrium, were also produced from rare-earth-bearing clay in China.

TABLE 5

MOLYCORP RARE-EARTH OXIDE PRICES

Product (oxide)	Percent[1] purity	Quantity (pounds)	Price per pound
Cerium	99.00	200.00	$8.75
Dysprosium	96.00	50.00	60.00
Erbium	98.00	50.00	65.00
Europium	99.99	25.00	745.00
Gadolinium	99.99	55.00	65.00
Lanthanum	99.99	300.00	8.75
Neodymium	96.00	300.00	6.75
Do.	99.90	50.00	40.00
Praseodymium	96.00	300.00	16.80
Samarium	96.00	55.00	65.00
Terbium	99.90	44.10	375.00
Yttrium	99.99	50.00	52.50

[1]Purity expressed as percent of total REO.

TABLE 6

MOLYCORP RARE-EARTH COMPOUND PRICES

Product (compound)	Percent[1] purity	Quantity (pounds)	Price per[2] pound
Cerium carbonate	99.0	150	$5.10
Cerium fluoride	Tech grade	250	3.00
Cerium nitrate	96.0	250	2.35
Lanthanide chloride	46.0	525	1.25
Lanthanum carbonate	99.9	175	5.90
Lanthanum-lanthanide carbonate	60.0	200	2.45
Lanthanum-lanthanide chloride	46.0	525	0.95
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 7

RHÔNE-POULENC RARE-EARTH OXIDE PRICES

Product (oxide)	Percent purity	Quantity (kilograms)	Price per kilogram
Cerium	99.50	20	$28.50
Dysprosium	95.00	20	132.00
Erbium	96.00	20	190.00
Europium	99.99	10	1,650.00
Gadolinium	99.99	50	136.50
Holmium	99.90	5	510.00
Lanthanum	99.99	25	23.00
Lutetium	99.99	2	7,000.00
Neodymium	95.00	20	19.70
Praseodymium	96.00	20	38.85
Samarium	96.00	25	175.00
Terbium	99.90	5	880.00
Thulium	99.90	5	3,600.00
Ytterbium	99.00	10	230.00
Yttrium	99.99	50	100.50

Scandium was recovered as a byproduct of processing ore for tungsten, tin, iron, and beryllium in China, and was previously produced as a byproduct of uranium processing in the United States.

Reserves.—World reserves of rare earths were estimated by the U.S. Bureau of Mines at 62 million tons of contained REO, of which 22% is in market economy countries. World reserves were revised upward for 1990 as a result of additional data on Australia and China. Rare-earth reserves for Australia were increased to almost 5 million tons REO while those for China advanced to 48 million tons REO. China has the largest share of world reserves with almost 78%.

Australia.—CRA Ltd. and Ocean Resources NL began a joint venture to develop an offshore heavy-mineral sands deposit off the coast of Queensland. The offshore deposit reportedly contains significant quantities of rutile and zircon, with smaller amounts of monazite and ilmenite. The CRA-Ocean joint venture planned to construct an offshore wet mill on a platform, similar to those presently used for oil production. After recovering the heavy minerals on the platform, the light minerals would be returned to the sea floor.[14]

CRA Ltd.'s subsidiary, Wimmera Industrial Minerals, continued studies of the WIM 150 and four other similar heavy-mineral sand deposits near Horsham, Victoria. The fine grain size of the deposits, about 50 microns, created the need for new process technology. The primary problem is that the fine grain size is hard to separate by conventional wet methods because of the very small differences in spe-

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF MONAZITE, BY COUNTRY

Country	1986		1987		1988		1989		1990	
	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	2,660	$978	—	—	382	$237	180	$117	—	—
India	300	128	—	—	—	—	—	—	—	—
Indonesia	—	—	—	—	1,144	687	r594	r413	800	$686
Malaysia	—	—	527	$298	197	125	—	—	—	—
Thailand	—	—	594	329	201	105	—	—	—	—
Total	2,960	1,106	1,121	627	1,924	1,154	r774	r530	800	686
REO content[e]	1,628	XX	617	XX	1,058	XX	r426	XX	440	XX

[e]Estimated. [r]Revised. XX Not applicable.
Source: Bureau of the Census. REO content estimated by the U.S. Bureau of Mines.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY[1]

Country	1988 r		1989 r		1990	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Cerium compounds:						
Austria	100	$1,690	591	$4,606	500	$3,663
Canada	6,276	72,662	—	—	—	—
China	—	—	—	—	67,100	95,565
France	86,286	197,013	221,019	964,289	287,925	1,818,998
Germany, Federal Republic of	3,323	77,545	3,669	154,565	578	47,585
Italy	—	—	173	42,413	—	—
Japan	109,888	828,337	25,353	770,381	2,585	65,683
Malaysia	103,499	110,940	—	—	—	—
Mali	103,499	110,945	—	—	—	—
Morocco	282,068	295,205	—	—	—	—
Norway	—	—	1	4,000	—	—
U.S.S.R.	—	—	—	—	2	2,394
United Kingdom	6	2,640	—	—	540	6,608
Total[2]	694,942	1,696,977	250,806	1,940,254	359,230	2,040,496
Other mixtures of rare-earth compounds:						
Canada	NA	NA	3,638	504,186	7,106	952,667
China	NA	NA	90,485	2,336,173	23,064	796,937
France	NA	NA	6,827,238	18,806,732	4,757,461	25,382,258
Germany, Federal Republic of	NA	NA	252,066	2,141,690	52,252	474,042
Hong Kong	NA	NA	—	—	1,750	31,137
Hungary	NA	NA	2,519	9,260	6,224	24,738
Japan	NA	NA	132,180	1,949,341	62,829	2,263,418
Korea, Republic of	NA	NA	—	—	10	4,300
Netherlands	NA	NA	4,000	4,720	—	—
Norway	NA	NA	11,619	1,089,092	13,905	1,352,905
South Africa, Republic of	NA	NA	106	1,067,415	134	1,043,390
Switzerland	NA	NA	985	19,396	5	2,159
Taiwan	NA	NA	—	—	200	9,130
U.S.S.R.	NA	NA	24,864	2,157,938	58,480	4,396,963
United Kingdom	NA	NA	40,905	598,972	6,226	590,897
Other	NA	NA	94	24,333	—	—
Total[2]	NA	NA	7,390,699	30,709,248	4,989,646	37,324,941
Rare-earth oxides, excluding cerium oxide:						
Austria	—	—	—	—	50	1,736
Brazil	—	—	15,061	23,645	—	—
Canada	528	69,227	—	—	—	—
China	21,306	794,020	2,108	156,719	68,194	1,267,819
France	104,900	8,050,994	168,978	3,638,954	31,249	3,326,187
Germany, Federal Republic of	150	20,595	1,050	232,266	2,804	606,921
Hong Kong	—	—	200	12,084	378	17,922
India	—	—	290,800	460,000	—	—
Ivory Coast	—	—	—	—	1,000	36,021
Japan	2,604	312,527	11,358	1,051,525	26,717	1,132,707
Netherlands	5,757	1,362,377	—	—	—	—
Norway	2,158	200,394	1,313	125,261	1,332	173,069
Switzerland	1,030	119,929	—	—	—	—
Taiwan	501	3,641	78	5,339	4,150	72,201
U.S.S.R.	6,058	365,996	4,019	381,893	1,956	362,539
United Kingdom	495	237,824	6,933	898,581	12,898	1,020,471
Total[2]	145,036	11,537,524	501,898	6,986,267	150,728	8,017,593

See footnotes at end of table.

TABLE 9—Continued

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY[1]

Country	1988[r]		1989		1990	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Rare-earth metals, whether intermixed or alloyed:						
Australia	752	$22,282	—	—	—	—
Austria	4,108	201,193	4,031	$43,785	20,119	$205,012
Brazil	107,998	609,769	139,896	728,099	52,669	320,682
Canada	3,147	27,692	7,191	228,706	—	—
China	51,005	700,127	110,860	754,063	107,919	562,349
France	23,853	666,018	—	—	100	4,520
Germany, Federal Republic of	1,400	26,827	1,906	28,619	—	—
Hong Kong	1,150	78,518	—	—	—	—
Japan	1,229	86,766	7,338	259,851	3,440	153,259
Kiribati	100	4,900	—	—	—	—
Norway	—	—	222	19,450	150	28,602
Sweden	—	—	980	182,139	981	181,924
U.S.S.R.	403	59,765	150	23,250	2,258	312,653
United Kingdom	3,750	416,549	21,632	1,908,627	11,170	1,278,221
Other	—	—	30	4,232	34	3,102
Total[2]	198,894	2,900,406	294,236	4,180,821	198,840	3,050,324
Rare-earth chlorides or mixtures of rare-earth oxides:[3]						
Austria	NA	NA	—	—	40	5,500
Brazil	NA	NA	837,746	1,250,378	710,988	1,193,349
China	NA	NA	35,590	297,734	42,620	1,249,338
France	NA	NA	—	—	784	2,976
Germany, Federal Republic of	NA	NA	38	3,998	—	—
India	NA	NA	302,000	575,000	211,160	219,725
Ivory Coast	NA	NA	—	—	500	345,273
Japan	NA	NA	221,379	5,409,189	318,189	9,179,220
Malaysia	NA	NA	—	—	53,260	170,926
Netherlands	NA	NA	—	—	13,500	173,624
Norway	NA	NA	1,686	181,197	1	1,640
Taiwan	NA	NA	—	—	11,656	169,621
United Kingdom	NA	NA	3,990	364,140	197	31,473
Other	NA	NA	19	4,319	56	70,297
Total[2]	NA	NA	1,402,448	8,085,955	1,362,951	12,812,962
Ferrocerium and other pyrophoric alloys:						
Austria	3,258	81,084	4,083	103,494	27,201	496,180
Belgium	—	—	—	—	4,126	54,974
Brazil	39,075	516,944	37,031	482,609	20,469	251,636
France	43,714	702,545	42,541	633,583	33,071	565,458
Germany, Federal Republic of	—	—	(4)	(4)	5,768	87,960
Italy	12,600	29,610	—	—	—	—
Japan	—	—	(4)	(4)	495	12,780
United Kingdom	2,015	18,270	(4)	(4)	2,000	26,000
Total[2]	100,662	1,348,453	r83,655	r1,219,686	93,130	1,494,988

[r]Revised. NA Not available.

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 and 1990 are not necessarily comparable with those of previous years.

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

[3]Listed as "Other compounds of rare-earth metal, including scandium and yttrium" under the Harmonized Tariff System.

[4]Revised to zero.

Source: Bureau of the Census.

TABLE 10

U.S. EXPORTS OF RARE EARTHS, BY COUNTRY

Country	1989		1990	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Thorium ore and concentrates:[1]				
France	r2,000	$29,780	—	—
Cerium compounds:				
Argentina	1,440	12,280	240	$2,726
Australia	34,063	292,140	46,932	428,488
Belgium	—	—	4,858	21,400
Brazil	67,103	222,198	319,991	558,347
Canada	20,246	130,596	308,585	1,833,895
Chile	558	3,465	580	3,107
China	—	—	4,369	19,447
Colombia	2,124	15,175	—	—
Egypt	—	—	2,880	16,427
France	47,754	296,549	65,507	466,086
Germany, Federal Republic of	107,816	777,276	156,278	1,709,933
Greece	1,926	10,120	6,131	2,900
Hong Kong	53,681	304,077	95,750	663,777
India	1,440	7,382	1,920	11,040
Indonesia	—	—	5,038	24,093
Ireland	1,920	8,258	—	—
Israel	2,860	14,627	2,541	21,635
Italy	10,353	62,109	35,577	109,016
Japan	599,253	2,684,774	266,312	1,635,416
Korea, Republic of	282,524	1,092,363	230,823	1,377,622
Luxembourg	—	—	2,400	18,672
Malaysia	963	274,334	654	2,978
Mexico	13,563	99,636	18,937	133,939
Netherlands	—	—	3,511	25,729
New Zealand	—	—	620	6,977
Portugal	960	3,907	6,720	29,491
Saudi Arabia	—	—	1,920	10,982
Singapore	5,047	30,923	300	3,341
Spain	14,609	90,884	26,460	167,322
Taiwan	33,150	182,975	56,096	297,401
Thailand	47,140	176,249	18,720	137,971
Trinidad and Tobago	8,628	105,000	4,314	55,000
Turkey	—	—	2,853	13,306
United Kingdom	71,800	85,779	26,356	132,665
Uruguay	960	4,214	—	—
Venezuela	—	—	4,760	33,579
Other	791	38,884	838	8,677
Total	1,432,672	7,026,174	1,729,771	9,983,385
Rare-earth metals, including scandium and yttrium:				
Australia	2,313	22,646	1,415	11,682
Canada	43,036	356,612	2,335	199,874
China	300	95,400	108	4,500
Dominica	170,697	87,664	—	—
Dominican Republic	92,896	20,000	81,455	15,000
France	670	17,907	1,016	66,726

See footnotes at end of table.

TABLE 10—Continued

U.S. EXPORTS OF RARE EARTHS, BY COUNTRY

Country	1989		1990	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Rare-earth metals, including scandium and yttrium—Continued				
Germany, Federal Republic of	9,243	200,203	937	9,420
Guatemala	—	—	19,958	10,583
Guyana	—	—	45,910	45,000
India	3,364	94,888	327	50,739
Japan	22,252	2,597,590	12,601	188,439
Korea, Republic of	213	15,686	3,364	74,573
Lichtenstein	—	—	255	96,900
Malaysia	—	—	797	11,666
Mexico	—	—	977	22,183
Netherlands	268	25,580	12,854	100,422
Netherlands Antilles	—	—	362	4,500
Norway	r11,422	523,043	106	15,200
Panama	3,938	6,902	—	—
Poland	388	75,264	—	—
Singapore	781	53,475	592	16,047
St. Lucia	—	—	14,490	18,100
Switzerland	1,163	171,519	394	166,802
Taiwan	20,010	49,973	722	63,200
United Kingdom	31,156	174,788	27	20,174
Venezuela	10,433	160,000	—	—
Other	r294	51,483	120	37,728
Total	424,837	4,800,623	201,122	1,249,458

rRevised.

[1]Data was erroneously reported as exported to Austria and Indonesia in 1989.

Source: Bureau of the Census.

FIGURE 6

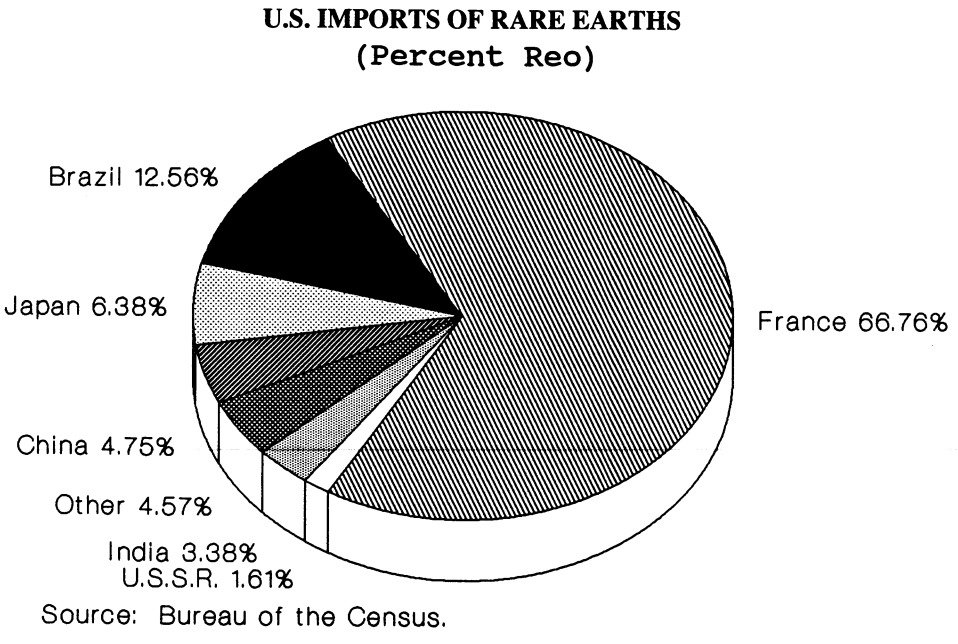
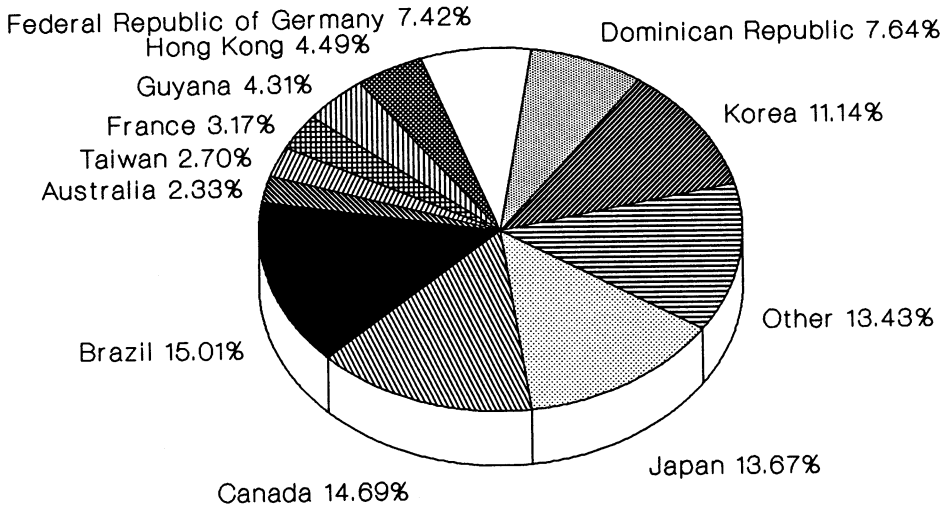


FIGURE 7

U.S. EXPORTS OF RARE EARTHS
(Percent Reo)



Source: Bureau of the Census.

TABLE 11

MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons, gross weight)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Australia	14,822	12,813	11,872	[e]13,500	14,500
Brazil	3,618	4,332	2,817	1,900	2,000
India[e]	4,000	4,000	4,000	[r]4,300	4,500
Malaysia	5,959	2,908	2,920	2,948	3,500
Mozambique[e]	3	—	—	—	—
South Africa, Republic of[e]	1,000	1,200	1,200	[r]1,200	1,200
Sri Lanka[e]	200	200	200	200	200
Thailand	1,609	458	590	631	650
United States	W	W	W	W	W
Zaire	7	97	168	175	170
Total	31,218	26,008	23,767	24,854	26,720

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."
[1]Table includes data available through Apr. 23, 1991.
[2]In addition to the countries listed, China, Indonesia, North Korea, the Republic of Korea, Nigeria, and the U.S.S.R. may produce monazite, but output, if any, is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels.

cific gravities. Separation systems being assessed for the initial concentration are a proprietary jig and bulk flotation. Wimmera Industrial Minerals reports the WIM 150 contains 580,000 tons of monazite and 170,000 tons of xenotime, making it one of Australia's largest rare-earth deposits.[15]

Westralian Sands Ltd. announced the shutdown of its Yoganup Extended mineral sands mine in Western Australia in August. The shutdown was reportedly in response to decreased demand for titanium pigments. Westralian's two other mineral sands mines continued to operate. The Yoganup Extended was slated to resume production of mineral sands, including monazite, when market conditions improve.

Renison Goldfields Consolidated Ltd. continued development of its Eneabba West mineral sands deposit in Western Australia. Production from the Eneabba West ore body was expected to commence in 1991, increasing the company's overall capacity by about 30%.

The largest mine to start up in Australia in 1990 was Cooljarloo, a joint venture of Minproc Chemicals Pty. Ltd. and KMCC Western Australia Pty. Ltd. The Western Australia mine was expected to employ 450 people and generate $225 million dollars in export income. Cooljarloo's reserves are set at 570 million tons of ore grading 3.2% heavy minerals, including monazite.[16]

TABLE 12

RARE EARTHS: WORLD MINE PRODUCTION, BY COUNTRY

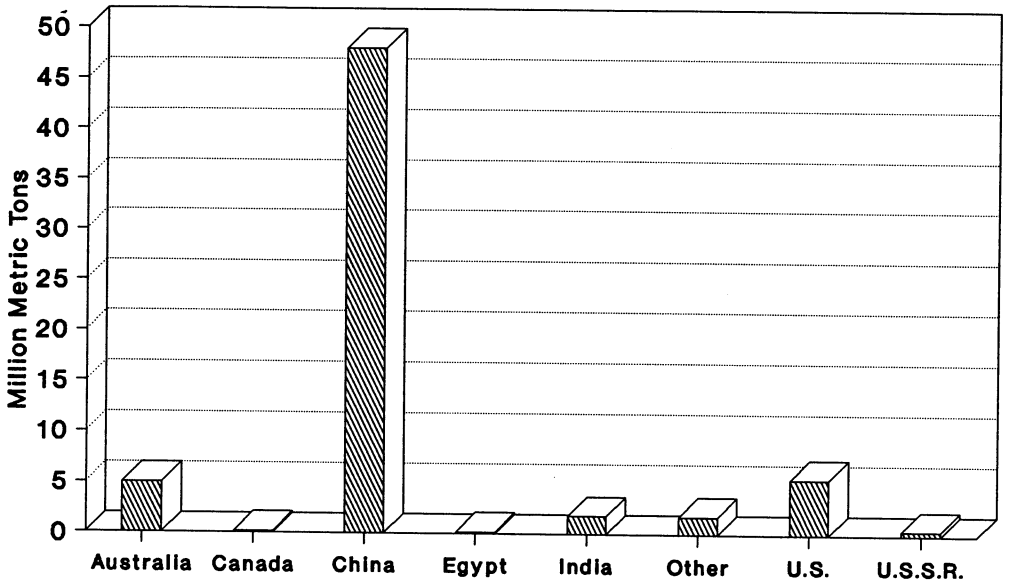
(Metric tons of REO equivalent)

Country[1]	1988	1989[p]	1990[e]
Australia	6,530	[e]7,400	7,975
Brazil	1,690	1,900	1,100
Canada[e]	100	100	—
China	29,640	25,220	[2]16,480
India[e]	2,200	2,200	2,475
Malaysia	1,630	1,646	[2]1,925
Sri Lanka[e]	110	110	110
Thailand	375	365	[2]358
United States[3]	11,533	20,787	[2]22,713
Zaire	92	96	[2]94
Total	53,900	59,824	53,230

[e]Estimated. [p]Preliminary.
[1]In addition to the countries listed, rare-earth minerals are believed to be produced in Indonesia, North Korea, Mozambique, Republic of South Africa, and the U.S.S.R., but general information is inadequate to formulate reliable estimates.
[2]Reported figure.
[3]Comprises only the rare earths derived from bastnasite as reported in Unocal Corp. annual report, 1990.

FIGURE 8

WORLD RESERVES OF RARE EARTHS
(Percent Reo)



Pivot Group Ltd. was granted a 21-year lease to mine mineral sands at Port Clinton, within the Shoalwater Military Training Area. Reserves at Port Clinton reportedly totaled 120 million tons grading 3% heavy minerals. Pivot planned to barge the wet concentrate by sea to a dry mill at Gladstone.[17]

Carr Boyd Minerals Ltd. announced it had started feasibility studies at its Mt. Weld rare-earth-bearing carbonatite. Thirty-five kilometers south of Laverton, Western Australia, the carbonatite contains the rare-earth phosphate mineral monazite (thorium-deficient), a hydrated yttrium-lanthanide phosphate, churchite, and the hydrated rare-earth-niobium-tantalum-bearing calcium-aluminum phosphate, crandallite. Reserves at Mt. Weld were 6.3 million tons grading 17.22% REO.[18]

Yardarino Mining NL explored a mineral sands deposit near Cataby, Western Australia. The deposit lies adjacent to the Cooljarloo mineral sands mine owned by Minproc Chemicals Pty. Ltd. and KMCC Western Australia Pty. Ltd. A 650-hole drilling program delineated resources of 32 million tons grading 4.4% heavy minerals. Additional exploration on the deposit was planned based on results of an aeromagnetic survey.[19]

Nissho Iwai Corp., through its wholly owned subsidiary, Cable Sands Pty. Ltd., continued development of the Jangardup mineral sands deposit south of Nannun, Western Australia. The Jangardup deposit is expected to come on-line in 1991 with the capacity to produce 4 million tons of ore per year.[20]

Australmin Holdings Ltd. proceeded with development of the Newrybar deposit after the New South Wales Land and Environment Court approved the project in late 1989 over the objections of an antimineral sands mining group. Production at Newrybar commenced in 1990 with an installed capacity to recover 3.5 million tons of ore per year. Dry mill capacity was planned to recover 12,000 tons of rutile, 10,000 tons of rutile, and lesser amounts of ilmenite and monazite.[21]

Brazil.—Production of monazite concentrates in 1988 was 2,817 tons, 2,038 tons from the State of Rio de Janiero, a decrease from the 1987 production of 3,217 tons; 779 tons from the State of Bahia, a decrease from the 884 tons of monazite produced in 1987; and no production from the State of Espírito Santo, down from 177 tons in 1987.

Measured reserves of monazite increased to 48,281 tons in 1988 from 36,806 tons in 1987. Estimated rare-earth oxide content based on these reserves was 26,600 tons. The increase in reserves was the result of additional tonnages added from the São João da Barra deposit in the State of Rio de Janeiro. Additional monazite reserves were in the States of Bahia, Espírito Santo, Minas Gerais.[22]

Production of rare-earth compounds in 1988 was 37,822 kilograms of rare-earth carbonate, 2,633,000 kilograms of rare-earth chloride, and 94,650 kilograms of rare-earth oxides.[23]

An agreement between Brazil's Mining Technology Center (CETEM) and China's Minerals and Non-Ferrous Metals Institute was signed to transfer China's technology to Brazil for the production of rare-earth oxides.[24]

Canada.—Hecla Mining Co. of Canada and Iron Ore Co. of Canada entered an agreement to resume evaluation of the Strange Lake, yttrium-zirconium-lanthanide deposit. On the border of Quebec and Labrador, northeast of Schefferville, Quebec, the deposit has reserves of 44 million tons of ore grading 0.41% yttrium oxide. The yttrium is contained in an unnamed mineral (proposed dickgarrenite) and gadolinite, an yttrium-iron-beryllium silicate. Hecla will reportedly evaluate metallurgical extraction methods and proceed with marketing studies in return for up to a 75% interest if the deposit goes into production.[25]

Malaysia.—Production of rare-earth concentrates of monazite and xenotime has decreased substantially since 1987. The

drop was reportedly due to a shortage of "amang," the mixed heavy-mineral by-product remaining after removal of the tin minerals.[26] The decrease was also attributed to increased competition from China and local environmental problems related to the disposal of monazite's radioactive component, thorium.

Mozambique.—Financing for Kenmare Resources PLC's Congolone deposit encountered delays when the Credit Guarantee Insurance Corp. decided not to finance the project. Based on Kenmare's inability to secure financing, Johannesburg Consolidated Investments Ltd. reportedly withdrew it's offer to participate in the joint venture. Reserves at the Congolone deposit reportedly contain 11,000 tons of monazite.[27]

New Zealand.—Fletcher Titanium Products Ltd. continued development of its Barrytown deposit. Construction of a wet mill was reportedly completed in the first half of 1990, and a dry separation plant was commissioned in January.[28]

Sweden.—In recognition of its importance to rare earths and the metals industry, the Ytterby Mine on Resaro Island was designated an ASM Historical Landmark by ASM International, the materials information society. The Ytterby Mine was the site of the discovery of many rare earths, including erbium, holmium, scandium, terbium, thulium, yttrium, and ytterbium.[29]

Vietnam.—W. T. Exporters Pty. Ltd. of North Queensland, Australia, reportedly obtained a license to develop a heavy-mineral sands deposit in Nghe Tinh Province. An initial production of 27,000 tons of ilmenite and zircon was planned.[30]

Current Research

Rare earths were used in a newly developed nickel-hydrogen rechargeable battery. Using a foamed nickel alloy as the positive pole and a rare-earth mixture as the negative pole, the battery operates by absorbing and desorbing hydrogen gas. The rare-earth-containing battery reportedly has twice the energy capacity of a nickel-cadmium rechargeable battery and will recharge at a much faster rate. The new battery is expected to replace nickel-cadmium batteries in most applications due to its improved properties and elimination of the hazardous material cadmium.[31]

Scientists at Argonne National Laboratory and Northwestern University developed a practical high-temperature superconducting device to monitor liquid nitrogen levels. Using superconducting yttrium-barium-copper-oxygen wires, the device measures the liquid nitrogen level by detecting resistance changes as the level drops. The sensor may be used for remote detection of coolant levels in human tissue refrigeration units and in other cryogenic devices.[32]

Researchers at NEC developed a handheld range finder based on a glass laser containing erbium. The erbium-glass laser reportedly emits 40 nanosecond, 7 millijoule pulses at 2.8 micrometers to calculate distances from 100 to 10,000 meters. The erbium lasing wavelength of 2.8 micrometers allows operation that is safe to the human eye.[33]

A holmium laser to treat glaucoma was developed at Sunrise Technologies, Inc. The experimental laser was given an investigational device exemption by the Food and Drug Administration so clinical use could begin. Holmium's emission wavelength of 2.10 micrometers allows a quartz fiber with a very small probe to be used for the eye treatment.[34]

Researchers developed a pulsed laser using rare earths that can be used in dentistry. The pulsed neodymium-yttrium-aluminum-garnet laser may be used on both soft and hard tissue. Hard tissue reportedly can be treated with little or no pain because the microsecond laser pulses give the nerves no time to respond. Lasing at 1.06 micrometers, the rare-earth device can also be used to vaporize tooth decay and treat gum disease. The laser is currently used in Canada and seven European countries. Domestic use is pending approval by the Food and Drug Administration.[35]

High-strength, rare-earth magnets were used in a new magnetic separator developed by International Process Systems Inc. Developed for dry mill applications, the separator has a unique roll assembly that reportedly provides easier control and maintenance in addition to lower manufacturing costs. The neodymium-iron-boron magnetic separator can be used on a variety of minerals, including the mineral sands ilmenite, rutile, zircon, and monazite. Mineral Deposits Ltd. of Australia was licensed to manufacture the separator.[36]

To minimize grinding of optical glass, a low melting point lead-phosphate glass containing scandium was invented by scientists at Oak Ridge Laboratory, TN. Both lead-indium phosphate and lead-scandium phosphate glasses were developed to be cast into the complex shapes needed by industry. The glasses may also be used for radiation-shielding windows because of their lead content.[37]

OUTLOOK

In the short-term, the domestic rare-earth industry is expected to experience flat demand in most uses and modest gains in a select group of emerging applications. Growth is expected to be greatest in permanent magnets, rechargeable batteries, specialty laser crystals, and optical storage devices. Growth in high-temperature superconductors is expected only in the long term. The international outlook is for continued offshore expansions and increased competition in the wide range of rare-earth markets. On the demand side, it is expected that new applications, such as mischmetal rechargeable batteries and erbium fiber optics, will improve both the traditional and emerging markets.

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RHENIUM

By John W. Blossom

Mr. Blossom, a physical scientist and engineer with 43 years of industry and Government experience, has been the commodity specialist for rhenium since 1983. Trade data were prepared by Sherwood C. Jordan, mineral data assistant.

Rhenium's two most important uses in the past decade have been in platinum-rhenium catalysts used primarily in producing lead-free high-octane gasoline and in high-temperature superalloys for jet engine components. Other uses of rhenium, primarily as tungsten-rhenium and molybdenum-rhenium alloys, though smaller in quantity, are more diverse. These include use in thermocouples, heating elements, temperature controls, flashbulbs, vacuum tubes, X-ray tubes and targets, metallic coatings, and electrical contact points. Research by industry continues in rhenium recovery from ore and concentrate and on development of new catalysts and alloys.

In 1990, domestic demand for rhenium metal and other rhenium products was met by domestic recovery, domestic stocks, and imports.

TABLE 1

SALIENT U.S. RHENIUM STATISTICS

(Kilograms)

	1986	1987	1988	1989	1990
Mine production[1]	9,843	9,888	11,929	17,463	17,463
Consumption[e]	5,897	7,031	7,711	8,165	7,711
Imports (metal)	2,492	3,373	3,094	3,785	6,068
Imports for consumption of ammonium perrhenate	5,529	3,277	2,712	948	15,353

[e]Estimated.
[1]Calculated rhenium contained in molybdenite concentrates.

DOMESTIC DATA COVERAGE

Domestic mine production data for rhenium are developed by the U.S. Bureau of Mines from reported molybdenum production at the seven operating porphyry copper-molybdenum-rhenium mines in the United States.

ANNUAL REVIEW

Rhenium is a byproduct of molybdenite recovered as a byproduct of porphyry copper ore from seven mines in the Western United States. Consumption of rhenium decreased about 6% in 1990. Imports for consumption increased 353% in 1990. Some of this increase in imports was the result of improved reporting in 1990 of trade data. The major uses for rhenium during the year were bimetallic platinum-rhenium catalysts and jet engine high-temperature components. The price of rhenium metal was about $1,544 per kilogram ($700 per pound), and the price for ammonium perrhenate about $1,433 per kilogram ($650 per pound).

Consumption and Uses

The major uses of rhenium are in petroleum-reforming catalysts and in high-temperature superalloys used in jet engine components. These two uses each represent about 45% of the total demand.

Rhenium is used in petroleum-reforming catalysts for the production of high-octane hydrocarbons, which are used in the production of lead-free gasoline. Bimetallic platinum-rhenium catalysts have replaced many of the monometallic catalysts. Rhenium catalysts tolerate greater amounts of carbon formation and make it possible to operate at lower pressures and higher temperatures, which leads to improved yields and octane ratings.

Catalytic units employing platinum-rhenium catalysts are used in about 80% of total U.S. reforming capacity. Platinum-rhenium catalysts are also used in the production of benzene, toluene, and xylenes, although this use is small compared with that used in gasoline production.

A significant property of rhenium is its ability to alloy with molybdenum and tungsten. Molybdenum alloys containing approximately 50 weight percent rhenium have greater ductility and can be fabricated by either warm or cold working. Unlike other molybdenum alloys, this alloy is ductile, even at temperatures down to 196° C, and can be welded. Also, alloys of tungsten with 24 weight percent rhenium have improved ductility and lower ductile-to-brittle transition temperature than pure tungsten. Rhenium improves the strength properties at high temperatures (1,000° C) of nickel alloys. Some of the uses for these alloys are in thermocouples, temperature controls, heating elements, ionization gauges, mass spectrographs, electron tubes and targets, electrical contacts, metallic coatings, vacuum tubes, crucibles, electromagnets, and semiconductors. These various uses represented only 10% of total demand in 1990.

Foreign Trade

Imports for consumption of ammonium perrhenate came from Brazil, Chile, the Federal Republic of Germany, Japan, Sweden, and the United Kingdom, whereas Chile, the Federal Republic of Germany, Japan, Sweden, Switzerland,

TABLE 2

HARMONIZED TARIFF OF U.S. RHENIUM IN 1990

(Kilograms)

Action	HTS No.	Commodity description	Duties, import only	
			Most favored nation (MFN)	Non-MFN
Export	2811.19.0000	Other inorganic acids: Other—rhenium, etc.	—	—
Import	2811.19.5050	do.	4.2% ad valorem	25% ad valorem.
Export	2841.90.0000	Salts of peroxometallic acids: Other—rhenium, etc.	—	—
Import	2841.90.2000	Salts of peroxometallic acids: Other—ammonium perrhenate	3.1% ad valorem	25% ad valorem.
Export	8112.91.0000	Rhenium, etc. (metals)—unwrought; waste and scrap; powders	—	—
Import	8112.91.0500	Rhenium, etc. (metals)—waste and scrap	Free	Free.
Do.	8112.91.5000	Rhenium, (metal)—unwrought; powders	3.7% ad valorem	25% ad valorem.
Export	8112.99.0000	Rhenium, etc. (metals)—wrought; etc.	—	—
Import	8112.99.0000	do.	5.5% ad valorem	45% ad valorem.

TABLE 3

U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM PERRHENATE, BY COUNTRY

Country	1988		1989		1990	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Brazil	—	—	—	—	125	$105
Chile	1,564	$1,892	263	$151	7,270	1,647
Germany, Federal Republic of	194	278	—	—	2,988	559
Japan	87	125	—	—	152	130
Netherlands	345	390	—	—	—	—
Sweden	522	729	132	188	1,614	1,447
Switzerland	—	—	553	610	—	—
United Kingdom	—	—	—	—	3,204	643
Total	2,712	3,414	948	949	15,353	4,531

Source: Bureau of the Census.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF RHENIUM METAL, BY COUNTRY

Country	1988		1989		1990	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Chile	2,431	$2,144,211	1,683	$1,582,515	3,971	$4,332,830
Germany, Federal Republic of	654	1,003,724	2,097	2,588,163	1,611	1,973,238
Other[1]	9	13,100	5	25,880	486	558,087
Total	3,094	3,161,035	3,785	4,196,558	6,068	6,864,155

[1]Includes France, Japan, Sweden, Switzerland, and Uruguay.

Source: Bureau of the Census.

and the United Kingdom supplied rhenium metal.

World production of rhenium was estimated to be 34 metric tons (75,000 pounds); however, the quantity of rhenium actually recovered is much lower because not all concentrates are processed to recover the rhenium values. Rhenium was recovered from some byproduct molybdenite concentrates from porphyry copper deposits in Canada, Chile, China, Iran, Peru, the U.S.S.R., and the United States. In addition, the U.S.S.R. also recovered rhenium as a byproduct from the Dzhezkazgan sedimentary copper deposit in Kazakhstan. Rhenium metal and compounds were recovered from molybdenum concentrates in Chile, France, the Federal Republic of Germany, Sweden, the U.S.S.R., the United Kingdom, and the United States.

World Review

The definitions of reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification For Minerals," which is reprinted in the introduction of "Mineral Facts and Problems, 1985 Edition" and "Mineral Commodity Summaries, 1990."

TABLE 5

WORLD RHENIUM RESERVES AND RESERVE BASE

(Kilograms)

Country	Reserves	Reserve base
Canada	31,751	1,542,213
Chile	1,306,345	2,540,115
Peru	45,359	544,310
U.S.S.R.	594,206	771,106
United States	385,553	4,535,920
Other countries	90,718	362,874
World total	2,453,932	10,296,538

Estimated world reserves and reserve base of rhenium appear in table 5. They are contained primarily in molybdenite in porphyry copper deposits. U.S. reserves are concentrated in Arizona and Utah, but are also found in Montana, Nevada, and New Mexico. Canadian reserves are in British Columbia, primarily on Vancouver Island. Chilean reserves are found primarily at four large porphyry copper mines and in lesser deposits in the northern half of the country. In Peru, reserves are concentrated primarily in the Toquepala open pit porphyry copper mine and in about a dozen other deposits in the southern half of the country.

Soviet reserves are in several porphyry copper deposits and one sedimentary copper deposit mainly in the south-central part of the country between the Caspian Sea and northwestern China. Other world reserves are in Europe and in sedimentary copper-cobalt deposits in Zaire, Africa.

OUTLOOK

In the next 5 years, demand for rhenium metal could increase to about 20 metric tons (45,000 pounds) annually, with propulsion component needs (superalloys) at 60%, petroleum-reforming catalysts at 30%, and the various other uses consuming 10%. This increase in demand may be met by processing a greater amount of concentrates containing rhenium and increasing the rate of recovery into the 90% range. Recycling of rhenium-bearing waste and scrap must be greatly improved. This area will require the development of new technologies.

SALT

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 12 years' U.S. Bureau of Mines experience, has been the commodity specialist for salt since 1980. Domestic survey data were prepared by Carleen Militello, mineral data assistant; and international data tables were prepared by William Zajac, Chief, International Data Section.

Sodium chloride, commonly known as salt, is an important compound that has a multitude of applications. Although most individuals usually only associate salt with highway deicing and food processing, 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.

DOMESTIC DATA COVERAGE

Domestic production data for salt are developed by the U.S. Bureau of Mines from an annual voluntary survey of U.S. salt-producing sites and of company operations. Of the 69 operations to which a survey request was sent, 66 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 1990 production estimate survey or brine production capabilities for chloralkali manufacture.

BACKGROUND

Salt has been an important commodity throughout history. Its presence has determined the location of cities, migration of populations, and routes of trade caravans. One of the earliest accounts of using salt in political-economic societies was traced to 2200 B.C. in China where Emperor Hsia Yu decreed that Shandong Province would supply the court with salt. The Phoenicians (1200 B.C.-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 in for their services. Aside from its use as a medium of monetary exchange, salt has also been used to signify hospitality. The custom of presenting newlyweds wine, bread, and salt shows salt as a 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 U.S.S.R. staffed spaceflights carry aloft bread and salt and leave them behind on the orbiting space station as presents for the next visiting crew.

The first production of salt in the United States was in 1614 by the Virginia colonists who evaporated seawater. The practice of extracting salt from subsurface brine was first employed in the United States at Onondaga, NY, in 1788. The first salt "mine" in the United States was dug in 1799 at Saltville, VA. A 6-foot-wide by 200-foot-deep shaft was dug to the top of the salt formation before ground water flooded the workings. The saline water in the shaft provided the feedstock to iron kettles in which the water was evaporated and the salt recovered. In 1862, the first commercial rock salt mine in North America began operating at Avery Island, LA. Solution mining of salt began in about 1882 and consisted of drilling a small diameter well down to a salt bed, pumping freshwater down to dissolve the salt, and pumping the resultant brine to the surface for subsequent evaporation. In 1887, the vacuum pan was adopted for salt production, which incorporated a vacuum during evaporation to allow the water to boil from the brine at a lower temperature. This technological achievement reduced fuel consumption below that of direct-heated units.

Definitions, Grades, and Specifications

Technically, salt is a generic term that describes compounds formed by the partial or complete replacement of the hydronium ion of an acid by a metal or metallic radical. Water and salts are the end products from the chemical reaction between acids and bases. Through time, however, "salt" has become synonymous with sodium chloride (common salt) and will be considered synonymous throughout this chapter.

Naturally occurring sodium chloride is mineralogically known as halite. Pure salt contains 39.3% sodium and 60.7% chlorine by weight. Halite deposits usually contain between 1% and 4% impurities, mainly gypsum, shale, dolomite, and quartz. Rock salt is halite that is mined underground by conventional room-and-pillar techniques.

Evaporated salt is the term applied to fine crystals of salt obtained by evaporating brines, either natural or manufactured from solution mining, in large, vacuum-enclosed or open steam-heated kettles. Solar evaporated salt is the product harvested from shallow ponds after the brine has been exposed to solar and wind evaporation.

The physical characteristics of salt vary with the type of production process. Salt specifications from vacuum pan operations are the same because the process is similar throughout the country. Rock salt, however, can vary in color and composition with locality, and these characteristics influence the specifications of the final product. Some impurities must be removed by chemical treatment or filtration to meet specifications for certain end uses.

There are various standards issued by different organizations that apply to salt. These standards may vary, depending on the intended end use. For example, salt for human consumption requires different specifications than those of salt for deicing highways.

Products for Trade and Industry

Salt for human consumption is packaged in different sized containers for several specialized purposes. Table salt can contain 0.01% potassium iodide as an additive that provides a source of iodine that is essential to the oxidation processes in the body.

TABLE 1

SPECIFICATIONS APPLYING TO THE SALT INDUSTRY

Type specification	Title	Designation	Jurisdiction
Analysis	Standard Methods for Chemical Analysis of Sodium Chloride	ASTM-E-534-81[1]	American Society for Testing and Materials.
Food[2]	Sodium Chloride	FCC III Food Chemicals Codex, 3rd Edition	Food and Nutrition Board, National Academy of Sciences.
Highway	Standard Specification for Sodium Chloride	ASTM-D-632-89	American Society for Testing and Materials.
Do.	do.	AASHTO-M-143-86	American Association of State Highway Transportation Officials.
Medical[3]	Official Monograph on Sodium Chloride	United States Pharmacopeia XXI, 1985, 21st Revision	United States Pharmacopeia Convention, Inc.
Packaging	Salt Packages	ANSI/Z353.1-1983[4]	American National Standards Institute Inc.
Do.	Federal Specification-Sacks, Shipping, Paper	UU-S-48F[5]	General Services Administration.
Reagent	Sodium Chloride	Reagent Chemicals 7th Edition, 1986	American Chemical Society.
Soil stabilization	Standard Test Methods for Water-Soluble Chlorides Present as Admixes in Graded Aggregate Road Mixes	ASTM-D-1411-82	American Society for Testing and Materials.
Table salt[2]	Proposed Federal Specification-Salt, Table	SS-S-31K	U.S. Army Natick Laboratories.
Water	Federal Specification Commericial Item Description Sodium Chloride, Technical (Water Conditioning Grade)	A-A-694	General Services Administration.
Do.	AWWA Standard for Sodium Chloride	ANSI/AWWA-B200-88	American Water Works Association.

[1]E-534-75 is an analytical standard that is necessary for a meaningful salt specification.
[2]Input regarding food and table salt specification is necessary to maintain quality products in these areas.
[3]Work has been done with medical salt standards to obtain reasonable specifications.
[4]The ANSI Packaging Standard is a voluntary standard for primary salt containers, secondary containers, and pelletized shipping units.
[5]UU-S-48F gives Federal Sack Specifications. An effort has been made in this area to obtain a reasonable standard.

Source: Salt Institute.

Kosher salt, seasalt, condiment salt, and salt tablets are special varieties of salt.

Water conditioning and animal feedstock salt are made into 50-pound pressed blocks. Sulfur, iodine, trace elements, and vitamins are occasionally added to salt blocks to provide missing nutrients not found naturally in the diet of certain livestock. Salt is also compressed into pellets and used for water conditioning.

Geology-Resources

The definitions of reserves and reserve base are published in the U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals."

The oceans are the world's largest resource of salt. Seawater contains 3.5% dissolved solids by weight with sodium chloride representing the major component, approximately 2.5% by weight. The world's oceans contain about 44 x 10^{15} short tons of sodium chloride, which is equivalent to 4.5 million cubic miles in volume or a cube measuring 165 miles on edge.

Domestic salt resources are found mainly in four large depositional basins, covering an area totaling about 0.5 million square miles in 18 States. These basins are (1) the gulf coast, which covers part of Florida, Alabama, Mississippi, Arkansas, eastern Texas, and all of Louisiana; (2) the Permian, which is in part of New Mexico, Colorado, Kansas, Oklahoma, and western Texas; (3) the Salina, covering part of New York, Pennsylvania, West Virginia, Ohio, and Michigan; and (4) the Williston, encompassing part of North and South Dakota, Montana, and Wyoming. The gulf coast and Permian basins extend into Mexico; the Salina and Williston both extend into Canada. The identified salt resources of the United States are estimated at 61 x 10^{12} tons and are being depleted at the rate of about 39 million tons annually. At the present level of production, the United States has enough salt to mine for more than 1.6 million years. Solar evaporation of coastal seawater would extend this 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 seafloor of ancient landlocked marine bodies of water. Extensive and widespread evaporation was essential to form these massive rock salt deposits, some of which measure up to 3,000 feet in thickness.

Salt domes form when vertical or lateral pressures are applied to stratified salt deposits in which low-density salt will flow plastically through the surrounding rocks of higher density. The salt domes of Romania, the Federal Republic of Germany, and the gulf coast of the United States are examples of diapiric salt flows. The appearance is usually cylindrical with circular or elliptical diameters. A cap-rock of anhydrite is common with overlying layers of gypsum and calcite. Oil, gas, and sulfur are associated with many domes and represent large mineral resources. There are 329 proven salt domes in the gulf coastal province and offshore regions of the United States. Louisiana has 183 domes onshore and offshore; Texas, 83; Mississippi, 61; and Alabama, 2.

Playas are flat, vegetation-free floors of an undrained desert basin that may occasionally be covered by water. Postevaporation minerals such as sodium carbonate, sodium sulfate, sodium chloride, borates, nitrates, phosphates, and potash result from

the leaching of the rocks surrounding the basin by water flowing into the playa. Searles Lake in California is a classic example of a salt-bearing playa lake.

Salt in Solution.—Ocean, lake, and ground water are the primary aqueous mediums in which salt is dissolved. Seawater contains many dissolved minerals, the major one being sodium chloride. Other dissolved minerals include various sulfate, magnesium, calcium, and potassium compounds.

Water tends to accumulate on land in topographic depressions created by tectonic uplifts or subsidences of the Earth's upper crust. As mineralized solutions from upland sources drain into these basins, solar evaporation concentrates the salts to form saline lakes. The Aral Sea in the U.S.S.R., Great Salt Lake in Utah, and the Dead Sea between Jordan and Israel are examples of this process.

Ground water is composed of mineralized connate and meteoric water found in permeable sedimentary formations. In some areas, sodium chloride-rich brines migrate to the surface through intersecting fractures and joints in the rock strata to form local salt springs. These springs have attracted animals because they are a source of salt. The springs also indicate where buried salt deposits are located. The salt springs at Saltville, VA, are an example of a locality that was developed based on an occurrence of salt springs.

Technology

Exploration.—Exploring for new salt deposits is based on examination of various geochemical and geophysical information. Analysis of the underlying strata by core drilling, oil and water well logs, or other techniques is the basis for establishing the size of the deposit. Usually the most favorable areas for mine development will be located near the market regions and convenient transportation routes.

The development of mines incorporates strict safety precautions while permitting for the maximum economic recovery of salt. During shaft sinking, water-bearing strata may be encountered, and waterproofing techniques must be employed to prevent mine flooding. At least two access shafts are constructed in room-and-pillar mines to provide adequate safety and ventilation.

Mining.—**Rock Salt.**—Rock salt is mined by the room-and-pillar method, which is similar to that used in coal and trona mining. The salt is drilled, cut, blasted, mucked, crushed, and transported to the surface for processing, which usually involves removing the impurities and screening the material to finer size fractions.

Underground mining practices of bedded rock salt and domal salt formations are similar except for the height differences within the mines of the two types of operations. For example, bedded formations usually are laterally extensive but are vertically restricted. Salt domes are laterally restrictive but are vertically extensive. Many salt domes have depths in excess of 20,000 feet, yet many outcrop at the surface. Most gulf coast salt mining operations are generally less than 1,000 feet below the surface. Working at deeper depths is difficult because of higher temperatures and denser rock.

Solar Evaporation.—Solar evaporation is an effective method of producing solar salt in areas of high evaporation and low precipitation. Along coastal margins in many parts of the world, seawater is collected and allowed to evaporate in specially constructed evaporating ponds. Saline lakewater is also processed using this method. The ponds are separated by levees that isolate the brine during different stages of fractional crystallization.

The initial step concentrates the brine to increase the salinity and allow many calcium, magnesium, and iron compounds to precipitate from solution. The brine is circulated among a network of interconnecting ponds, with salinity increasing with each transfer. The brine is then treated with lime to remove excess calcium sulfate and then pumped to evaporation ponds and then transferred to harvesting ponds to permit the salt to crystallize. After about 85% of the salt is precipitated, the remaining supernatant liquid, called "bitterns," can be drained to adjacent ponds for subsequent extraction of magnesium, potassium, bromine, and sodium compounds. The harvesting pond is flooded again with new brine from the lime pond to repeat the cycle. It takes about 5 years once seawater is first introduced into the system for the completion of the crystallization process. The salt is harvested by special tractors equipped with scrapers and ready for processing.

Solution Mining.—The first reported use of solution mining was about 250 B.C. in China when holes were drilled into deep salt deposits. The brine was brought to the surface by pipes made of bamboo. The brine was evaporated over fires fueled with wood, coal, or natural gas. The basis of current technology began in France about A.D. 858. An injection well is sunk, and pressurized freshwater is introduced to hydraulically fracture the bedded salt. Once communication with the production well is established, the brine is pumped to the surface for treatment.

Roof collapse of the overlying strata and surface subsidence are potential problems associated with solution mining; however, producers have taken precautions to minimize these hazards. One method that was once used was injecting air with the water into the salt caverns. The air formed a protective cover between the water and the top of the cavity that reduced the amount of dissolution of the roof.

Processing.—**Rock Salt.**—About 64% of total rock salt produced and imported is for highway deicing. Crushing and screening to the proper physical size is usually the only processing that road salt undergoes. In many operations, these steps are done underground in the mine to minimize haulage and storage costs. In addition, the extremely fine fraction, which often is unusable, remains underground rather than on the surface, which would represent a waste product that would have to be disposed.

Solar Salt.—After harvesting, the salt crystals are washed with dilute brine to remove residual bitterns and impurities. The salt is transferred to processing facilities where it is washed with saline water, dried for about 8 minutes at approximately 300° F, and screened into fine to coarse sizes, depending on the end use of the salt to be sold. Most operations ship solar salt in bags and in bulk, using barges, truck, and rail transportation.

Mechanical Evaporation.—Salt obtained by dehydrating brine using heat alone or in combination with a vacuum is vacuum pan salt. The vacuum pan process conserves energy by utilizing multiple-effect evaporators connected to vacuum pumps. A saturated salt solution will boil at a higher temperature than pure water. When a vacuum is applied, the brine boils at a lower temperature, enabling the superheated vapor that is generated to act as the heating medium for the next evaporator.

The grainer or open pan process uses open, rectangular pans with steam-heated

immersion coils to evaporate the water in the brine. Rotating rakes scrape the salt precipitate into a sump or up a ramp, depending on the method, and onto conveyors for debrining and drying treatment. The final product is usually flake-shaped rather than the typical cubic form. Flake salt is preferred for production of cheese, butter, and baked goods.

The Alberger process is a modified grainer operation that produces cubic salt with some flake salt. The pans are shallow, circular units with external heating units, rather than heating coils. The open pan process cannot be operated successfully in regions with high humidities because the evaporation rate is too slow and more energy is required to evaporate the brine.

Desalination.—The conversion of saline water into freshwater has important municipal, industrial, and agricultural applications. Aside from obtaining pure water, desalination also produces byproduct salt. There are four processes presently employed in water desalination, and each has different cost and energy factors. The processes are distillation, membrane, freezing, and ion exchange. Some salt from these processes is used by the chemical industry. In some regions, salt is returned to the saline water source. Seawater typically contains 3.5% to 4.5% salt, or 35,000 to 45,000 parts per million. The standard for drinking water in the United States is 500 parts per million.

Byproducts and Coproducts

Salt is a coproduct from various seawater and saline lake operations. Depending on the cost of recovery and processing, certain magnesium, potassium, and bromine compounds can be produced from the bitterns. Subterranean brines also contain borax, calcium chloride, sodium carbonate, and sodium sulfate in addition to the above. Certain potash operations in the world also produce salt as a coproduct. When discharged to tailing ponds as a byproduct of potash mining, salt is often harvested and sold by second parties.

Economic Factors

Energy and labor costs are important factors that affect production costs, and ultimately the selling price, for all types of salt. After the salt is produced, shipping costs become very important when producers attempt to sell to a customer that is in proximity to other salt producers. Industry sources indicate that within the United States, a 300-mile radius is an effective limit of competition for a producing location before the influence of other competitors is noticed. Some of the major U.S. producers also have foreign subsidiaries that produce salt, which is imported at prices favorable to many consumers because transportation costs are less.

Capital investment and energy costs are important factors that influence the selling price of the type of salt produced. Vacuum pan and open pan processing requires more equipment and energy than solution mining, and, consequently, the average value of evaporated salt is considerably higher than that of salt in brine.

Prices.—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 1970. The data are compared with 1990 constant dollars to show the effect of inflation and general economic conditions on the values.

Tariffs.—The United States historically imports more salt than it exports. In 1990, U.S. salt imports were 2.6 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 has a 26% ad valorum tax imposed.

Operating Factors

Environmental Requirements.—The environmental problems associated with salt mining are few and tend to be localized without major impacts on the environment. A major concern in solution mining is the potential of land subsidence. As the salt is dissolved, some roof collapse may occur, causing sections of the surface to partially or totally fill the cavity. Subsidence is unpredictable, and once the process begins, it must be allowed to finish and reach equilibrium. Another issue pertaining to solution mining is the potential problem of well casing leakage. Any excursion of salt brine could affect ground water supplies, which are protected by various State and Federal water quality regulations. Solar evaporation facilities may substantially disturb coastal marsh areas because of the large extent of the lagoons needed for efficient operation.

Employment.—According to the Bureau of Labor Statistics, 1,659 people were employed in the mining and processing of rock salt in 1990. Of the 12 rock salt facilities surveyed, 854 personnel worked 1.75 million hours underground, 296 people worked 609,000 hours on surface duties, and 509 people worked 978,000 hours in the mills. 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 to the consumers' location, and transportation can become an important cost. Pumping salt brine through pipelines is an economic means of transportation but cannot be used for dry salt. Large bulk shipments of dry salt in ocean freighters or river barges are low in cost but are restricted in points of origin and consumption. River and lake movement of salt in winter is often severely curtailed because of frozen waterways. As salt is packaged, handled, and shipped in smaller units, the costs are increased and are reflected in higher selling prices.

Oceanborne imports of salt have been increasing in some areas of the United States because they are less expensive with respect to transportation costs than what could be purchased from many domestic suppliers using rail transportation. Salt continued to be one of the most heavily traded chemical industry ores in the world, representing about 66% of world seaborne mineral trade.

ANNUAL REVIEW

Issues

Nearly one-half of the domestic production of salt is for use as feedstock by the chloralkali industry to manufacture chlorine and coproduct caustic soda. This industry has undergone changes since 1988, when environmental concerns regarding emissions of chlorine-base compounds, such as those used in chlorofluorocarbons (CFC's) and in paper bleaching, reduced the demand of chlorine and thereby the availability of caustic soda. A decrease in chlorine production because of demand

TABLE 2

TIME-VALUE RELATIONSHIPS FOR VARIOUS TYPES OF SALT[1]

Year	Average annual value and 1990 constant dollars,[2] dollars per short ton							
	Salt in brine		Rock salt		Solar salt		Vacuum pan and open pan salt	
	Annual value	Based on constant 1990 dollars	Annual value	Based on constant 1990 dollars	Annual value	Based on constant 1990 dollars	Annual value	Based on constant 1990 dollars
1970	3.67	11.49	6.60	20.66	6.62	20.73	25.51	79.87
1971	3.57	10.57	6.41	18.98	11.02	32.64	26.28	77.83
1972	3.29	9.30	6.19	17.51	8.40	23.75	26.76	75.68
1973	3.57	9.48	6.19	16.44	8.99	23.88	29.65	78.77
1974	3.69	8.99	7.14	17.39	9.30	22.65	34.50	84.01
1975	3.91	8.67	8.94	19.82	14.21	31.51	43.01	95.38
1976	3.80	7.92	7.82	16.30	14.36	29.93	50.73	105.72
1977	3.91	7.64	8.94	17.47	14.21	27.77	52.01	101.62
1978	4.24	7.72	10.10	18.40	14.67	26.72	58.86	107.20
1979	4.51	7.55	10.00	16.73	12.16	20.34	61.64	103.13
1980	6.50	9.97	14.65	22.48	15.65	24.01	76.44	117.29
1981	5.91	8.27	13.76	19.25	18.35	25.67	79.68	111.47
1982	6.21	8.17	13.89	18.27	17.89	23.53	86.72	114.04
1983	5.22	6.61	13.43	17.00	21.47	27.17	87.39	110.60
1984	5.05	6.17	13.78	16.83	19.67	24.02	92.78	113.28
1985	6.14	7.28	15.15	17.96	23.10	27.39	92.66	109.87
1986	5.15	5.95	14.51	16.77	23.76	27.46	91.27	105.47
1987	4.93	5.52	14.34	16.06	25.40	28.45	94.21	105.52
1988	3.58	3.88	14.46	15.68	26.59	28.83	97.71	105.93
1989	5.67	5.90	16.38	17.05	27.88	29.03	92.73	96.55
1990	4.89	4.89	16.11	16.11	31.40	31.40	100.32	100.32

[1]Values are based on the average of all salt producers' valuations reported to the U.S. Bureau of Mines of the finished salt in bulk, compressed pellets, and packaged, f.o.b. plant, and includes all processing costs, depreciation of equipment, taxes, and profit.
[2]From final 1990 implicit price deflators for gross national product, by the Council of Economic Advisors. Based on 1982=100.

changes will have a corresponding effect on salt production. The pulp and paper industry, which consumes about 14% and 24% of the domestic chlorine and caustic soda production, respectively, has been under investigation for discharging harmful effluents into the environment. Dioxin investigations have been conducted since 1983, and 104 bleached pulp mills were investigated in April 1988 by the U.S. Environmental Protection Agency to determine the cumulative risk of a certain dioxin (2,3,7,8 tetrachlorodibenzo-p-dioxin or TCDD) and a furan (2,3,7,8 tetrachlorodibenzo furan or TCDF) released by the processes. Dioxins are toxic synthetic compounds that have been identified as carcinogenic to some animals, but studies investigating their effect on humans are controversial and inconclusive. Some pulp mills have begun converting from chlorine-base bleaching chemicals to environmentally safe oxygen-base chemicals, such as hydrogen peroxide and sodium chlorate. Although less chlorine would be made, more sodium chlorate, which also uses salt as feedstock, would be produced.

The environmental issues that affected chlorine have caused a tightness in the caustic soda market that resulted in higher caustic soda prices. Since 1986, when there were large inventories of caustic soda in the world, prices have risen fourfold as demand increased. Although certain uses for chlorine are expected to decrease during the next several years, one major sector, polyvinyl chloride (PVC), would have favorable growth potential if the domestic economy improves to assist the building and residential construction industry. PVC, which is the second most widely used plastic after low-density polyethylene, remained the main use for vinyl chloride, chlorine's primary market accounting for 24% of the end use. Although domestic demand for PVC pipe and fittings has been decreasing since 1988, which indicated a slowdown in domestic construction starts, exports of PVC have been strong. Demand for vinyl chloride is anticipated to grow by more than 4% per year through 1994, which should ease some of the tightness for caustic soda as more chlorine will be required. To alleviate some of the caustic soda shortages, three domestic natural soda ash producers are also engaged in producing caustic soda directly from trona, the ore of natural soda ash, or from soda ash directly. Production of caustic soda from soda ash was the preferred method of manufacture until it was replaced by the electrolysis of salt around the turn of the century.

Production

According to the U.S. Bureau of Mines survey for 1990, 31 companies operated 69 salt-producing plants in 14 States. Eight of the companies and 11 of the plants produced more than 1 million short tons each and accounted for 85% and 58%, respectively, of the U.S. total. Several companies and

plants produced more than one type of salt. In 1990, 12 companies (17 operations) produced solar-evaporated salt; 5 companies (17 operations), vacuum pan salt; 10 companies (14 operations), rock salt; and 17 companies (29 operations), salt brine.

The four leading States in terms of total salt sold or used were Louisiana, 35%; Texas, 20%; New York, 13%; and Kansas, 6%. Although Louisiana, New York, and Ohio were major rock salt-producing States, a substantial amount of salt was produced in Alabama, Kansas, Louisiana, New York, Ohio, Texas, Utah, and West Virginia as brine for the chemical industry.

Consolidations and name changes occurred in the U.S. salt industry during 1990. The formation of North American Salt Co., through the mergers of three moderate-sized salt companies, resulted in North American becoming the third largest domestic salt producer.[1] Carey Salt Holdings Ltd., a merger of the former American Salt Co. and Carey Salt Co., sought to acquire the Canadian assets of the Sifto Salt Div. of Domtar in 1989 as well as those of Domtar's Cote Blanche rock salt mine in Louisiana. On March 13, 1990, the U.S. Department of Justice determined that the acquisition of the Canadian operations was permissible but Carey Salt Holdings would have to divest itself of its Kansas rock salt operations because of possible antitrust violations before it would be allowed to acquire the Louisiana facility. The Canadian assets were acquired March 30, at which time Carey Salt Holdings merged with Domtar to become Carey Salt Co., a division of North American Salt. North American sold its two Kansas rock salt businesses to Hutchinson Salt Co. (formerly Carey Salt Co.'s rock salt mine) and to Lyons Salt Co. (formerly American Salt Co.'s rock salt mine) but retained the two vacuum pan facilities in Kansas and the solar salt plant at Grantsville, UT. North American was allowed to market the majority of the rock salt for the two Kansas rock salt companies. The Louisiana rock salt mine finally was purchased in November.

Hunter Environmental Services, Inc. of Southport, CT, obtained permits from the Texas Water Commission for developing a facility to process and dispose of hazardous waste into deep salt dome cavities. Using a mixture of portland cement and other additives, the waste would be formed into hard pellets and pneumatically pumped into the caverns of a 45,000-foot-deep salt dome. Final permits for the $70 million project were pending at yearend.[2]

TABLE 3

SALIENT SALT STATISTICS

(Thousand short tons and thousand dollars)

	1986	1987	1988	1989	1990
United States:					
Production[1]	37,282	36,943	39,170	39,278	40,558
Sold or used by producers[1]	36,663	36,493	38,940	38,856	40,693
Value	$665,400	$684,170	$699,323	$776,846	$826,659
Exports	1,165	541	884	1,567	2,498
Value	$16,928	$8,217	$10,858	$20,211	$32,944
Imports for consumption	6,665	5,716	5,474	6,084	6,580
Value	$79,709	$66,936	$77,357	$74,474	$88,419
Consumption, apparent[2]	42,163	41,668	43,530	43,373	44,775
World: Production	r192,612	r195,846	202,695	p209,949	e202,339

eEstimated. pPreliminary. rRevised.
[1]Excludes Puerto Rico.
[2]Sold or used plus imports minus exports.

TABLE 4

SALT PRODUCTION IN THE UNITED STATES

(Thousand short tons)

	Vacuum pans and open pans	Solar	Rock	Brine	Total[1]
1986	3,637	2,679	13,333	17,633	37,282
1987	3,776	3,120	12,230	17,817	36,943
1988	3,824	3,379	12,750	19,218	39,170
1989	3,975	3,140	13,979	18,184	39,278
1990	4,037	3,290	14,079	19,152	40,558

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

TABLE 5

SALT PRODUCED IN THE UNITED STATES, BY TYPE AND PRODUCT FORM

(Thousand short tons)

Product form	Vacuum pans and open pans	Solar	Rock	Brine	Total[1]
1989					
Bulk	850	2,136	13,292	18,184	34,462
Compressed pellets	1,146	164	XX	XX	1,310
Packaged	1,655	761	652	XX	3,068
Pressed blocks	324	82	33	XX	439
Total[1]	3,975	3,140	13,979	18,184	39,278
1990					
Bulk	718	2,259	13,392	19,152	35,521
Compressed pellets	1,118	276	XX	XX	1,394
Packaged	1,844	669	652	XX	3,165
Pressed blocks	357	86	35	XX	478
Total[1]	4,037	3,290	14,079	19,152	40,558

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

TABLE 6

SALT SOLD OR USED[1] IN THE UNITED STATES, BY TYPE AND PRODUCT FORM

(Thousand short tons and thousand dollars)

Product form	Vacuum pans and open pans		Solar		Rock		Brine		Total[2]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1989										
Bulk	837	36,321	1,822	26,929	13,261	192,143	18,198	103,244	34,118	358,637
Compressed pellets	1,142	119,355	148	10,539	NA	XX	XX	XX	1,290	129,894
Packaged:										
Less-than-5-pound units	123	NA	—	NA	75	NA	XX	XX	198	XX
More-than-5-pound units	1,543	NA	708	NA	569	NA	XX	XX	2,820	XX
Total[2]	1,666	182,323	708	37,217	644	35,695	XX	XX	3,018	255,235
Pressed blocks:										
For livestock	154	NA	60	NA	7	NA	XX	XX	221	XX
For water treatment	168	NA	16	NA	26	NA	XX	XX	210	XX
Total[2]	322	24,731	76	5,653	33	2,696	XX	XX	431	33,080
Grand total[2]	3,967	362,730	2,754	80,338	13,938	230,534	18,198	103,244	38,856	776,846
1990										
Bulk	717	32,480	1,827	29,319	13,672	205,030	19,537	94,996	35,753	361,825
Compressed pellets	1,116	124,362	246	19,737	NA	XX	XX	XX	1,362	144,099
Packaged:										
Less-than-5-pound units	249	NA	—	NA	84	NA	XX	XX	333	XX
More-than-5-pound units	1,592	NA	594	NA	599	NA	XX	XX	2,785	XX
Total[2]	1,841	211,739	594	35,229	683	36,201	XX	XX	3,118	283,169
Pressed blocks:										
For livestock	166	NA	55	NA	8	NA	XX	XX	229	XX
For water treatment	189	NA	14	NA	28	NA	XX	XX	231	XX
Total[2]	355	28,452	69	6,104	36	3,009	XX	XX	460	37,565
Grand total[2]	4,029	397,033	2,736	90,389	14,391	244,240	19,537	94,996	40,693	826,659

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 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.

The United States continued to be the world's largest producer of salt, accounting for about 21% of total world production. Production and trade of salt increased slightly compared with those of the previous year. World production of all types of salt decreased slightly. The depressed market for chlorine and the 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

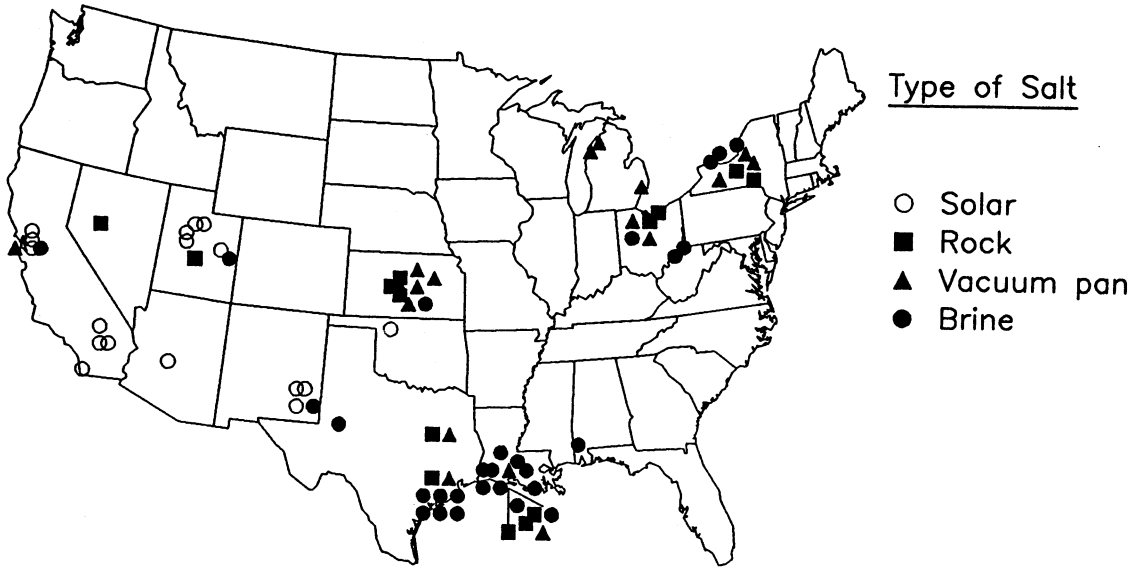
More than 45.1 million tons of domestic and imported salt was consumed in the United States in 1990, based on the annual survey of the U.S. salt producers. The reported percent distribution of salt by major end use was chemicals, 47%; ice control, 25%; distributors, 10%; food and agricultural, 7%; industrial, 5%; primary water treatment, 1%; and other, combined with exports, 5%. Distributors represent a substantial share of salt sales by the salt industry; however, all the salt ultimately is resold to many end users. Some customers have specific uses. For a more complete analysis of end-use markets, specific sectors of distribution in table 9 can be combined, such as agricultural and water conditioning with agricultural and water conditioning distribution, respectively. On an annual per capita basis, the average citizen consumes about 360 pounds, based on an estimated U.S. population of 250 million and total reported consumption data in table 9. This total includes the amount of salt used by everyone in the above categories. Using the data for the food processing and three-fourths of the grocery wholesalers sectors from table 9, the quantity of salt used for direct human consumption is about 16.6 pounds per person per year.

The chemical industry is the largest consumer of salt, primarily salt brine. Although most salt brine is captively produced by chemical producers, many chlor-alkali manufacturers 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-base 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%.

Using Bureau of the Census data, the chlorine and caustic soda industry consumed about 19.1 million tons of salt for feedstock, based on the industry average ratio of 1.75 tons of salt required to produce 1.0 ton of chlorine and 1.1 tons of coproduct sodium hydroxide. Reported consumption of total domestic and imported salt for chlorine manufacture was 19.2 million tons,

FIGURE 1

U.S. SALT PRODUCTION LOCATIONS IN 1990



as noted in table 9. The difference between the calculated and reported quantities was the amount of salt unreported to the U.S. Bureau of Mines from imports or captive brine production of chlor-alkali producers. Production of chlorine gas and liquid sodium hydroxide, as reported by the Bureau of the Census and The Chlorine Institute, is shown in table 11.

Table 12 lists the domestic chlorine-producing facilities that used only salt as feedstock. Based on these estimates and using Bureau of the Census chlorine production data, the U.S. salt-base chlorine industry operated at 88% of capacity. According to The Chlorine Institute, the industry operated at an average of 89% of nominal capacity and 95% of effective capacity in 1990. Because these capacities include chlorine produced from nonsalt sources, i.e., from the electrolysis of magnesium chloride and the oxidation of hy-

TABLE 7

SALT SOLD OR USED[1] BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1989		1990	
	Quantity	Value	Quantity	Value
Kansas[2]	r1,948	r82,212	2,390	92,119
Louisiana	13,218	r115,203	14,348	120,827
New York	5,424	161,427	5,401	162,900
Texas	7,856	69,935	8,212	75,149
Utah	1,183	r40,421	1,171	50,436
Other Eastern States[3]	6,835	248,960	6,815	266,312
Other Western States[4]	2,391	58,690	2,356	58,916
Total[5]	38,856	776,846	40,693	826,659
Puerto Rico[e]	45	1,250	45	1,500

[e]Estimated. [r]Revised.

[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 8

DISTRIBUTION OF DOMESTIC AND IMPORTED[1] SALT BY PRODUCERS IN THE UNITED STATES, BY END USE AND TYPE

(Thousand short tons)

End use	Standard industrial classification	Vacuum pans and open pans		Solar		Rock		Salt in brine		Grand total[2]	
		1989	1990	1989	1990	1989	1990	1989	1990	1989	1990
Chemical:											
Chloralkali producers	2812	51	58	399	402	1,464	1,264	16,865	17,458	18,780	19,182
Other chemical	28 (excludes 2812, 2899)	735	755	163	158	246	250	33	883	1,177	2,046
Total[2]		786	813	562	560	1,710	1,514	16,897	18,341	19,957	21,228
Food-processing industry:											
Meat packers	201	197	207	61	99	175	292	1	(3)	434	598
Dairy	202	133	130	5	6	4	4	—	—	141	140
Canning	2091, 203	144	157	56	68	89	91	1	2	290	318
Baking	205	146	144	11	16	12	11	—	—	168	171
Grain mill products	204 (excludes 2047)	77	85	(3)	1	11	11	—	—	88	97
Other food processing	206-208, 2047, 2099	184	199	51	48	48	51	—	(3)	283	298
Total[2]		877	922	184	238	339	460	2	2	1,404	1,622
General industrial:											
Textiles and dyeing	22	148	144	52	55	28	23	4	4	233	227
Metal processing	33, 34, 35, 37	12	14	35	34	352	298	(3)	(3)	400	346
Rubber	2822,30 (excludes 3079)	2	3	4	8	3	2	26	32	34	45
Oil	13, 29	34	42	303	321	81	120	302	310	720	793
Pulp and paper	26	28	22	269	191	68	63	7	7	373	283
Tanning and/or leather	311	14	9	37	50	66	50	—	—	116	109
Other industrial	9621	114	113	76	79	87	91	3	5	279	288
Total[2]		352	347	776	738	685	647	342	359	2,155	2,091
Agricultural:											
Feed retailers and/or dealers-mixers	434	320	317	217	242	357	542	(3)	(3)	893	1,101
Feed manufacturers	2048	57	74	104	127	240	345	—	—	400	546
Direct-buying end user	02	17	17	13	23	18	15	—	—	48	55
Total[2]		394	407	334	391	615	903	(3)	(3)	1,341	1,701
Water treatment:											
Government (Federal, State, local)	2899	28	28	70	71	228	194	2	4	329	297
Commercial or other	2899	16	13	116	139	49	40	8	7	188	198
Total[2]		44	41	186	210	277	234	11	11	518	495
Ice control and/or stabilization:											
Government (Federal, State, local)	9621	5	4	225	332	10,700	10,420	1	1	10,930	10,757
Commercial or other	5159	6	6	66	32	446	507	12	—	531	545
Total[2]		11	10	291	364	11,146	10,927	13	1	11,461	11,302
Distributors:											
Agricultural distribution	5159	259	268	169	142	155	209	(3)	(3)	584	619
Grocery wholesalers and/or retailers	514, 54	611	590	230	196	129	108	—	—	970	894
Institutional wholesalers and end users	58, 70	26	34	26	29	28	33	(3)	(3)	82	96
Water-conditioning distribution	7399	275	286	465	635	227	199	4	3	970	1,123
U.S. Government resale	9199	6	6	2	2	1	1	—	—	9	9
Other wholesalers and/or retailers	5251	761	764	288	352	744	732	(3)	3	1,793	1,851
Total[2]		1,938	1,948	1,180	1,356	1,284	1,282	4	6	4,408	4,592
Other n.e.s.[4]		122	162	230	256	1,247	1,186	967	426	2,566	2,030
Grand total[2]		4,524	4,650	3,743	4,113	17,303	17,153	18,236	19,146	43,810	45,061

[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 16, 17, and 18.

[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 3, 6, 7, and 8, which are derived from plant reports at salt production locations. Data may differ from totals shown in table 10 because of changes in inventory and/or incomplete data reporting.

[3]Less than 1/2 unit.

[4]Includes exports.

TABLE 9

EVAPORATED SALT SOLD OR USED[1] BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1989		1990	
	Quantity	Value	Quantity	Value
Kansas	r1,092	r74,040	1,042	79,001
Louisiana	214	20,582	211	22,187
New York	783	65,173	808	74,861
Utah	1,171	r38,065	1,093	47,928
Other[2]	r3,459	r245,208	3,607	263,348
Total[3]	r6,719	r443,068	6,764	487,423
Puerto Rico[e]	45	1,250	45	1,500

[e]Estimated. [r]Revised.
[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]Includes Arizona, California, Michigan, New Mexico, North Dakota, Ohio, Oklahoma, and Texas.
[3]Data may not add to totals shown because of independent rounding.

drochloric acid, these data may differ from other reported chlorine capacity utilization information.

Stocks

Total yearend stocks reported by producers were 1.9 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 U.S. Bureau of Mines. The quotations do not necessarily represent prices at which transactions

TABLE 10

DISTRIBUTION OF DOMESTIC AND IMPORTED EVAPORATED AND ROCK SALT[1] IN THE UNITED STATES, BY DESTINATION

(Thousand short tons)

Destination	1989				1990			
	Evaporated		Rock	Total	Evaporated		Rock	Total
	Vacuum pans and open pans	Solar			Vacuum pans and open pans	Solar		
Alabama	57	(2)	355	412	59	(2)	288	347
Alaska	1	W	(2)	1	1	W	(2)	1
Arizona	9	72	13	94	8	92	28	128
Arkansas	36	W	97	133	39	W	65	104
California	169	981	W	1,150	172	959	W	1,131
Colorado	20	91	81	192	19	123	143	285
Connecticut	11	9	165	185	10	12	243	265
Delaware	2	17	6	25	3	33	11	47
District of Columbia	1	5	W	6	1	8	W	9
Florida	101	64	31	196	95	87	21	203
Georgia	233	35	83	351	258	44	84	386
Hawaii	18	3	—	21	20	4	—	24
Idaho	8	60	W	68	8	88	W	96
Illinois	391	82	1,464	1,937	386	139	1,491	2,016
Indiana	176	48	792	1,016	195	55	660	910
Iowa	172	46	305	523	179	70	481	730
Kansas	98	6	394	498	102	10	687	799
Kentucky	52	W	393	445	56	W	365	421
Louisiana	52	W	344	396	54	W	602	656
Maine	132	3	248	383	116	15	248	379
Maryland	63	101	295	459	65	107	174	346
Massachusetts	38	6	323	367	38	8	482	528
Michigan	246	25	1,355	1,626	250	25	1,611	1,886
Minnesota	157	118	548	823	148	168	518	834
Mississippi	28	(2)	143	171	26	(2)	144	170
Missouri	127	17	360	504	139	30	623	792
Montana	1	31	W	32	1	43	W	44

See footnotes at end of table.

TABLE 10—Continued

DISTRIBUTION OF DOMESTIC AND IMPORTED EVAPORATED AND ROCK SALT[1] IN THE UNITED STATES, BY DESTINATION

(Thousand short tons)

Destination	1989				1990			
	Evaporated				Evaporated			
	Vacuum pans and open pans	Solar	Rock	Total	Vacuum pans and open pans	Solar	Rock	Total
Nebraska	91	22	147	260	90	31	251	372
Nevada	1	222	W	223	1	237	W	238
New Hampshire	3	3	136	142	3	4	101	108
New Jersey	122	121	299	542	123	97	268	488
New Mexico	6	97	1	104	6	114	1	121
New York	249	61	2,345	2,655	251	64	2,284	2,599
North Carolina	263	105	51	419	262	94	41	397
North Dakota	20	15	4	39	21	23	8	52
Ohio	347	28	1,778	2,153	377	24	1,419	1,820
Oklahoma	42	W	72	114	42	W	141	56
Oregon	13	46	(2)	59	15	53	(2)	68
Pennsylvania	192	185	1,258	1,635	193	123	38	1,054
Rhode Island	6	2	68	76	5	4	89	98
South Carolina	50	9	11	70	46	12	9	67
South Dakota	36	25	41	102	39	52	52	143
Tennessee	75	1	632	708	73	1	497	571
Texas	178	120	219	517	180	142	293	615
Utah	4	259	W	263	7	270	W	277
Vermont	6	W	265	271	6	W	188	194
Virginia	82	60	212	354	81	69	161	311
Washington	18	230	(2)	248	18	230	(2)	248
West Virginia	12	W	157	169	13	W	146	159
Wisconsin	227	65	919	1,211	236	110	899	1,245
Wyoming	(2)	23	1	24	(2)	39	(2)	39
Other[3]	83	139	536	758	115	200	625	940
Total[4]	4,525	3,658	16,947	25,130	4,651	4,113	17,153	25,917

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]Less than 1/2 unit.

[3]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.

[4]Data may not add to totals shown because of independent rounding. 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 3, 6, 7, and 8, which are derived from plant reports at salt production locations. Data may differ from totals shown in table 9 because of changes in inventory and/or incomplete data reporting.

TABLE 11

CHLORINE AND SODIUM HYDROXIDE PRODUCTION IN THE UNITED STATES

(Thousand short tons)

	Bureau of the Census		The Chlorine Institute	
	Chlorine gas, 100%	Sodium hydroxide liquid, 100%	Chlorine gas, 100%	Sodium hydroxide liquid, 100%
1985	10,402,060	10,810,509	10,394,659	10,893,294
1986	10,426,072	11,055,060	10,488,664	11,006,709
1987	11,078,189	11,552,686	11,068,581	11,649,078
1988	11,257,478	10,533,288	11,597,282	12,261,834
1989	11,412,592	10,491,951	11,908,810	12,506,814
1990	10,942,857	11,688,182	11,846,882	12,459,157

Sources: Bureau of the Census and The Chlorine Institute.

TABLE 12

U.S. CHLORINE FACILITIES THAT REQUIRE SALT[1]

(Thousand short tons)

Company	Location	Annual chlorine production capacity[2]	Salt requirements[3]	Source of salt requirements
Akzo Chemicals, Inc.	Lemoyne, AL	74	129	Purchased.
Atochem North America[4]	Portland, OR	150	263	Imported.
Do.	Tacoma, WA	91	159	Do.
Brunswick Pulp and Paper Co.	Brunswick, GA	36	63	Do.
Dow Chemical USA	Freeport, TX[5]	2,856	4,998	Captive brine.
Do.	Plaquemine, LA	997	1,745	Do.
E.I. du Pont de Nemours & Co. Inc.	Niagara Falls, NY	84	147	Purchased.
Formosa Plastics Corp., USA	Baton Rouge, LA	2,003	50	Purchased brine.
Fort Howard Corp.	Green Bay, WI	9	16	Imported.
Do.	Muskogee, OK	9	16	Purchased.
General Electric Co.	Burkville, AL	27	47	Do.
Do.	Mt. Vernon, IN	70	123	Do.
Georgia Gulf Corp.	Plaquemine, LA	452	791	Purchased brine.
Georgia Pacific Corp.	Bellingham, WA	91	159	Purchased.
BF Goodrich Group	Calvert City, KY	128	224	Do.
LaRoche Chemicals	Gramercy, LA	219	383	Captive brine.
Hanlin Group[6]	Acme, NC	53	93	Imported.
Do.	Brunswick, GA	108	189	Do.
Do.	Moundsville, WV	91	159	Captive brine.
Do.	Orrington, ME	80	140	Imported.
Niachlor (Du Pont-Olin)	Niagara Falls, NY	240	420	Purchased brine.
Occidental Chemical Corp.	Convent, LA	296	518	Do.
Do.	Corpus Christi, TX	460	805	Do.
Do.	Deer Park, TX	383	670	Do.
Do.	Delaware City, DE	139	243	Imported.
Do.	LaPorte, TX	515	901	Purchased brine.
Do.	Muscle Shoals, AL	146	255	Purchased.
Do.	Niagara Falls, NY	350	613	Purchased brine.
Do.	Tacoma, WA	237	415	Imported.
Do.	Taft, LA	611	1,069	Purchased brine.
Olin Corp.	Augusta, GA	115	201	Purchased.
Do.	Charleston, TN	256	448	Do.
Do.	McIntosh, AL	365	639	Captive brine.
Pioneer Chlor-Alkali Co. Inc.	Henderson, NV	119	208	Do.
Do.	St. Gabriel, LA	173	303	Do.
PPG Industries, Inc.	Lake Charles, LA	1,150	2,012	Captive and purchased brine.
Do.	Natrium, WV	280	490	Captive brine.
RMI Co.	Ashtabula, OH	37	65	Do.
Vulcan Materials Co.	Geismar, LA	246	431	Purchased brine.
Do.	Port Edwards, WI	73	128	Imported.
Do.	Wichita, KS	273	478	Captive brine.
Weyerhaeuser Co.	Longview, WA	130	228	Imported.
Total		12,419	21,734	

[1]Includes only those chlorine plants that use salt directly as a feedstock. Does not include plants that produce byproduct chlorine from magnesium chloride and hydrochloric acid oxidation or plants using potassium chloride.
[2]Based on 365 days per year.
[3]Based on 1.75 tons of salt required to manufacture 1.0 ton of chlorine with the plant operating at 100% capacity. Salt may be from natural brines, rock, or solar sources, domestic or imported.
[4]Formerly Pennwalt Corp.
[5]An additional 730,000 tons available on standby basis; included in "Total."
[6]Includes LCP Chemicals and Hanlin Chemicals-West Virginia Inc.

NOTE.—The following plants closed in 1990: Dow at Pittsburg, CA; Olin at Niagara Falls, NY.

actually occurred, nor do they represent bid and asked prices. They are quoted here to serve only as a reference to yearend price levels. Yearend prices were quoted in Chemical Marketing Reporter, as shown in table 13.

TABLE 13

SALT YEAREND PRICES

	1989	1990
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. 237, No. 1, Jan. 1, 1990, p. 39; and v. 238, No. 27, Dec. 31, 1990, p. 31.

Foreign Trade

Section 1205 of the Omnibus Trade and Competitiveness Act of 1988 required the United States to adopt an international nomenclature and metric units for reporting trade information. On January 1, 1989, the Harmonized Commodity Description and Coding System (HTS) replaced the Tariff Schedule of the United States, Annotated, for import data and schedule B for exports. Previously, salt imports had three different categories—bulk, other (formerly known as bags, sacks, and barrels), and salt in brine. Exports had one classification, sodium chloride-salt. Under the new HTS 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.

The United States imported in 1990 more than 2.5 times 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 Akzo Salt Co., American Salt Co., Carey Salt Co., Cargill Inc., Domtar Industries Inc., Morton International, and North American Salt Co. imported 52% of the total imports of 5.64 million tons. Five companies that manufacture chlorine, which was the single largest domestic salt market, consumed 26% 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 chlor-alkali producers imported 78% of total imports; the remainder was to many small direct buyers. Eleven domestic salt-producing companies exported 79% of the 704,909 tons exported in 1990, according to PIERS. The Journal of Commerce data contain only ocean commerce and no rail or truck trade between Canada and Mexico. These data may differ from total data reported by the Bureau of the Census. Tables 15 through 18 list the import and export statistics reported by the Bureau of the Census for 1989 and 1990.

TABLE 14

AVERAGE VALUES[1] OF SALT, BY PRODUCT FORM AND TYPE

(Dollars per short ton)

Product form	Vacuum pans and open pans	Solar	Rock	Brine
1989				
Bulk	43.39	14.78	14.49	5.67
Compressed pellets	104.51	71.21	XX	XX
Packaged	109.44	52.57	55.42	XX
Average[2]	92.73	27.88	16.38	5.67
Pressed blocks	76.80	74.38	81.69	XX
1990				
Bulk	45.30	15.88	14.99	4.89
Compressed pellets	111.44	80.23	XX	XX
Packaged	115.01	59.31	53.00	XX
Average[2]	100.32	31.40	16.11	4.89
Pressed blocks	80.15	88.46	83.58	XX

XX Not applicable.

[1]Net selling value, f.o.b. plant, excluding container costs.

[2]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 6.

World Review

Table 19 lists world salt production statistics for 97 countries based on reported and estimated information. World production decreased 4% in 1990 compared with that of the previous year. Since 1971, world salt production has increased more than 27%, whereas world population has risen 44%, from 3.63 billion to 5.3 billion individuals. Based on these statistics, the world annual per capita consumption has decreased from 88 pounds to 76 pounds.

Industry Structure.—The United States remains the world's leading salt-producing nation, representing about one-fifth of total world production. The structure of the U.S. industry has changed throughout the years. In 1970, there were 50 companies operating 95 plants in the United States. Market competition, energy and labor costs, less expensive imports, and an excess of production capacity reduced the size of the industry to 31 companies and 69 plants by 1990.

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. The data shown in tables 12 and 20 are rated capacities for mines and refineries and salt requirements for salt-base chlorine facilities as of December 31, 1990. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Capacity data were derived from industry sources, published reports, and estimates based on production trends.

Rock.—Because the majority of rock salt was used for deicing, the operating rate of rock salt facilities fluctuated with the demand for deicing salt, again dependent on the severity of winter weather conditions. During periods of strong demand, production levels often achieve, or exceed in certain situations, the rated capacities. Full mine capacity generally is a function of the

TABLE 15

U.S. EXPORTS OF SALT, BY COUNTRY[1]

(Thousand short tons and thousand dollars)

Country	1989		1990	
	Quantity	Value	Quantity	Value
Argentina	—	—	(2)	6
Australia	13	182	1	154
Bahamas	6	262	2	172
Bahrain	10	158	1	143
Belize	1	20	(2)	8
Bolivia	10	115	20	197
Brazil	(2)	8	(2)	8
Canada	1,367	14,465	2,301	25,980
Chile	1	6	(2)	3
Costa Rica	(2)	11	—	—
Dominican Republic	3	152	1	73
El Salvador	3	160	1	352
France	3	61	(2)	120
Germany, Federal Republic of	7	68	3	34
Honduras	(2)	4	(2)	8
Hong Kong	—	—	2	256
Ireland	—	—	4	40
Japan	8	184	2	81
Korea, Republic of	—	—	2	18
Mexico	66	1,178	101	2,090
Netherlands Antilles	1	64	1	121
Panama	5	72	(2)	29
Saudi Arabia	43	2,072	25	1,535
Sudan	—	—	9	290
Taiwan	1	19	2	62
Trinidad	(2)	13	(2)	3
United Arab Emirates	3	102	1	79
United Kingdom	4	331	1	176
Venezuela	1	25	1	52
Other	11	479	17	854
Total	1,567	20,211	2,498	32,944

[1]Before 1989, the Schedule B export code no. was 4209500. In 1989, it was changed to HTS code No. 2501000000.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 16

U.S. IMPORTS FOR CONSUMPTION OF SALT

(Thousand short tons and thousand dollars)

	Salt in brine[1]		In bags, sacks, barrels, or other packages		Bulk	
	Quantity	Value	Quantity	Value	Quantity	Value
1986	(2)	34	70	3,170	6,595	76,505
1987	1	67	44	5,122	[3]5,671	61,747
1988	2	125	78	6,682	5,394	70,550
1989	(4)	(4)	(4)	(4)	6,084	74,474
1990	(4)	(4)	(4)	(4)	6,580	88,419

[1]Anhydrous salt content.
[2]Less than 1/2 unit.
[3]Data were adjusted to correct for erroneous notation of shipment from Italy in August.
[4]Included in bulk because categories were merged under HTS code No. 2501000000 in 1989. Before 1989, salt imports were listed under TSUS code Nos. 4209200 for salt in brine, 4209400 for bulk salt, and 4209600 for other salt.

Source: Bureau of the Census.

hoisting capabilities of the mines. Assuming that the workweek is 5 days (250 workdays per year), two working shifts and one maintenance shift per day, and at least one short-term planned turnaround for the mine and mill per year, table 20 lists the production capacities for domestic rock salt operations.

Solar.—Solar salt, also known as marine and sea salt, is obtained from the solar evaporation of seawater, of landlocked bodies of saline water, and of discharged brines. Because evaporation rates must exceed the precipitation rates, the climatic conditions and geographic locations of solar evaporation facilities are critical to the successful production and harvesting of solar salt. Therefore, rated capacities generally are based on the historical evaporation patterns within a region and vary depending on the location and the surface areas of the evaporation ponds. Only unpredictable seasonal precipitation and market conditions usually affect the production.

Vacuum Pan.—The mechanical evaporation of salt by the vacuum pan process is dependent on the number and size of the vacuum crystallizers operating in series. Rated capacities are usually easier to establish because of the proven design performance of the equipment.

Brine.—Brine capacities are difficult to derive because they are based on the variabilities of the injection rate of the solvent and the solubility rates of the underground salt bodies. Both determine the quantity of brine produced. In addition, production levels are dependent on the demand for the products that the brine is being used to manufacture. Therefore, individual company brine capacities are not included in table 20.

Table 12 lists the quantity, type, and source of the salt required to manufacture chlorine. The amount of brine purchased or used captively is close to the quantity of brine used for chlor-alkali production as noted in table 9.

Australia.—Dampier Salt Co. announced plans to increase solar salt production capacity by 500,000 tons at its Dampier, Western Australia, facility by 1992. The $23 million project will raise total company capacity to 4.5 million tons, which includes 1.5 million tons of solar salt capacity at Lake MacLeod. The project has the potential of raising total capacity to 7 million tons in the future if necessary.[3]

TABLE 17

U.S. IMPORTS FOR CONSUMPTION OF SALT, BY COUNTRY[1]

(Thousand short tons and thousand dollars)

Country	1989		1990	
	Quantity	Value	Quantity	Value
Bahamas	607	7,405	874	9,757
Canada	2,260	29,501	2,102	31,581
Chile	335	3,320	847	6,411
France	243	579	214	422
Germany, Federal Republic of:				
Western states	90	927	24	31
Eastern states	107	343	31	75
Ireland	34	246	38	436
Italy	39	424	103	1,039
Korea, Republic of	25	180	51	212
Mexico	1,502	17,227	1,569	20,146
Netherlands	459	10,233	441	12,545
Netherlands Antilles	122	1,817	179	2,795
Spain	28	102	13	74
Tunisia	60	462	—	—
United Kingdom	126	1,272	58	1,452
Other	47	436	36	543
Total	6,084	74,474	6,580	88,419

[1]Before 1989, salt imports were listed under TSUS code Nos. 4209200 for salt in brine, 4209400 for bulk salt, and 4209600 for other salt. In 1989, it was changed to HTS code No. 2501000000.

Source: Bureau of the Census.

TABLE 18

U.S. IMPORTS FOR CONSUMPTION OF SALT, BY CUSTOMS DISTRICT[1]

(Thousand short tons and thousand dollars)

Customs district	1989		1990	
	Quantity	Value	Quantity	Value
Anchorage, AK	12	475	17	391
Baltimore, MD	304	3,418	534	6,461
Boston, MA	202	2,271	245	3,159
Buffalo, NY	32	837	37	1,179
Chicago, IL	453	6,160	88	1,507
Charleston, SC	122	2,428	71	1,841
Cleveland, OH	85	938	77	1,548
Dallas-Fort Worth, TX	(2)	299	(2)	942
Detroit, MI	769	10,625	820	11,725
Duluth, MN	97	1,120	126	1,754
Great Falls, MT	(2)	19	(2)	18
Houston, TX	(2)	24	—	—
Laredo, TX	(2)	49	(2)	8
Los Angeles, CA	97	2,050	67	1,215
Miami, FL	(2)	92	(2)	38
Milwaukee, WI	540	6,909	579	8,948
Minneapolis, MN	(2)	6	60	792
New Orleans, LA	157	1,756	168	2,703

See footnotes at end of table.

TABLE 18 —Continued

U.S. IMPORTS FOR CONSUMPTION OF SALT, BY CUSTOMS DISTRICT[1]

(Thousand short tons and thousand dollars)

Customs district	1989		1990	
	Quantity	Value	Quantity	Value
New York, NY	586	4,609	672	5,251
Nogales, AZ	1	31	1	22
Norfolk, VA	127	1,468	203	1,813
Ogdensburg, NY	73	668	63	712
Pembina, ND	(2)	15	14	322
Philadelphia, PA	263	2,657	354	4,090
Portland, ME	368	4,459	610	7,180
Portland, OR	449	4,216	464	4,421
Providence, RI	63	416	143	1,570
St. Albans, VT	1	63	(2)	8
St. Louis, MO	40	219	(2)	2
San Diego, CA	(2)	72	(2)	35
San Francisco, CA	44	378	(2)	8
San Juan, PR	16	368	21	327
Savannah, GA	309	5,505	340	6,842
Seattle, WA	585	6,425	477	5,970
Tampa, FL	123	1,051	173	2,170
Wilmington, NC	165	2,378	157	3,447
Total[3]	6,084	74,474	6,580	88,419

[1]Before 1989, salt imports were listed under TSUS code Nos. 4209200 for salt in brine, 4209400 for bulk salt, and 4209600 for other salt. In 1989, it was changed to HTS code No. 2501000000.
[2]Less than 1/2 unit.
[3]Data may not add to totals shown because of independent rounding.
Source: Bureau of the Census.

Gulf Holdings Pty. Ltd. proposed the construction of an $80 million 1.5-million-ton-per-year solar salt operation southeast of Onslow. Production was scheduled for late 1992.[4]

Botswana.—Soda Ash Botswana, which is a joint venture between the Botswanan Government (47%) and a consortium of African Explosives and Chemical Industries (26.5%), Anglo American (13.25%), and De Beers Holdings (13.25%), finished construction of its salt and natural soda ash facility at Sua Pan in the Makgadikgadi Basin. About 650,000 tons of salt and 300,000 tons of soda ash will be produced annually, with the majority of the commodities being sold to the Republic of South Africa.[5]

Canada.—North American Salt Co. through Carey Salt Holdings, Inc., acquired the assets, on March 30, 1990, of Domtar Inc.'s Sifto Salt Div., which had salt operations in Goderich, Ontario; Nappan, Nova Scotia; and Unity and Patience Lake, Saskatchewan. As part of a consent agreement, the U.S. Department of Justice excluded Domtar's Cote Blanche rock salt mine near Baldwin, LA, from the transaction until North American relinquished its holdings in two Kansas rock salt mines. The Canadian facilities will operate as North American's Canadian subsidiary known as

FIGURE 2

PERCENT OF SALT IMPORTED THROUGH U.S. CUSTOMS DISTRICTS IN 1990

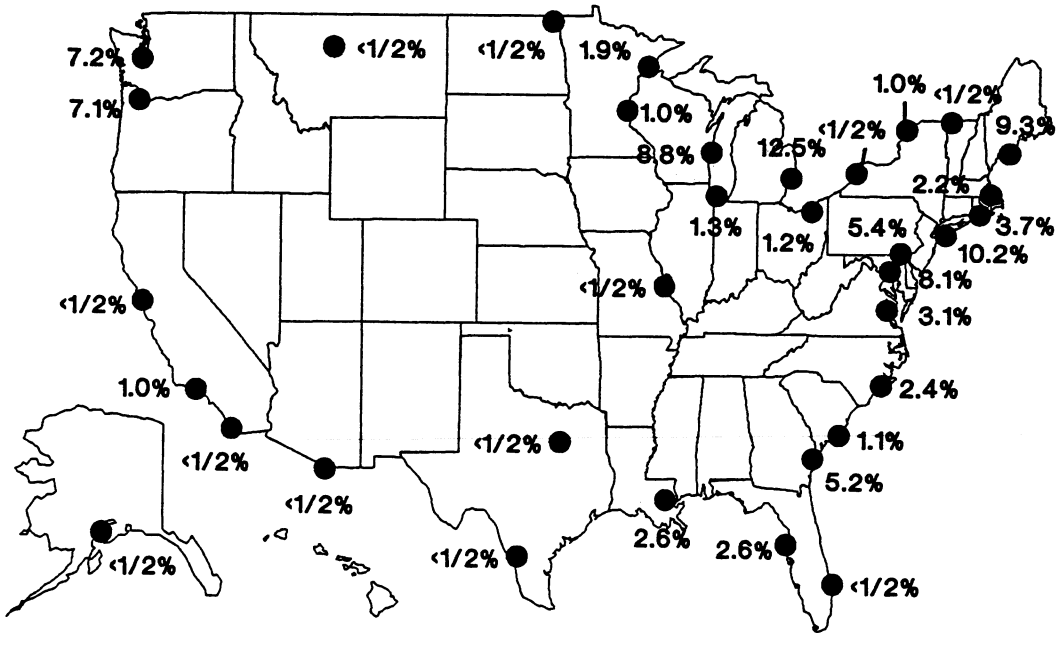


TABLE 19

SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Afghanistan[e]	11	11	39	39	39
Albania[e]	82	83	80	80	80
Algeria	209	[r]257	[re]260	[re]265	265
Angola[e]	61	66	77	77	77
Argentina:					
Rock salt[e]	[3]1	1	1	1	1
Other salt	1,342	1,048	1,373	1,306	1,325
Australia (marine salt and brine salt)	6,758	7,150	7,898	[e]8,100	8,200
Austria:					
Rock salt	2	2	1	1	1
Evaporated salt	536	534	455	437	440
Other salt	237	198	282	277	275
Bahamas	991	811	679	946	[3]828
Bangladesh[4]	[e]550	459	451	457	450
Benine	([5])	([5])	([5])	([5])	([5])
Brazil:					
Rock salt	661	1,047	1,473	1,431	1,430
Marine salt	1,764	3,968	3,329	2,596	2,850
Bulgaria	100	101	114	85	75
Burkina Faso[e]	7	7	7	7	7
Burma[6]	271	[r]283	271	289	290
Cambodia[e]	45	45	45	45	45
Canada	11,389	11,165	11,781	12,188	[3]12,232
Chile	1,138	954	1,149	996	[3]2,022
China[e]	19,070	19,800	24,250	30,850	22,050
Colombia:					
Rock salt	250	226	230	209	220
Marine salt	552	496	521	518	525
Costa Rica (marine salt)	[e]33	14	30	33	33
Cuba	293	255	221	227	220
Cyprus	7	—	—	—	—
Czechoslovakia	373	[r]373	386	379	375
Denmark	622	585	714	[e]717	717
Dominican Republic	[e]60	[e]61	41	33	33
Egypt	[e]1,400	1,115	1,017	1,281	1,100
El Salvador	3	3	3	[e]3	3
Ethiopia:[e 4]					
Rock salt	17	17	17	11	11
Marine salt	130	130	130	110	110
France:					
Rock salt	425	1,627	1,262	1,047	1,100
Brine salt[e]	[3]1,240	1,180	1,200	1,200	1,200
Marine salt[e]	[3]1,775	1,795	1,820	1,930	1,930
Salt in solution[e]	[3]4,368	4,040	4,050	4,080	4,080
Germany, Federal Republic of:					
Eastern states:					
Rock salt[e]	3,390	3,390	3,300	3,300	2,760
Marine salt	65	65	66	[re]66	60
Western states: Marketable:					
Rock salt and other	13,777	14,178	13,117	[e]13,780	13,200
Marine salt	666	666	603	[e]660	610

See footnotes at end of table.

TABLE 19—Continued

SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Ghana[e]	55	55	55	55	55
Greece[e]	r165	r165	r165	r165	160
Guatemala	43	41	46	70	66
Honduras[e]	35	35	35	35	35
Iceland[e]	2	2	2	2	2
India:					
Rock salt[e]	2	2	4	r3	3
Marine salt	11,151	10,913	e10,141	re10,580	10,470
Indonesia[e]	660	660	660	660	660
Iran[7]	783	898	1,091	re1,100	1,100
Iraq[e]	80	80	80	110	55
Israel[e]	170	170	170	170	170
Italy:					
Rock salt and brine salt	3,784	4,072	3,978	3,859	3,750
Marine salt[e 8]	635	630	750	785	750
Jamaica	14	17	17	11	11
Japan	1,510	1,540	1,502	1,507	1,510
Jordan[e]	35	320	20	20	20
Kenya (crude salt)	e100	79	104	114	115
Korea, North[e]	630	630	630	630	630
Korea, Republic of	804	732	1,124	915	990
Kuwait	31	39	44	35	33
Laos[e]	33	r14	33	39	9
Lebanon[e]	3	3	3	3	3
Leeward and Windward Islands[e]	55	55	55	55	55
Libya[e]	13	13	13	13	13
Madagascar[e]	33	33	33	33	33
Mali[e]	5	5	5	35	5
Malta[e]	(5)	(5)	(5)	(5)	(5)
Mauritania[e]	6	6	6	6	6
Mauritius[e]	7	7	7	7	7
Mexico	6,840	7,047	7,483	7,652	7,865
Mongolia[e]	18	18	18	18	18
Morocco	106	119	146	98	100
Mozambique[e]	30	r33	r41	r44	44
Namibia (marine salt)	148	138	138	157	155
Nepal[9]	8	2	7	8	38
Netherlands	4,148	4,386	4,071	4,140	4,200
Netherlands Antilles[e]	390	390	390	390	390
New Zealand[e]	—	70	70	70	70
Nicaragua[e]	17	17	17	17	17
Niger[e]	3	3	3	3	3
Pakistan:[4]					
Rock salt	635	r295	448	798	770
Other	267	277	293	276	275
Panama (refined salt)[e]	311	11	11	11	11
Peru	440	490	e390	e390	390
Philippines	866	492	542	e550	550
Poland:					
Rock salt	r1,347	r1,360	1,375	re1,200	1,300
Other	r4,626	r5,447	5,437	re3,940	4,000

See footnotes at end of table.

TABLE 19—Continued

SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Portugal:					
Rock salt	506	566	591	643	660
Marine salt	214	196	153	[re]165	140
Romania	5,903	5,947	[e]5,950	7,464	7,200
Senegal	[r]126	83	[e]83	110	110
Sierra Leone[e]	220	220	220	220	220
Somalia[e]	33	33	33	33	33
South Africa, Republic of	829	778	748	763	[3]800
Spain:					
Rock salt	2,316	2,481	2,706	[e]2,300	2,400
Marine salt and other evaporated salt	1,102	1,041	[e]1,100	[e]1,100	1,100
Sri Lanka	115	127	118	166	[3]58
Sudan	[e]44	57	[e]55	100	85
Switzerland	429	430	431	268	250
Syria	[e]100	89	140	[e]143	143
Taiwan	150	110	123	187	88
Tanzania	24	45	22	22	22
Thailand:					
Rock salt	2	4	6	17	[3]131
Other[e]	180	180	180	180	180
Tunisia	457	468	535	[e]530	530
Turkey	1,292	1,342	1,497	[e]1,490	1,490
Uganda[e]	6	6	6	6	6
U.S.S.R.	16,865	16,976	16,314	16,535	16,000
United Kingdom:					
Rock salt	2,249	2,045	967	992	1,100
Brine salt[10]	1,664	1,713	1,572	[e]1,320	1,320
Other salt[10]	3,643	4,048	4,219	[e]3,970	3,860
United States including Puerto Rico:					
United States:					
Rock salt	12,598	11,965	12,900	13,938	314,391
Solar salt	2,562	2,627	2,617	2,754	[3]2,736
Vacuum pan salt	3,583	3,776	3,822	3,967	[3]4,029
Brine	17,920	17,124	19,601	18,198	[3]19,537
Puerto Rico[e]	40	40	40	45	45
Venezuela[e]	[3]564	550	550	550	[3]474
Vietnam[e]	500	250	330	350	375
Yemen, Republic of[e]	410	260	245	245	260
Yugoslavia:					
Rock salt	163	169	140	[e]138	165
Brine salt	311	312	221	[e]220	220
Marine salt	77	71	64	[e]44	30
Total	[r]192,612	[r]195,846	202,695	209,949	202,339

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through June 14, 1991.

[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]Brine salt production as reported by the Burmese Government in short tons was as follows: 1986—52,281 (revised); 1987—63,760 (revised); 1988—65,883 (revised); 1989—66,391; and 1990—68,000 (estimated).

[7]Year begining Mar. 21 of that stated.

[8]Does not include production from Sardinia and Sicily, estimated at 200,000 metric tons annually.

[9]Year ending July 15 of that stated.

[10]Data captioned "Brine salt" for the United Kingdom are the quantities of salt obtained from the evaporation of brines; that captioned "Other salt" is the salt content of brines used for purposes other than production of salt by evaporation.

TABLE 20

U.S. SALT ANNUAL PRODUCTION CAPACITIES IN 1990

(Thousand short tons)

Company	Plant	Type of salt			
		Rock	Solar	Vacuum pan	Total
Akzo Salt Inc.	Avery Island, LA	2,400	—	—	2,400
Do.	Manistee, MI	—	—	325	325
Do.	St. Clair, MI	—	—	395	395
Do.	Retsof, NY	4,000	—	—	4,000
Do.	Watkins Glen, NY	—	—	335	335
Do.	Akron, OH	—	—	300	300
Do.	Cleveland, OH	2,300	—	—	2,300
Do.	Lakepoint, UT[1]	—	150	—	150
Cargill Inc.	Amboy, CA[2]	—	75	—	75
Do.	Napa, CA[2 3]	—	275	—	275
Do.	Newark, CA[2]	—	750	150	900
Do.	Redwood City, CA[2]	—	350	—	350
Do.	Hutchinson, KS	—	—	250	250
Do.	Breaux Bridge, LA	—	—	150	150
Do.	Lansing, NY	1,300	—	—	1,300
Do.	Watkins Glen, NY	—	—	250	250
Do.	Freedom, OK	—	200	—	200
Great Salt Lake Minerals and Chemicals Corp.	Ogden, UT	—	1,500	—	1,500
Huck Salt Co.	Fallon, NV	15	—	—	15
Hutchinson Salt Co.[4]	Hutchinson, KS	300	—	—	300
Independent Salt Co.	Kanopolis, KS	400	—	—	400
Lyons Salt Co.[5]	Lyons, KS	250	—	—	250
Moab Salt Inc.	Moab, UT	—	200	—	200
Morton International Inc.	Glendale, AZ	—	100	—	100
Do.	Hutchinson, KS	—	—	350	350
Do.	Weeks, LA	1,500	—	125	1,625
Do.	Manistee, MI	—	—	360	360
Do.	Silver Springs, NY	—	—	275	275
Do.	Fairport, OH	2,000	—	—	2,000
Do.	Rittman, OH	—	—	600	600
Do.	Grand Saline, TX	400	—	100	500
Do.	Salt Lake City, UT	—	200	—	200
New Mexico Salt and Mineral Corp.	Carlsbad, NM	—	30	—	30
North American Salt Co.[6]	Lyons, KS	—	—	300	300
Do.	Hutchinson, KS	—	—	225	225
Do.	Baldwin, LA	1,700	—	—	1,700
Do.	Grantsville, UT	—	300	—	300
Pacific Salt and Chemical Co.	Trona, CA	—	175	—	175
Redmond Clay and Salt Co. Inc.	Redmond, UT	80	—	—	80
Salt Products Co.	Milligan, CA	—	10	—	10
United Salt Corp.	Carlsbad, NM	—	250	—	250
Do.	Hockley, TX	150	—	—	150
Do.	Houston, TX	—	—	125	125
Western Salt Co.	Chula Vista, CA	—	125	—	125
Williams Brine Service	Carlsbad, NM	—	10	—	10
Total		16,795	4,700	4,615	26,110
Brine producers[7]	Various locations	—	—	—	19,152
Grand total		16,795	4,700	4,615	45,262

[1]Operated as Akzo Salt of Utah Inc., a wholly owned subsidiary of Akzo.

[2]Operated by Leslie Salt Co.

[3]Closed Dec. 1990.

[4]Formerly Carey Salt Co's. rock salt operation. The vacuum pan salt operation is owned by North American Salt Co. effective Dec. 1990.

[5]Formerly American Salt Co's. rock salt operation. The vacuum pan salt operation is owned by North American Salt Co. effective Dec. 1990.

[6]New company formed by the acquisition of the Kansas vacuum pan salt operations of American Salt Co. and Carey Salt Co., and the rock salt and solar salt facilities of Domtar Industries Inc., in Louisiana and Utah, respectively.

[7]Includes brine for sale and for captive use. Brine production capacity is assumed to be equal to the quantity of annual brine production, as shown in tables 4 and 5. Brine producers include those chlor-alkali manufacturers that purchase brine or use captive brine, as listed in table 12.

Sifto Canada, Inc., whereas the Louisiana rock salt plant will be under North American Salt Co.

Chile.—Asahi Glass Co. of Japan obtained a contract to import 235,000 tons of Chilean rock salt by yearend 1991. The high-purity rock salt, which is more pure than the solar salt from Australia and Mexico, where Asahi had been purchasing, will be used for feedstock in Japan's chlor-alkali industry.[6]

China.—A rock salt mine with reserves of 1.2 million tons began operation at Dingyuan, Anhui Province. The mine had an initial capacity of 100,000 tons per year. Prior to the startup of the mine, the Province obtained its salt from solar salt operations in adjacent Provinces.[7]

Tanzania.—Coastal Salt Works received $3 million of financial aid from Italy to increase salt production at Sadani, which is north of Dar es Salaam. Annual salt production is slated to rise from 10,000 tons to 40,000 tons by 1992, with total capacity reaching 100,000 tons in the future.[8]

OUTLOOK

Of the approximate 14,000 uses of salt, only two continue to arouse public interest, namely, the deleterious effects of salt on the environment, bridge decks, and automobiles due to highway deicing, and the hypertension issue caused from too much salt in the diet.

The salt industry has been responsive to the public's awareness of the corrosion problems associated with highway deicing. Five of the major salt producers have developed corrosion inhibitors that, when added to rock salt, will reduce the corrosive action to bridges and roads when using rock salt during the winter. Although calcium magnesium acetate (CMA) is a noncorrosive deicer, it is very expensive when compared with regular rock salt or the corrosion inhibitor-treated salt. Cheese whey has also been examined as an alternate way to manufacture CMA. About 20 billion pounds of unused whey is produced in the United States annually. Work is still being done to reduce production costs. The outlook for treated-salt products is very favorable, especially in areas of the country that want to regulate the use of deicing salt.

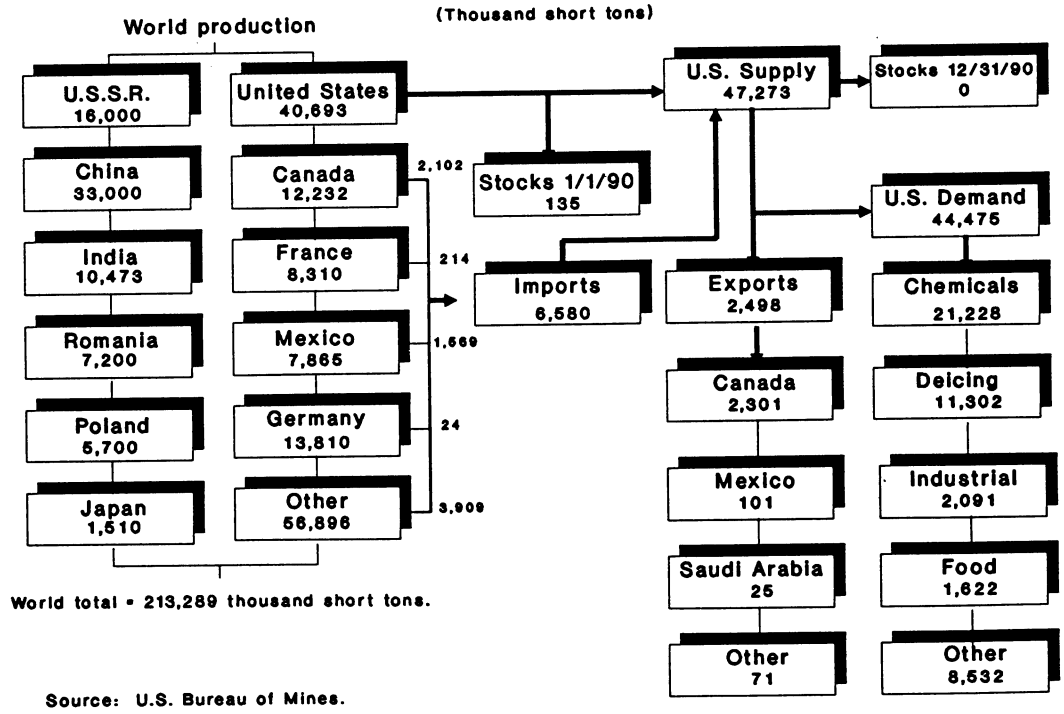
The construction industry has also responded to the corrosion problems. Resin-coated reinforcement rods and wire have helped reduce the corrosive damage to roads. Special containment and runoff guards on bridges have lessened the damage salt causes to roadside environments. Progress has been made, and will continue to be made in the 1990's, in combating the adverse effects of salt on the environment.

After a decade of research and millions of dollars spent on studies, there is still no positive proof that salt causes high blood pressure. Health authorities had advised health-conscious people to restrict their salt intake to reduce hypertension. Newer studies indicated that of the 60 million U.S. citizens who have high blood pressure, only about one-half of them are "salt sensitive," or about 10% of the U.S. population. The remaining majority of the population do not show any severe adverse reactions to higher salt intake.

INTERSALT, which was an international salt study done by the World Health Organization in 1988, received very little attention in the medical community. The study analyzed the salt consumption patterns of 10,079 men and women in 52 communities in 32 countries. It concluded that there was no relationship between how much salt people ate and their blood pressures.[9] If people decreased their salt consumption by 6 grams daily, they would reduce their diastolic pressure by one-tenth of a point. Maintaining a reasonable weight, quitting smoking, reducing alcohol intake, exercising, and reducing fat intake play greater roles in controlling blood pressure than salt consumption.

FIGURE 3

SALT SUPPLY-DEMAND RELATIONSHIPS—1990



Source: U.S. Bureau of Mines.

In November, the Federal Government modified its dietary guidelines from "avoid too much sodium" to "use salt or sodium in moderation." The Salt Institute, which is the trade association for the majority of the producers, and the U.S. salt industry have worked closely and effectively with salt consumers and the public to educate them and to promote the benefits of salt.

Between 1970 and 1990, world salt production has increased about 1.3% per year, while the United States had a -1%-per-year rate of decline in production and -0.7%-per-year decline in consumption. The negative growth rate for the United States was for total salt. It should be noted that the dry salt component (vacuum pan, solar, and rock) grew at about 0.5% per year. Production and consumption of brine declined since 1970, causing the growth rate for the commodity to decline proportionally. Brine consumption decreased because of the demise of the synthetic soda ash industry, which used salt brine as feedstock. In 1970, there were eight synthetic soda ash plants in operation in the United States; only one was in existence in 1979. It closed in 1986.

In the 1980's, world production increased 1.2% per year, while U.S. production declined -0.8% annually, and consumption decreased about -0.5% per year. As with the previous assessment of the industry, domestic dry salt usage grew 1.2% per year

TABLE 21

U.S. SALT SUPPLY-DEMAND RELATIONSHIPS

(Thousand short tons)

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
WORLD PRODUCTION										
Production:										
United States	44,700	44,010	44,298	46,423	41,710	43,80	142,922	42,878	46,317	41,483
Rest of world[e]	114,407	117,340	126,185	136,813	136,497	133,304	130,185	142,584	144,790	144,673
Total[e]	159,107	161,350	170,483	183,236	178,207	177,105	173,107	185,462	191,107	186,156
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY										
Components of U.S. supply:										
Domestic sources	44,700	44,010	44,298	46,423	41,710	43,801	42,922	42,878	46,317	41,483
Sold or used[1]	44,077	45,022	43,910	46,536	41,030	44,191	43,412	42,869	45,793	40,352
Imports	3,855	3,463	3,207	3,358	3,215	4,352	4,529	5,380	5,275	5,263
Industry stocks, January 1[2]	—	—	—	—	—	—	—	—	—	—
Total U.S. supply	47,932	48,485	47,117	49,894	44,245	48,543	47,941	48,249	51,068	45,615
Distribution of U.S. supply:										
Industry stocks, December 31[2]	—	—	—	—	—	—	—	—	—	—
Exports	670	869	609	521	1,332	1,007	1,008	776	697	831
Industrial demand	47,262	47,616	46,508	49,373	42,913	47,536	46,933	47,473	50,371	44,784
U.S. DEMAND PATTERN[3]										
Agriculture	1,941	1,963	2,083	1,983	1,862	1,925	1,825	1,851	1,917	1,834
Alkalies and chlorine	26,075	26,725	28,344	28,600	24,154	25,970	25,111	24,511	26,962	24,744
Deicing	9,859	11,248	7,306	9,111	8,840	10,193	10,416	10,690	11,138	7,476
Food products	2,942	2,953	2,951	2,970	2,734	2,766	2,756	2,815	2,526	2,368
Metal production	182	227	228	252	265	342	351	346	356	272
Other chemicals	1,286	1,063	1,402	1,734	1,021	1,158	1,122	1,159	1,222	1,020
Paper products	279	201	209	165	172	213	222	221	194	230
Petroleum	164	202	215	242	261	312	361	451	550	709
Textiles and dyeing	193	207	201	205	180	204	196	182	188	177
Water treatment	790	842	816	1,029	905	720	812	890	958	865
Other[4]	3,070	2,833	2,917	3,328	3,254	3,655	3,620	3,504	3,528	3,275
Undistributed[5]	481	-848	-164	-246	-735	78	141	853	832	1,814
Total U.S. primary demand	47,262	47,616	46,508	49,373	42,913	47,536	46,933	47,473	50,371	44,784
VALUES[6]										
Average annual value (dollars per ton):										
Salt in brine	3.57	3.29	3.57	3.69	3.91	3.80	3.91	4.24	4.51	6.50
Rock salt	6.41	6.19	6.19	7.14	8.94	7.82	8.94	10.10	10.00	14.65
Solar salt	11.02	8.40	8.99	9.30	14.21	14.36	14.21	14.67	12.16	15.65
Vacuum pan and open pan salt	26.28	26.76	29.65	34.50	43.01	50.73	52.01	58.86	61.64	76.44

See footnotes at end of table.

TABLE 21—Continued

U.S. SALT SUPPLY-DEMAND RELATIONSHIPS

(Thousand short tons)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
WORLD PRODUCTION										
Production:										
United States	38,899	37,665	32,973	39,181	39,217	37,282	36,943	39,170	39,278	40,558
Rest of world[e]	150,054	143,406	142,126	151,077	151,412	r155,330	r158,903	r163,525	r170,671	161,781
Total[e]	188,953	181,071	175,099	190,258	190,629	r192,612	r195,846	r202,695	r209,949	202,339
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY										
Components of U.S. supply:										
Domestic sources	38,899	37,665	32,973	39,181	39,217	37,282	36,943	39,170	39,278	40,558
Sold or used[1]	38,907	37,894	34,573	39,225	40,067	36,663	36,493	38,940	38,856	40,693
Imports	4,319	5,451	5,997	7,545	6,207	6,665	5,716	5,474	6,084	6,580
Industry stocks, January 1[2]	—	—	—	—	—	—	—	—	—	—
Total U.S. supply	43,226	43,345	40,570	46,770	46,274	43,328	42,209	44,414	44,940	47,273
Distribution of U.S. supply:										
Industry stocks, December 31[2]	—	—	—	—	—	—	—	—	—	—
Exports	1,046	1,001	517	820	904	1,165	541	884	1,567	2,498
Industrial demand	42,180	42,344	40,053	45,950	45,370	42,163	41,668	43,530	43,373	44,775
U.S. DEMAND PATTERN[3]										
Agriculture	1,788	1,566	1,605	1,722	1,718	1,651	1,755	1,827	1,925	2,320
Alkalies and chlorine	22,722	19,151	20,240	20,142	20,436	18,983	17,955	19,968	18,780	19,182
Deicing	8,257	10,839	6,889	10,721	11,180	10,541	9,878	11,125	11,461	11,302
Food products	2,203	2,352	2,292	2,175	2,109	2,171	2,328	2,287	2,374	2,516
Metal production	294	294	242	326	382	304	311	374	400	346
U.S. DEMAND PATTERN[3]—Continued										
Other chemicals	1,133	865	952	1,258	768	818	760	766	1,177	2,046
Paper products	247	209	274	337	311	307	387	376	373	283
Petroleum	837	1,035	918	870	965	627	597	819	720	793
Textiles and dyeing	220	165	171	191	186	226	237	229	234	227
Water treatment	1,006	806	795	1,948	1,441	1,553	1,455	1,514	1,487	1,618
Other[4]	3,754	3,954	4,049	4,188	3,382	3,063	4,074	3,805	4,875	4,428
Undistributed[5]	-281	1,108	1,626	2,072	2,492	1,919	1,931	440	-433	-286
Total U.S. primary demand	42,180	42,344	40,053	45,950	45,370	42,163	41,668	43,530	43,373	44,775
VALUES[6]										
Average annual value (dollars per ton):										
Salt in brine	5.91	6.21	5.22	5.05	6.14	5.15	4.93	3.58	5.67	4.89
Rock salt	13.76	13.89	13.43	13.78	15.15	14.51	14.34	14.46	16.38	16.11
Solar salt	18.35	17.89	21.47	19.67	23.10	23.76	25.40	26.59	27.88	31.40
Vacuum pan and open pan salt	79.68	86.72	87.39	92.78	92.66	91.27	94.21	97.71	92.73	100.32

[e]Estimated. [r]Revised.

[1]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.

[2]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.

[3]Includes imports for consumption.

[4]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.

[5]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.

[6]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.

since 1980, while salt brine consumption decreased. The outlook for salt in the 1990's is optimistic; however, consumption of salt for chlor-alkali manufacture will continue to decline for the rest of this decade. The major producers have diversified into all types of salt across the Nation and have developed reliable import sources in Canada, the Caribbean, Mexico, and South America. Consolidations and restructuring within the U.S. salt industry have strengthened it into a competitive North American enterprise in the Western Hemisphere.

[1]Industrial Minerals (London). World of Minerals. Domtar Sells Sifto Salt to North American Salt. No. 272, May 1990, p. 15.
[2]Engineering News Record. Industrial Park Would Pump Waste Into Caverns. July 12, 1990, p. 5.
[3]Industrial Minerals (London). Dampier Salt Expansion. No. 275, Aug. 1990, p. 9.
[4]———. Mineral Notes. Western Australia Solar Salt Project. No. 278, Nov. 1990, p. 82.
[5]Mining Annual Review. 1990. Salt. p. 115.
[6]Chemical Week. Chilean Salt for Japan. V. 147, No. 10, Sept. 12, 1990, p. 40.
[7]Industrial Minerals. Mineral Notes. Chinese Salt Mine Trial. No. 277, Oct. 1990, p. 81.
[8]———. Mineral Notes. Italy Aids Tanzanian Salt Project. No. 277, Oct. 1990, p. 81.
[9]Washingtonian. Overkill. V. 25, No. 11, Aug. 1990, pp. 64-67 and pp. 194-204.

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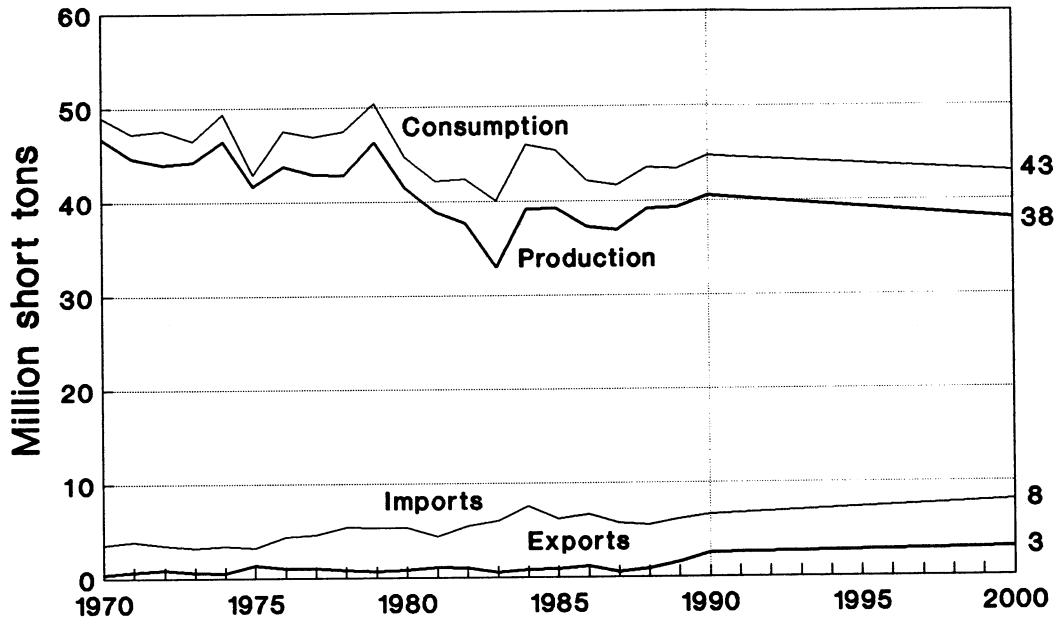
FIGURE 4

U.S. SALT FORECASTS TO THE YEAR 2000



CONSTRUCTION SAND AND GRAVEL

By Valentin V. Tepordei

Mr. Tepordei, a geological engineer with more than 20 years 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 relatively low value of its basic products, the construction sand and gravel industry is a major contributor to and an indicator of the economic well-being of the Nation.

A total of 911 million short tons of construction sand and gravel was produced in the United States in 1990, a 1.5% increase compared with the estimated total of 1989. This tonnage represents the fifth consecutive year of production of more than 880 million tons, indicating a continuation of the strong demand for construction aggregates in the United States.

Foreign trade of construction sand and gravel remained relatively minor. Exports decreased 58.4% to 468,000 tons, while value decreased 12.6% to $11.9 million. Imports increased 191.3% to 1.7 million tons, while the value increased 138.1% to $22.9 million. Domestic apparent consumption of construction sand and gravel was 912 million tons.

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 construction sand and gravel industry. The new regulatory requirements being proposed by the Occupational Safety and Health Administration (OSHA) continue to be the other areas of concern for the industry. They include the revised asbestos standards governing occupational exposure to nonasbestiform varieties of actinolite, tremolite, and anthophyllite minerals, and the final promulgation of the permissible exposure limit for crystalline silica measured as respirable silica.

DOMESTIC DATA COVERAGE

Domestic production data for construction sand and gravel are developed by the U.S. Bureau of Mines from voluntary surveys of U.S. producers. Full surveys of construction sand and gravel producers are conducted for even-numbered years only. For odd-numbered years, only annual estimates for each State are generated based on information provided by the 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.

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

TABLE 1

SALIENT U.S. CONSTRUCTION SAND AND GRAVEL STATISTICS

		1986	1987	1988	1989	1990
Sold or used by producers:						
Quantity[1]	thousand short tons	883,000	e896,200	923,400	e897,300	910,600
Quantity	thousand metric tons[2]	801,044	813,019	837,695	814,017	826,083
Value[1]	thousand dollars	$2,747,200	e$3,002,500	$3,126,000	$3,249,100	$3,249,400
Exports	value, thousand dollars	$7,838	$10,533	$11,048	$13,591	$11,880
Imports	do.	$1,412	$2,367	$3,163	$6,618	$22,912

eEstimated.

[1]Puerto Rico excluded from all sand and gravel statistics.

[2]One metric ton is equal to 2,204.6 pounds. To convert from short tons to metric tons, multiply short tons by 0.907185.

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.[1]

Specifications for sand and gravel used in roadbuilding and concrete construction are usually rigid regarding particle size gradation and shape and include physical as well as some chemical properties. However, these specifications can differ in detail from State to State or even from city to city within the State. Soil conditions, climate, and peculiarities in different deposits may necessitate adjustments of requirements of sand and gravel mixtures and chemical composition.

Specifications are written by commercial users; Government agencies, including Federal; State, county, and city construction and highway departments; and the ASTM. Problems arise for the producers of construction aggregates when their product is sold or used in several different cities, counties, or States, many of which may have different specifications. Some progress is being made toward the standardization of aggregate sizes for similar requirements. A need exists for a more active interchange of data and experience among aggregate consumers and producers.

Products for Trade and Industry

Concrete is made by mixing properly sized aggregate, portland cement, and water into a slurry. Chemical action between the cement and the water results in the crystallization of hydrous calcium aluminum silicates, which causes the mass to bind and harden. Round particles in the aggregate are desirable because they improve the workability of the concrete as it is poured. If broken material is used and angular or flattish fragments exceed about 15% of the total volume, workability can be maintained only by increasing the amount of sand and water, thus reducing strength, or by adding more cement, thus increasing the cost of the concrete.

Sized and broken sand and gravel is used to make asphaltic concrete aggregate and road bases. Broken surfaces adhere to the hot asphaltic mixture better than do rounded surfaces and provide interlocking surfaces that tend to strengthen the asphaltic concrete. Broken particles pack better and tend to move less under load than do rounded particles and, therefore, make better road bases for highway and road construction. This is essential because bases and asphaltic concrete tend to flow when placed under great or long duration stresses.

Industry Structure

Because of the low unit value, construction sand and gravel is produced near the point of use; therefore, the industry is concentrated in or nearby large, rapidly expanding urban areas and, on a transitory basis, in areas where highways, dams, and other large-scale public and private works are under construction. In the United States, sand and gravel is produced in every State. The largest operations tend to be concentrated in the States with the largest population and largest production of sand and gravel.

Construction sand and gravel is produced in virtually all countries, but relatively few of them survey this industry and even fewer regularly publish official statistics on sand and gravel.

On the basis of tonnage, the construction sand and gravel industry is the second-largest nonfuel mineral industry in the United States. In 1990, there were 4,094 companies producing construction sand and gravel operating 5,665 pits. The individual operations range in size from those producing millions of tons annually to those reporting less than 25,000 tons per year. Most operations are small, turning out one product or a limited range of products, but most of the tonnage comes from large operations. For example, the 18 operations reporting more than 2.5 million tons each in 1990 represented only 0.3% of the total number of operations but produced 8% of the total tonnage, while 101 operations reporting between 1 and 2.5 million tons each, representing only 1.8% of the total number of operations, produced 15.5% of the total tonnage. For the same year, most of the construction sand and gravel was produced by operations reporting between 200,000

and 1 million tons each; 1,094 operations, representing 19.2%, produced 49.2% of the total tonnage.

The leading companies producing construction sand and gravel, in descending order of tonnage, based on the 1990 survey, were Beazer U.S.A. Inc. of Pittsburgh, PA; CalMat Co. of Los Angeles, CA; CSR Ltd., of Sydney, Australia; Tarmac America of Herndon, VA; and Teichert Aggregates of Sacramento, CA. The top five companies operated 122 pits and produced 10.5% 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 lake beds and as sanitary landfill areas has been successful at numerous localities. Automatic controls, along with monitoring by closed-circuit television coordinated with automated counting and recording and radio communications systems, have been installed in many of the larger and newer operations; these, along with the use of improved equipment, have permitted recovery of salable fractions from deposits previously considered too low in quality for profitable exploitation. These practices will increase as pressures build to increase productivity and minimize environmental conflicts.

Exploration.—Sand and gravel deposits, like any mineral deposit, must be explored and evaluated before development. Preliminary examination can establish the extent and nature of the deposits. This is followed by a detailed exploration program aimed at obtaining reasonably accurate information on the quantity of material available, the degree of uniformity throughout the deposit, and especially, variations in particle size, both vertically and horizontally. Also the nature and amount of waste materials and the economic feasibility of their removal must be studied.

Geophysical methods are of value in preliminary surveys. Detailed exploration may be achieved by a systematic arrangement of test pits, trenches, boreholes, or other procedures designed to obtain a cross section of the deposit in conjunction with sampling and testing. Advances in interpretation of aerial photographs and increased application of geophysical techniques have made evaluation of sand and gravel deposits more quantitative. For underwater exploration, mining devices such as dredges and draglines are used. Pilot runs are necessary to determine if required specifications can be met consistently and economically.

Much of the sand and gravel that is being mined in stream, floodplain, 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 trans-

porting, redepositing, or stockpiling it at or off the site; (2) mining—removing the sand and gravel from the deposit; (3) processing—screening, washing, crushing, blending, and stockpiling the mined material to conform to standards and specifications; and (4) reclamation of the extraction area. Processing may or may not take place at the mining site. Mining equipment ranges from small, simple units such as tractor-mounted high-loaders and dump trucks to more sophisticated systems involving large power shovels, draglines, bucketwheel excavators, and belt conveyors. Increasingly, mining systems are being designed to provide for more efficient and economical land reclamation.

Mining with a dredge usually involves mounting the equipment on boats or barges. Suction or bucket-type dredges are used most commonly to harvest sand and gravel from the bottom of a body of water. The sand and gravel is processed either on board or transported to land for processing.

Processing.—Although small amounts of unprocessed bank-run sand and gravel are used for fill, most of the U.S. production is processed in some way. Present methods include washing with water during the screening process, in some cases followed by crushing of the larger particles in cone or gyratory crushers. Secondary crushing may be done by roll crushers. Sizing is done in most plants by horizontal or sloped single or multideck vibratory screens. If necessary, heavy-media separation or jigging is used to remove heavy, unusable materials. Sand for use in construction is freed from clay by log washers or rotary scrubbers. The scrubbing is followed by classification, use of separatory cones or hydroseparators to remove water, and fine screening for grading. In many cases, rodmilling is 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 $3.57 in 1990. 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 and low unit-value of sand and gravel requires that operations be close to the market location. Markets for sand and gravel are construction sites that are mostly in areas of high population density. New operations, close to population centers, are difficult to develop because the land is often attractive for other uses such as housing, shopping centers, agriculture, parks or recreational areas, and because of public dislike for mining

TABLE 2

TIME-PRICE RELATIONSHIP FOR CONSTRUCTION SAND AND GRAVEL

Year	Actual unit prices	Unit prices in 1982 constant dollars
1970	$1.11	$2.64
1971	1.18	2.66
1972	1.23	2.65
1973	1.31	2.65
1974	1.46	2.70
1975	1.56	2.63
1976	1.88	2.98
1977	2.02	3.00
1978	2.13	2.95
1979	2.27	2.89
1980	2.62	3.06
1981[e]	2.79	2.97
1982	2.82	2.82
1983[e]	2.95	2.84
1984	2.90	2.69
1985[e]	3.05	2.75
1986	3.11	2.73
1987[e]	3.35	3.00
1988	3.39	2.79
1989[e]	3.62	2.87
1990	3.57	2.71

[e]Estimated.

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 generally 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 Environmental Impact Statement (EIS). A reclamation plan and a use permit application may also be required, with considerable overlap of subject matter with the EIS. A complete EIS may cover all the problem areas at once and facilitate acceptance.

Environmental Requirements.—Two main points are involved in environmental land use and reclamation factors. First, the industry must be concerned about any practices that can affect the community environment. An effective effort must be made to reduce noise, air, and water pollution; to reclaim pits after the operation is complete; and to improve the overall appearance of the operating mine, processing plant, and transportation facilities. Second, the industry and community must recognize the time and costs required to protect the environment and the importance of agreeing on fair and realistic environmental standards.

Because sand and gravel is a local commodity, the effect of supply deficiencies and cost of material will affect the local community first. Undue delay and unreasonably high cost can strongly affect the movement of sand and gravel into the marketplace. Also, stringent controls by the local government that prevent permits being issued to operators can have adverse economic effects on the communities around them. These conditions can make it difficult to assess the timing and even the possibility of plants going on-stream and can therefore affect the supply of sand and gravel into the marketplace.

Although much progress is being made through premining planning, the sand and gravel industry continues to have problems with environmental controls, land use conflicts, and reclamation practices. Many of these problems are acute because extraction areas and plants must be reasonably near to consumers who are largely in metropolitan areas. Major environmental considerations that must be dealt with in mining and processing sand and gravel are emission of particulate matter into the air, processing water discharge, noise abatement, and employee and public health and safety.

Transportation.—Transportation is a major factor in the delivered price of construction sand and gravel. The cost of moving construction sand and gravel from the plant to the market often exceeds the sales price of the product at the plant. Because of the high cost of transportation, construction sand and gravel continues to be marketed locally. Economies of scale, which might be realized if fewer, larger operations served larger marketing areas, would probably not offset the increased transportation costs.

Truck haulage is the main form of transportation used in the construction sand and gravel industry. Many producers have their own truck fleet and deliver their own raw materials and products. A significant and increasing amount of sand and gravel, however, is being hauled by independent truckers because of the cost of maintaining a truck fleet, particularly when the market is highly variable or down. Rail and water transportation combined account for about 10% to 20% of total construction sand and gravel shipments.

ANNUAL REVIEW

In 1990, the construction sand and gravel industry reached the sixth highest production level ever recorded and the fifth consecutive year of production of more than 880 million tons. This high level of production indicates a continuation of the strong demand for construction aggregates. During the year, production of construction sand and gravel increased in the first, second, and fourth quarters of 1990 compared with the same period of 1989, while remaining at the same level with the prior period in the third quarter of 1990.

Legislation

On November 15, 1990, the U.S. Congress enacted the 1990 Amendment to the Clean Air Act of 1970, Public Law 101-549. Most of the regulatory programs and air quality standards established by the original Clean Air Act of 1970 were revised, and new provisions were amended. The new clean air law contains 11 parts covering the following: National Ambient Air Quality Standards, Mobile Sources, Hazardous Air Pollutants, Acid Rain Control, and Stratospheric Ozone Protection. The new law will be implemented through rules written by the Environmental Protection Agency (EPA) and laws passed by the States. The standard for measuring the amount of solid or liquid "particulate" matter suspended in the atmosphere (PM-10) and the designation of PM-10 noncompliance areas, the new system of operating permits, and the en-

forcement and review of Air Pollutant Emission Factors are areas that will have an impact on the construction sand and gravel industry.

On October 28, 1990, the U.S. Congress approved the Department of Transportation's appropriation bill, which increased funding for the Federal highway and airport programs. The Federal Highway Program increased from a total of $13.5 billion in fiscal year 1990 to $16 billion in fiscal year 1991. The Airport Improvement Program increased from $1.4 billion in fiscal year 1990 to $1.8 billion in fiscal year 1991. The U.S. Congress also approved the Omnibus Budget Reconciliation Act of 1990, which increased the Federal motor fuels taxes by 5 cents, divided 50-50 between the General Revenue Fund and the Highway Trust Fund.

On February 7, 1990, the EPA and the U.S. Army Corps of Engineers (USACE) signed a revised Memorandum of Agreement (MOA) intended to clarify the policies and procedures to be used by their field personnel in determining compliance with the provisions of section 404 of the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, dealing with "wetlands." A Wetland Delineation Manual developed by the EPA, the USACE, the U.S. Department of Agriculture, and the U.S. Fish and Wildlife Service was published with the intent to bring consistency to the definition process of wetlands for Federal regulatory purposes.

On February 12, 1990, OSHA issued a notice of proposed supplemental rulemaking on its standards, issued June 17, 1986, governing "Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite in general industry and the construction industry. An administrative stay of enforcement of the standards was extended until November 1990 to provide time to complete this supplemental rulemaking. The former asbestos standard remains in effect for the extent of the stay. Based on available information, OSHA believes that there is insufficient evidence to conclude that exposure to nonasbestiform Anthophyllite, Tremolite and Actinolite (AT&A) mineral fragments presents a risk similar in magnitude or type to fibers of their asbestiform counterparts. Therefore, OSHA proposed that nonasbestiform AT&A minerals should no longer be regulated in the same way as asbestos, either under the 1972 asbestos standard or under the revised asbestos standard. Public hearings on the proposed supplemental rulemaking were held on May 8, 1990, at the Labor Department, in Washington, DC. After reviewing the notice of proposed rulemaking regarding the Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite, the Department of the Interior informed OSHA that it "recommends that OSHA deal with asbestos and AT&A as separate issues, introduce a mineralogical definition of asbestos into the asbestos regulation, and initiate a separate rulemaking for AT&A because of the potential im-pact on the mining and minerals industries, the uncertainty in the health risks, and the lack of exposure data and health studies in the consuming industries."[5]

Issues

The implementation of the provisions of the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, section 404, dealing with "wetlands" and the establishment of a "no net loss of wetlands" policy constitutes one of the major areas of concern to the construction sand and gravel 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. The many criticisms of the current wetland regulatory process include the following: it fails to cover activities that are destructive to wetland; it ignores basic, fundamental rights of private property owners; and covers privately owned lands that provide minimal wetland functions and values. Several bills were introduced in the 102d U.S. Congress to replace the current section 404 of the Federal Water Pollution Control Act. The new proposed bills plan to provide a concise and structured program for the delineation of wetlands based upon their functions and values and will balance the need for effective protection of the Nation's important wetlands with the need for essential community growth and the constitutional rights of landowners.

The regulatory requirements being proposed by OSHA continue to be the other areas of concern for the industry. They include the revised asbestos standards governing occupational exposure to nonasbestiform varieties of AT&A minerals and the final promulgation of the permissible exposure limit for crystalline silica measured as respirable silica. The revised OSHA regulations for airborne asbestos standards, if implemented, are expected to have a significant impact on the aggregates and the construction industries that could include increased mining and construction costs and disruption of the supply of aggregates in most areas.

Although progress is being made toward better cooperation between the aggregates industry and the local communities in most parts of the country, problems still exist in other areas. An attempt was made in 1990 in Colorado to amend the State constitution and prohibit surface mining of aggregates in the Front Range mountains within view of six major cities—Colorado Springs, Denver, Manitou Springs, Boulder, Pueblo, and Fort Collins—and in various other parts of the State. The amendment would have allowed local governments to adopt and enforce their own reclamation and bonding requirements for aggregate mines. The proposed amendment was challenged in the State Supreme Court, and due to the delay caused by the challenge, backers of the amendment could not gather in time the number of signatures required to place the issue on the November 1990 ballot. Backers of the proposed amendment plan to have it included in Colorado's 1992 general elections.

Production

U.S. production of construction sand and gravel increased 1.5% in 1990 compared with the estimated total of 1989 but decreased 1.4% compared with that of 1988 when the previous full annual survey was conducted. Of the four major geographic regions, the West again led the Nation in the production of construction sand and gravel with 318 million tons, or 34.9% of the U.S. total, followed by the Midwest with 282 million tons or 31% of the total; the South with 204 million tons or 22.4%; and the Northeast with 107 million tons or 11.8%. Compared with that of 1988, production by major geographic regions decreased 17.3% in the Northeast and 0.9% in the West but increased 3.9% in the Midwest and 0.9% in the South.

Of the nine geographic regions, the Pacific again led the Nation with 204 million tons or 22.4% of the U.S. total. Next was the East North Central with 184 million tons or 20.2% of the total and the

Mountain with 114 million tons or 12.5% of the total. Compared with that of 1988, production increased in only three of the nine regions, the largest increases being recorded in the East South Central region, 14%; the West North Central, 7.9%; and the East North Central region with only 1.9%. The production decreased in the remaining six geographic regions with the major decreases occurring in New England, 26.3%; Middle Atlantic, 10.1%; and West South Central, 2.5%.

The estimated production by quarters for 1990 indicated that most of the construction sand and gravel in the United States was produced in the third quarter, followed by the second quarter and the fourth quarter. The variations in production between quarters are mostly due to seasonal changes in weather conditions that have an impact on the construction activities and on the demand for construction aggregates as well. Estimated production by each quarter of 1990 was also available for most of the States.

Construction sand and gravel was produced in every State, and the 10 leading States in 1990 were, in descending order of tonnage, California, Michigan, Texas, Ohio, Washington, Minnesota, Illinois, New York, Wisconsin, and Arizona. Their combined production represented 51.7% of the national total.

Compared with that of 1988, production increased in 29 States, including 4 of the top 10 States. The increases were significant in Washington, 29.1%; Iowa, 25.9%; and Alabama, 9.6%.

Limited information about the production of construction sand and gravel in foreign countries may be found in the U.S. Bureau of Mines Minerals Yearbook, 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.

Changes in ownership, acquisitions by foreign or domestic companies, and mergers continued in the crushed stone industry. In January 1990, Colonial Sugar Refineries (CSR) Ltd. of Sydney, Australia, completed the acquisition of ARC America Corp. of Newport Beach, CA, and all its subsidiaries. The transaction included American Aggregates Co. of Greenville, OH, Associated Sand and Gravel Co. of Everett, WA, and WMK Co. of Las Vegas, NV, as well as Hydro Conduit, a large producer of concrete pipes with operations in Florida and most of the Western States. The acquisition added 48 aggregates operations located in six States and 40 concrete pipe plants in 20 States to CSR holdings. CSR also acquired, through its subsidiary Rinker Materials Corp. of West Palm Beach, FL, Cox Sand Co. of Brunswick, GA. CSR acquired Rinker Materials in 1988.

In midyear, C. H. Beazer PLC, of Bath, United Kingdom, reorganized its American subsidiaries in two separate companies. All Beazer operations located west of the Mississippi, including Gifford-Hill & Co. operations, became Beazer West Inc. of Dallas, TX, while Beazer Materials and Services of Pittsburgh, PA,

FIGURE 1

PRODUCTION OF CONSTRUCTION SAND AND GRAVEL IN THE UNITED STATES IN 1990, BY GEOGRAPHIC REGION

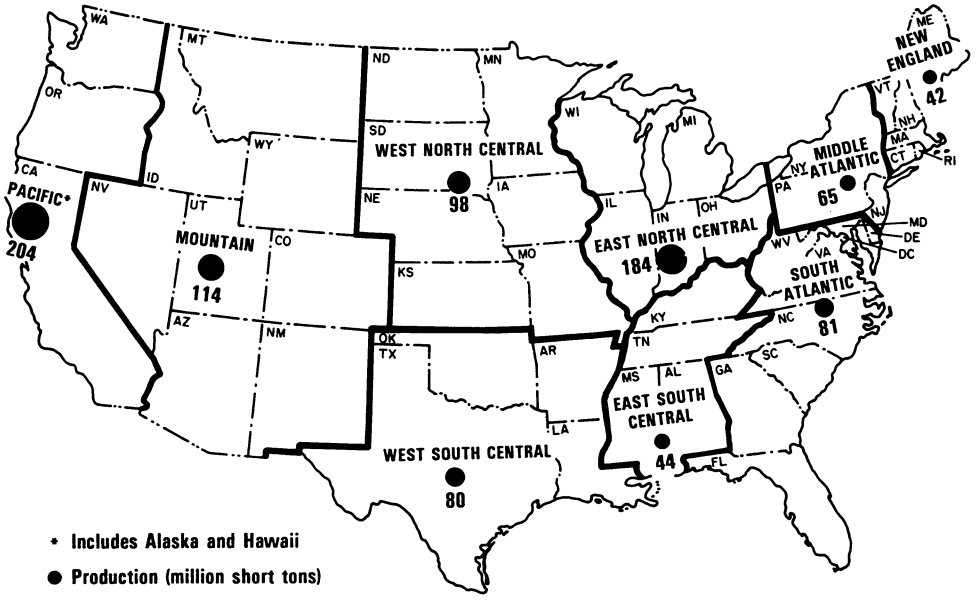


TABLE 3

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY GEOGRAPHIC REGION

Geographic region	1989[e]				1990			
	Quantity (thousand short tons)	Percent of total	Value (thousands)	Percent of total	Quantity (thousand short tons)	Percent of total	Value (thousands)	Percent of total
Northeast:								
New England	42,300	5	$156,500	5	42,726	4	$166,347	3
Middle Atlantic	66,300	7	281,500	9	64,495	7	283,118	9
Midwest:								
East North Central	176,700	20	545,200	17	184,113	20	573,815	18
West North Central	94,700	11	256,800	8	97,715	11	244,166	8
South:								
South Atlantic	76,700	9	288,500	9	80,748	9	320,469	10
East South Central	37,600	4	125,000	4	43,555	5	149,115	5
West South Central	73,500	8	255,700	8	79,581	9	271,450	8
West:								
Mountain	121,400	13	443,000	13	113,858	13	376,660	12
Pacific	208,100	23	896,900	27	203,787	22	864,254	27
Total[1]	897,300	100	3,249,100	100	910,600	100	3,249,400	100

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

TABLE 4

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1990, BY GEOGRAPHIC REGION AND QUARTERS[1]

(Thousand short tons and thousand dollars)

Geographic region	Quantity				Total[2]	Value	Number of companies[3]
	1st Quarter	2d Quarter	3d Quarter	4th Quarter			
Northeast:							
New England	6,200	9,900	13,000	12,300	41,400	153,200	29
Middle Atlantic	8,300	17,700	20,100	14,900	61,000	274,500	31
Midwest:							
East North Central	20,200	51,400	60,700	54,700	187,000	579,700	53
West North Central	12,000	28,800	41,400	27,300	109,500	284,700	53
South:							
South Atlantic	17,600	20,900	19,300	17,100	74,900	307,100	49
East South Central	7,600	13,000	14,400	11,500	46,500	153,500	24
West South Central	18,900	22,800	24,100	22,300	88,100	317,200	24
West:							
Mountain	24,000	33,200	37,100	29,100	123,400	456,600	42
Pacific[4]	39,500	48,200	48,000	43,600	179,300	788,900	29
Total[2]	154,300	246,000	278,000	232,900	[5]927,100	[5]3,408,700	XX

XX Not applicable.
[1]As published in the "Crushed Stone and Sand and Gravel in the Fourth Quarter of 1990," Mineral Industry Survey.
[2]Data may not add to totals shown because of independent rounding.
[3]Number of companies reporting for the quarterly survey.
[4]Does not include Alaska and Hawaii in quarterly estimates.
[5]Includes Alaska and Hawaii.

and all its operations east of the Mississippi became Beazer East Inc. Beazer West acquired all assets of Crystal Hills Sand and Gravel Co. of Lucerne, CA. The acquisition included a long-term lease for the sand and gravel operation as well as a ready-mix plant and a hot-mix asphalt plant located at that site.

The Rogers Group Inc. of Nashville, TN, acquired the assets of Billy Holloway Aggregates of Louisville, KY, that included two quarries at Avoca and Fern Creek, TN. In addition, the new Rogers Group affiliate, Billy Holloway Ready-Mix of Louisville, KY, and American Builders Supply, of Louisville, KY, an affiliate of Sibo Services Inc. of Louisville, KY, formed a joint venture that will operate under the name of American Builders Supply, a Rogers Group company. Sibo Services Inc. of Louisville, KY, a subsidiary of Sibo Gruppe, Dyckerhoff Cement Co., Hans Sievert A.G. & Co., Oppermann Sand and Gravel, and Homann Co., all of the Federal Republic of Germany, is a holding company with assets in aggregates and concrete in Kentucky and Indiana. Rogers Group also acquired Price Sand and Gravel Co. of Norwalk, OH.

Inspiration Resources Corp. of New York, NY, acquired Rogue Aggregates Inc. and LTM Inc., of Medford, OR. Rogue Aggregates has three crushed stone and sand and gravel operations, while LTM is an aggregates, ready-mix concrete, and asphalt producer. Inspiration Resources is a diversified natural resources company that operates base and precious-metals mines as well as coal mines and also produces construction materials.

Dravo Basic Materials Co. of Kenner, LA, acquired R&S Materials Inc. of Montgomery, AL, and its five sand and gravel operations in central Alabama.

Lone Star Industries of Greenwich, CT, has sold most of its interest in Lone Star Northwest of Seattle, WA, to Onoda Cement Co., of Tokyo, Japan, its partner in the joint venture established in 1988. Lone Star Northwest operates three sand and gravel plants and six cement terminals in Alaska, Oregon, and Washington.

Consumption and Uses

Sand and gravel reported by producers to the U.S. Bureau of Mines is actually

TABLE 5

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1989[e]		1990	
	Quantity	Value	Quantity	Value
Alabama	10,400	36,500	14,103	50,243
Alaska	17,000	48,500	15,100	41,800
Arizona	33,900	133,900	27,915	92,166
Arkansas	7,500	25,500	9,663	35,475
California	138,300	670,800	132,214	626,000
Colorado	25,300	104,000	24,938	86,541
Connecticut	5,800	24,700	8,542	37,943
Delaware	1,900	6,200	2,184	6,967
Florida	17,900	55,500	18,472	59,123
Georgia	6,100	18,900	5,158	16,644
Hawaii	600	3,200	438	2,459
Idaho	5,800	18,900	9,222	25,590
Illinois	33,000	108,900	32,380	104,728
Indiana	29,600	99,200	23,879	76,886
Iowa	12,800	37,800	14,953	46,432
Kansas	13,000	33,200	10,863	24,170
Kentucky	5,500	15,100	8,802	29,581
Louisiana	13,600	54,400	14,589	55,902
Maine	8,600	30,100	7,865	29,349
Maryland	16,900	84,500	18,271	104,023
Massachusetts	13,900	57,000	12,774	51,466
Michigan	48,000	132,000	53,729	153,057
Minnesota	33,700	82,600	33,869	77,502
Mississippi	15,600	51,500	13,032	45,817
Missouri	10,000	32,500	9,243	25,097
Montana	5,800	13,900	5,114	14,319
Nebraska	15,200	41,800	11,453	30,056
Nevada	20,000	70,000	18,377	59,008
New Hampshire	6,000	20,400	7,901	26,599
New Jersey	15,200	68,400	13,862	64,245
New Mexico	11,800	45,400	10,362	39,708
New York	31,600	118,500	29,750	121,525
North Carolina	11,200	43,700	11,733	44,872
North Dakota	3,600	8,100	7,644	17,219
Ohio	44,400	148,700	44,552	165,394
Oklahoma	8,500	20,000	9,235	21,993
Oregon	14,400	49,700	15,785	60,928
Pennsylvania	19,500	94,600	20,883	97,348
Rhode Island	1,100	3,900	1,969	9,042
South Carolina	7,500	23,300	8,627	24,941
South Dakota	6,400	20,800	9,689	23,689
Tennessee	6,100	21,900	7,619	23,474
Texas	43,900	155,800	46,093	158,080
Utah	14,300	41,500	13,601	44,881
Vermont	6,900	20,400	3,675	11,948
Virginia	12,900	49,700	13,096	48,950
Washington	37,800	124,700	40,251	133,067
West Virginia	2,300	6,700	3,208	14,950
Wisconsin	21,700	56,400	29,572	73,750
Wyoming	4,500	15,400	4,329	14,446
Total[1]	897,300	3,249,100	910,600	3,249,400

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

TABLE 6

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1990, BY STATES AND QUARTERS[1]

(Thousand short tons and thousand dollars)

State	Quantity					Value	Number of companies[3]
	1st Quarter	2d Quarter	3d Quarter	4th Quarter	Total[2]		
Alabama	3,200	4,600	5,300	4,400	17,500	60,900	9
Alaska[4]	—	—	—	—	15,000	44,800	—
Arizona	7,000	7,800	8,500	7,700	31,000	129,200	10
Arkansas	1,800	2,100	2,600	2,100	8,600	30,700	4
California	28,800	34,200	32,900	30,200	126,100	623,200	17
Colorado	2,600	7,400	8,600	4,800	23,400	104,100	10
Connecticut	1,100	2,500	1,500	2,100	7,200	27,700	8
Delaware	400	500	800	1,000	2,700	7,900	5
Florida	4,100	4,200	3,800	3,100	15,200	51,200	9
Georgia	1,500	1,500	1,500	1,200	5,700	19,600	9
Hawaii[4]	—	—	—	—	1,000	5,600	—
Idaho	1,500	1,800	1,600	2,700	7,600	20,900	5
Illinois	3,800	9,800	11,200	8,800	33,600	117,300	8
Indiana	3,400	6,200	7,500	6,700	23,800	100,000	14
Iowa	1,100	3,400	4,500	3,100	12,100	35,300	8
Kansas	1,900	4,500	4,100	3,300	13,800	36,700	10
Kentucky	1,000	1,700	2,000	1,600	6,300	17,600	6
Louisiana	3,700	5,000	4,600	4,300	17,600	66,800	5
Maine	1,400	900	2,700	2,000	7,000	22,100	4
Maryland	3,800	4,900	4,200	3,700	16,600	89,800	10
Massachusetts	1,300	2,400	2,200	2,400	8,300	38,200	7
Michigan	4,100	15,200	17,700	19,000	56,000	140,000	10
Minnesota	3,700	8,900	15,400	10,200	38,200	80,200	17
Mississippi	2,900	5,500	5,900	4,900	19,200	59,000	9
Missouri	2,400	2,800	4,300	2,700	12,200	40,200	6
Montana[4]	—	—	—	—	5,500	13,900	—
Nebraska	1,800	5,000	6,000	4,000	16,800	45,700	8
Nevada	5,700	7,200	6,700	5,500	25,100	93,500	7
New Hampshire	1,500	1,100	3,100	2,400	8,100	28,600	6
New Jersey	2,500	3,900	3,600	3,100	13,100	61,500	8
New Mexico	1,600	4,000	5,300	3,300	14,200	46,900	4
New York	2,900	5,800	7,900	4,700	21,300	83,200	11
North Carolina	2,900	3,500	2,700	2,500	11,600	51,200	7
North Dakota[4]	—	—	—	—	5,000	10,400	—
Ohio	5,600	12,900	15,800	12,800	47,100	157,800	14
Oklahoma	1,700	1,900	1,800	1,700	7,100	16,900	8
Oregon	2,200	3,500	3,100	3,700	12,500	44,900	4
Pennsylvania	2,500	6,900	7,900	6,000	23,300	115,500	15
Rhode Island[4]	—	—	—	—	1,000	3,700	—
South Carolina	2,000	2,000	1,900	1,500	7,400	25,800	6
South Dakota	300	2,400	2,900	1,500	7,100	27,600	7
Tennessee	900	1,800	1,700	1,100	5,500	21,500	7
Texas	12,000	14,200	15,000	14,600	55,800	210,700	13
Utah	2,100	4,100	5,900	3,100	15,200	47,000	5
Vermont	400	1,400	2,500	2,100	6,400	19,000	5
Virginia	2,800	3,800	3,200	2,900	12,700	52,900	7
Washington	8,200	11,000	13,300	11,000	43,500	158,600	10
West Virginia	300	800	900	900	2,900	8,600	5
Wisconsin	2,900	7,700	8,900	8,600	28,100	76,400	13
Wyoming	1,000	1,200	2,100	800	5,100	17,900	6
Total[2]	XX	XX	XX	XX	927,100	3,408,700	XX

XX Not applicable.

[1]As published in the "Crushed Stone and Sand and Gravel in the Fourth Quarter of 1990," Mineral Industry Survey.

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

[3]Number of companies reporting for the quarterly survey.

[4]Owing to a very low number of reporting companies in some States, no production estimates by quarters were generated.

TABLE 7

CONSTRUCTION SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES IN 1990, BY USE

Use	Quantity (thousand short tons)	Value (thousands)	Value per ton
Concrete aggregates (including concrete sand)	240,076	$947,843	$3.95
Plaster and gunite sands	10,007	43,599	4.36
Concrete products (blocks, bricks, pipe, decorative, etc.)	11,171	45,840	4.10
Asphaltic concrete aggregates and other bituminous mixtures	76,491	326,590	4.27
Road base and coverings	135,642	428,314	3.16
Road stabilization (cement)	1,819	5,198	2.86
Road stabilization (lime)	772	2,638	3.42
Fill	73,152	173,624	2.38
Snow and ice control	7,307	24,971	3.42
Railroad ballast	869	3,590	4.13
Roofing granules	566	2,876	5.08
Filtration	1,110	6,113	5.51
Other	16,466	58,322	3.54
Unspecified:			
Actual	219,893	837,118	3.81
Estimated	115,237	342,757	2.97
Total[1] or average	910,600	3,249,400	3.57

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

material that is "sold or used" by the companies and is defined as such. Stockpiled production is not reported until it is sold to a user or consumed by the producer outside its own operation. Because no consumption surveys are conducted by the U.S. Bureau of Mines, the "sold or used" tonnage is assumed to represent the amount produced for domestic consumption and export.

Of the 911 million tons of construction sand and gravel produced in 1990, 26.4% was used as concrete aggregates; 15.2% for road base and coverings and road stabilization; 8.4% as asphaltic concrete aggregates and other bituminous mixtures; 8% as construction fill; 1.2% for concrete products such as blocks, bricks, pipes, etc.; 1.1% for plaster and gunite sands; and the remainder for snow and ice control, railroad balast, roofing granules, filtration, and other miscellaneous uses. Because some producers did not report a breakdown by end uses, their total production as well as the estimated production for nonrespondents were included in "Other unspecified uses," which represents 36.8% of the U.S. total. Two-thirds of this total was production reported by producers, and only one-third was production estimated for nonrespondents. The estimated production for nonrespondents represents only 12.7% of the U.S. total, a relatively small percentage, taking into account the number of producers covered by this survey.

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, 33.5%, the South, 29.4%, and the Midwest, 25.5%, regions with high levels of construction activity. Most of the sand and gravel for road base and coverings was used in the West, 43.3%, and the Midwest, 34.4%, while most of the sand and gravel used for asphaltic concrete aggregates and other bituminous mixtures was used in the West, 46.5%, and the Midwest, 30.1%.

Additional information regarding production and consumption of construction sand and gravel by major uses in each State and the State districts is published in the U.S. Bureau of Mines Minerals Yearbook State chapters, Volume II of the U.S. Bureau of Mines 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. Reports regarding the method of transportation were provided by the producers for about 63.4% of the total production of construction sand and gravel. Of this total, 69.5% was transported by truck, 2.5% by waterway, and 1% by rail. A significant amount of construction sand and gravel produced, about 25.9%, was not transported and, therefore, was used at site. 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

TABLE 8

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS

(Thousand short tons

State	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
Alabama	5,999	16,379	W	W	W	W	589	4,400	920	2,190
Alaska	1,680	5,276	W	W	W	W	1,052	3,039	832	2,718
Arizona	3,198	11,788	878	1,632	379	1,538	2,586	8,973	3,768	8,518
Arkansas	2,299	7,448	3	12	143	390	476	1,633	833	2,511
California	47,198	227,722	2,750	15,487	587	3,781	15,325	87,017	19,890	83,529
Colorado	6,224	22,730	235	1,192	1,352	5,480	3,078	14,180	7,093	20,130
Connecticut	1,480	9,363	8	137	W	W	272	1,272	506	2,570
Delaware	577	2,267	W	W	106	435	W	W	—	—
Florida	8,377	30,906	249	867	427	1,489	125	1,084	W	W
Georgia	2,357	7,266	177	457	W	W	48	75	—	—
Hawaii	W	W	—	—	—	—	—	—	50	227
Idaho	1,613	5,598	48	170	13	50	850	2,467	5,256	14,677
Illinois	15,332	44,238	239	876	855	2,855	2,626	9,776	4,906	21,461
Indiana	7,055	18,511	106	444	580	1,691	1,750	5,547	2,514	8,931
Iowa	2,098	7,321	47	209	101	378	417	1,264	1,704	4,116
Kansas	2,258	4,880	178	383	64	201	1,212	2,868	2,448	5,150
Kentucky	557	1,675	W	W	45	270	76	181	W	W
Louisiana	3,715	12,126	W	W	—	—	568	5,771	247	737
Maine	775	3,942	2	9	W	W	405	2,791	1,676	4,848
Maryland	9,144	53,559	230	1,031	61	228	1,134	5,939	1,638	5,187
Massachusetts	3,484	18,404	72	633	205	1,842	889	4,283	1,345	3,814
Michigan	7,461	22,015	75	286	310	1,189	4,007	11,788	6,574	16,216
Minnesota	4,604	14,944	161	668	502	1,208	3,755	9,909	6,689	11,796
Mississippi	4,259	17,503	58	276	41	156	1,546	6,226	1,442	4,134
Missouri	3,250	9,067	49	137	333	829	803	1,312	366	1,392
Montana	888	3,355	2	4	W	W	1,262	4,235	2,204	5,150
Nebraska	1,869	5,213	162	310	206	469	755	1,949	3,865	10,078
Nevada	2,726	12,015	253	1,350	85	625	1,949	6,510	4,811	13,655
New Hampshire	778	4,612	W	W	42	251	731	3,693	513	2,129
New Jersey	5,226	24,687	377	1,906	251	1,390	1,108	5,504	1,017	6,239
New Mexico	1,881	7,788	156	635	11	27	1,720	7,163	1,708	6,367
New York	8,667	43,812	316	1,403	957	4,957	1,893	9,682	6,725	21,740
North Carolina	3,569	12,582	1,122	3,056	118	354	1,217	6,614	750	2,597
North Dakota	W	W	W	W	W	W	309	1,147	2,957	5,001
Ohio	11,424	38,807	234	1,334	1,247	4,951	5,573	18,898	7,008	28,732
Oklahoma	2,948	6,555	49	137	50	311	403	699	1,203	2,675
Oregon	3,669	14,207	19	113	9	45	2,377	10,902	4,183	16,100
Pennsylvania	6,718	34,767	239	1,745	497	2,911	2,426	13,153	5,189	19,633
Rhode Island	461	2,630	W	W	W	W	W	W	266	895
South Carolina	4,492	14,448	331	878	108	276	272	681	462	2,157
South Dakota	657	2,875	5	23	4	24	356	1,509	3,554	6,897
Tennessee	2,313	7,354	145	761	150	704	832	3,306	1,754	3,843
Texas	16,935	61,453	241	1,125	42	246	1,146	4,725	2,387	7,242
Utah	3,873	14,912	75	233	267	838	2,036	10,496	3,054	9,243
Vermont	336	1,611	W	W	17	79	352	1,971	1,103	2,819
Virginia	1,570	7,653	169	1,042	97	310	681	2,905	282	1,556
Washington	6,185	22,890	69	218	505	1,289	2,936	10,796	5,486	18,614
West Virginia	1,373	7,699	—	—	—	—	335	1,286	470	1,772
Wisconsin	4,913	14,593	80	506	213	686	1,457	3,335	5,000	11,313
Wyoming	1,027	3,025	5	47	W	W	424	2,119	1,448	4,421
Total[2]	239,492	944,471	9,614	41,732	10,980	44,753	76,139	325,073	138,096	435,720
Undistributed	582	3,373	393	1,868	194	1,083	354	1,519	137	423
U.S. total[2]	240,076	947,843	10,007	43,599	11,171	45,840	76,491	326,590	138,233	436,150

W Withheld to avoid disclosing company proprietary data, included by State in "Other and undistributed uses" column, and by use in "Undistributed" line. XX Not applicable.
[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]Less than 1/2 unit.

IN THE UNITED STATES IN 1990, BY STATE AND MAJOR USE

and thousand dollars)

Fill		Snow and ice control		Railroad ballast		Other and undistributed uses		Total[2]	
Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
146	246	—	—	7	20	6,443	27,008	14,103	50,243
10,956	28,987	339	1,344	—	—	241	436	15,100	41,800
345	1,065	—	—	289	927	16,472	15,726	27,915	92,166
52	182	W	W	—	—	5,857	23,299	9,663	35,475
7,139	24,409	62	341	98	468	39,165	183,246	132,214	626,000
1,703	2,975	683	2,113	17	68	4,554	17,673	24,938	86,541
788	2,601	364	1,782	—	—	5,125	20,219	8,542	37,943
597	1,273	4	17	—	—	900	2,976	2,184	6,967
635	1,329	—	—	—	—	8,659	23,448	18,472	59,123
35	94	—	—	2	10	2,538	8,743	5,158	16,644
—	—	—	—	W	W	387	2,232	438	2,459
579	776	75	517	9	36	779	1,299	9,222	25,590
3,700	9,354	106	289	74	278	4,541	15,603	32,380	104,728
2,440	5,749	219	673	W	W	9,216	35,340	23,879	76,886
707	1,381	88	313	W	W	9,792	31,451	14,953	46,432
1,013	1,495	60	157	W	W	3,631	9,038	10,863	24,170
287	415	—	—	—	—	7,837	27,040	8,802	29,581
131	244	—	—	W	W	9,929	37,024	14,589	55,902
987	2,976	757	1,846	—	—	3,264	12,937	7,865	29,349
700	1,495	W	W	—	—	5,364	36,584	18,271	104,023
1,164	3,308	322	1,483	W	W	5,292	17,698	12,774	51,466
3,381	7,604	365	877	15	38	31,541	93,043	53,729	153,057
986	1,407	330	854	10	70	16,833	36,646	33,869	77,502
231	329	—	—	—	—	5,454	17,193	13,032	45,817
303	632	51	165	W	W	4,089	11,562	9,243	25,097
193	291	45	138	(3)	(3)	519	1,147	5,114	14,319
477	919	84	190	3	6	4,032	10,922	11,453	30,056
979	2,090	31	117	8	41	7,535	22,604	18,377	59,008
571	1,223	170	444	—	—	5,096	14,247	7,901	26,599
953	3,752	121	621	62	487	4,746	19,659	13,862	64,245
338	755	—	—	3	18	4,545	16,954	10,362	39,708
2,571	6,192	1,613	5,694	19	97	6,989	27,949	29,750	121,525
906	1,463	14	48	—	—	4,038	18,157	11,733	44,872
144	243	3	11	W	W	4,229	10,819	7,644	17,219
4,903	13,710	238	861	W	W	13,924	58,102	44,552	165,394
1,267	1,805	39	81	—	—	3,276	9,730	9,235	21,993
434	1,245	93	499	W	W	5,002	17,818	15,785	60,928
599	2,277	195	911	—	—	5,021	21,952	20,883	97,348
116	209	9	96	—	—	1,117	5,213	1,969	9,042
948	1,195	W	W	—	—	2,014	5,307	8,627	24,941
565	737	37	60	—	—	4,512	11,565	9,689	23,689
334	610	W	W	W	W	2,091	6,896	7,619	23,474
2,338	3,576	1	3	—	—	23,005	79,712	46,093	158,080
1,979	2,729	90	162	W	W	2,227	6,266	13,601	44,881
304	542	220	619	(3)	2	1,343	4,305	3,675	11,948
2,284	5,055	46	135	—	—	7,967	30,293	13,096	48,950
8,651	18,434	201	691	132	585	16,085	59,550	40,251	133,067
274	1,269	2	4	—	—	754	2,920	3,208	14,950
1,948	2,760	156	492	—	—	15,805	40,063	29,572	73,750
72	222	34	57	W	W	1,319	4,556	4,329	14,446
73,152	173,624	7,266	24,705	748	3,151	353,272	1,247,186	910,600	3,249,400
—	—	41	266	119	441	XX	XX	XX	XX
73,152	173,624	7,307	24,971	869	3,590	XX	XX	910,600	3,249,400

TABLE 9

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1990, 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	7,315	40,562	W	W	379	3,002	2,759	14,518	5,409	17,074
Middle Atlantic	20,612	103,266	932	5,054	1,704	9,258	5,427	28,338	12,930	47,612
Midwest:										
East North Central	46,185	138,164	734	3,446	3,205	11,372	15,413	49,344	26,003	86,653
West North Central	15,077	46,175	646	1,952	1,218	3,129	7,606	19,959	21,583	44,429
South:										
South Atlantic	31,460	136,380	2,334	7,620	953	3,223	4,054	19,594	3,725	13,657
East South Central	13,127	42,910	367	1,624	238	1,141	3,043	14,114	4,131	10,212
West South Central	25,896	87,582	W	W	235	947	2,593	12,827	4,670	13,164
West:										
Mountain	21,429	81,210	1,653	5,264	2,134	8,618	13,906	56,143	29,342	82,161
Pacific	58,975	271,594	2,843	15,869	1,104	5,149	21,690	111,754	30,440	121,187
Total[2]	240,076	947,843	10,007	43,599	11,171	45,840	76,491	326,590	138,233	436,150

	Fill		Snow and ice control		Railroad ballast		Other uses		Total[2]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Northeast:										
New England	3,930	10,859	1,842	6,270	W	W	20,906	72,617	42,726	166,347
Middle Atlantic	4,122	12,221	1,929	7,225	82	584	16,756	69,560	64,495	283,118
Midwest:										
East North Central	16,372	39,176	1,084	3,192	139	448	74,977	242,018	184,113	573,815
West North Central	4,194	6,812	654	1,750	36	260	46,701	119,700	97,715	244,166
South:										
South Atlantic	6,379	13,172	88	337	2	10	31,753	126,475	80,748	320,469
East South Central	998	1,599	W	W	W	W	21,627	77,365	43,555	149,115
West South Central	3,788	5,807	W	W	W	W	42,026	149,656	79,581	271,450
West:										
Mountain	6,189	10,903	958	3,104	331	1,101	37,917	128,156	113,858	376,660
Pacific	27,180	73,075	694	2,875	255	1,111	60,606	261,640	203,787	864,254
Total[2]	73,152	173,624	7,307	24,971	869	3,590	353,272	1,247,186	910,600	3,249,400

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.

transportation, overhead costs, and profit.

Compared with that of 1988, when the last full annual survey was conducted, the 1990 average unit prices increased 5.3% to $3.57 per ton. By uses, the unit prices varied from a high of $5.51 for filtration sand to a low of $2.37 for fill. The largest increases in unit prices by uses were recorded for road stabilization-lime, 30%; roofing granules, 25.7%; asphaltic concrete aggregates and other bituminous mixtures, 10.3%; concrete products, 9.6%; road stabilization-cement, 5.9%; and road base and coverings, 4.3%. Average unit prices for railroad ballast and plaster and gunite sands showed a decline of 7.6% and 6.8%, respectively.

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 decreased 58.4% to 468,000 tons compared with that of 1989, while the value decreased 12.6% to $11.9 million. Canada was the major destination, receiving about 62.6% of the total, followed by Mexico with 15.8%. No information on exports of construction gravel was available for this year from the Bureau of the Census due to some changes made in the reporting procedures under the new

TABLE 10

CONSTRUCTION SAND AND GRAVEL PRODUCTION IN THE UNITED STATES IN 1990, BY SIZE OF OPERATION

Size range	Number of operations	Percent of total	Quantity (thousand short tons)	Percent of total
Less than 25,000	1,720	30.4	17,316	1.9
25,000 to 49,999	844	14.9	31,002	3.4
50,000 to 99,999	1,000	17.7	72,169	7.9
100,000 to 199,999	888	15.7	128,239	14.1
200,000 to 299,999	415	7.2	101,307	11.0
300,000 to 399,999	233	4.1	80,027	8.8
400,000 to 499,999	157	2.8	69,689	7.7
500,000 to 599,999	103	1.8	56,308	6.2
600,000 to 699,999	73	1.3	47,094	5.2
700,000 to 799,999	47	.8	35,201	3.9
800,000 to 899,999	40	.7	33,844	3.7
900,000 to 999,999	26	.5	24,639	2.7
1,000,000 to 1,499,999	74	1.3	90,244	9.9
1,500,000 to 1,999,999	18	.3	30,650	3.4
2,000,000 to 2,499,999	9	.2	19,696	2.2
2,500,000 and over	18	.3	73,154	8.0
Total	5,665	100.0	[1]910,600	100.0

[1]Data do not add to total shown because of independent rounding.

harmonized coding system.

Imports.—Imports of construction sand and gravel increased 191.3% to 1.7 million tons compared with that of 1989, while the value increased 138.1% to $22.9 million. The significant increase in imports is due to the fact that the 1990 data include construction sand and gravel, while in 1989 no data on construction gravel were available. Canada was the major source of imported construction sand and gravel with 56.4% of the total, followed by the Bahamas with 19.4%, and Antigua and Barbuda, and Australia with 7.5% each.

Current Research

The 5-year Strategic Highway Research Program (SHRP), which will conclude in 1992, passed its midpoint this year. The program made significant progress toward its main goal of improving the Nation's highways through the use of high-performance technology. SHRP's mission is to produce usable research results targeted toward technical areas where there is potential for rapid progress that could yield significant cost savings. SHRP was conceived as a research program with the following distinguished characteristics: an accelerated research activity to be conducted during the short 5-year life of the

TABLE 11

NUMBER OF CONSTRUCTION SAND AND GRAVEL OPERATIONS AND PROCESSING PLANTS IN THE UNITED STATES IN 1990, BY GEOGRAPHIC REGION

Geographic region	Mining operations on land				Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable	Number of plants or unspecified		
Northeast:						
New England	167	183	28	51	3	432
Middle Atlantic	208	257	42	68	33	608
Midwest:						
East North Central	375	404	56	102	78	1,015
West North Central	319	460	42	107	202	1,130
South:						
South Atlantic	134	41	14	96	116	401
East South Central	86	38	8	22	61	215
West South Central	191	50	10	143	89	483
West:						
Mountain	264	414	67	51	16	812
Pacific[1]	279	144	60	62	24	569
Total	2,023	1,991	327	702	622	5,665

[1]An undetermined number of operations leased from the Bureau of Land Management in Alaska are counted as one operation.

TABLE 12

NUMBER OF CONSTRUCTION SAND AND GRAVEL OPERATIONS AND PROCESSING PLANTS IN THE UNITED STATES IN 1990, BY STATE

State	Mining operations on land				Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable	Number of plants or unspecified		
Alabama	30	5	2	7	21	65
Alaska[1]	2	1	2	4	3	12
Arizona	56	55	15	4	2	132
Arkansas	20	17	1	9	6	53
California	147	67	33	12	13	272
Colorado	49	124	15	17	10	215
Connecticut	34	19	8	4	2	67
Delaware	5	—	—	1	2	8
Florida	7	1	—	1	33	42
Georgia	11	1	—	5	28	45
Hawaii	1	2	1	3	—	7
Idaho	14	41	2	11	1	69
Illinois	53	31	13	21	25	143
Indiana	59	23	6	3	17	108
Iowa	79	51	4	13	25	172
Kansas	38	26	3	27	46	140
Kentucky	7	8	3	—	3	21
Louisiana	35	11	—	6	25	77
Maine	24	55	4	20	—	103
Maryland	21	7	6	21	4	59
Massachusetts	55	42	10	8	—	115
Michigan	87	180	6	29	12	314
Minnesota	57	163	17	24	5	266
Mississippi	29	22	3	9	25	88
Missouri	22	25	2	4	25	78
Montana	25	33	1	—	—	59
Nebraska	21	37	4	4	100	166
Nevada	25	33	8	7	—	73
New Hampshire	27	24	3	1	—	55
New Jersey	38	3	2	7	14	64
New Mexico	29	63	12	2	—	106
New York	109	212	30	51	7	409
North Carolina	37	12	3	45	23	120
North Dakota	37	51	5	1	—	94
Ohio	115	24	13	35	22	209
Oklahoma	38	10	1	58	35	142
Oregon	45	16	9	5	6	81
Pennsylvania	61	42	10	10	12	135
Rhode Island	8	1	2	—	—	11
South Carolina	17	8	1	11	12	49
South Dakota	65	107	7	34	1	214
Tennessee	20	3	—	6	12	41
Texas	98	12	8	70	23	211
Utah	51	34	12	5	—	102
Vermont	19	42	1	18	1	81
Virginia	31	12	3	12	12	70
Washington	84	58	15	38	2	197
West Virginia	5	—	1	—	2	8
Wisconsin	61	146	18	14	2	241
Wyoming	15	31	2	5	3	56
Total	2,023	1,991	327	702	622	5,665

[1]An undetermined number of operations leased from the Bureau of Land Management in Alaska are counted as one operation.

TABLE 13

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1990, BY REGION AND METHOD OF TRANSPORTATION

(Thousand short tons)

Geographic region	Truck	Rail	Water	Other	Not transported	Not specified	Total[1]
Northeast:							
New England	16,235	—	12	119	7,874	18,486	42,726
Middle Atlantic	38,558	80	783	66	11,463	13,543	64,495
Midwest:							
East North Central	80,962	150	3,535	992	33,496	64,978	184,113
West North Central	36,096	269	2,164	177	12,559	46,449	97,715
South:							
South Atlantic	36,444	1,105	2,378	865	8,440	31,515	80,748
East South Central	16,890	311	1,213	435	4,497	20,210	43,555
West South Central	25,359	1,037	—	76	11,798	41,311	79,581
West:							
Mountain	51,788	416	—	1,231	19,297	41,126	113,858
Pacific	98,645	2,463	4,279	2,426	40,208	55,767	203,787
Total	401,000	5,800	14,400	6,400	149,600	333,400	910,600

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

program; a dollar-driven and performance-oriented program; management-directed activities determined by management imperatives; and a product-oriented program designed to develop better and more useful highway technology for immediate practical application.[6] SHRP's research activities account today for more than one-quarter of all highway research conducted in the United States by the Federal agencies, the States, and the private industry.

SHRP's four areas of research are asphalt, concrete and structures, highway operations, and long-term pavement performance. The broad objective of SHRP's research program in the asphalt area is to improve the long-term durability and cost-effectiveness of the Nation's annual $10 billion-plus investment in asphalt pavements. Preliminary drafts of the performance-based specifications for asphalt and asphalt binders were released for discussion in 1990. The report indicates that "the chemical and physical properties of the asphalt binder determine, to an important degree, the level of performance achieved by the asphalt pavement."[7] Accordingly, chemical analysis of the asphalt yields a large amount of information on how the asphalt will perform as a binder in pavement. An initial draft of specifications for asphalt-aggregate mixture was also released in an effort to generate input from users and producers. "The specifications address five pavement performance characteristics—aging, fatigue cracking, moisture sensitivity, permanent deformation, and low-temperature cracking. Applying mixture and binder specifications in the design of specific highways will enable designers to account for severe traffic and climatic conditions. The result will be more durable and economical pavements."[8]

The concrete and structure program includes research in the area of improved concrete materials and corrosion of steel in concrete structures. Tables that provide guidance for curing concrete, developed by the Pennsylvania State University, and a new test for selecting the type of concrete to be used depending on the environment in which the concrete will be placed are some of the emerging products from the concrete program. A new test for control of freeze-thaw damage was developed as an alternative to the standard ASTM C-666B test, as well as a fiber-optic air meter, a portable, battery-operated device for measurement on-site of air voids in fresh concrete. All new products and methods will be pilot-tested by State highway agencies around the country.

Highway maintenance problems and their high costs are addressed by SHRP's highway operations research program, while SHRP's long-term pavement performance (LTPP) program is measuring pavement performance in different climate, traffic, and subgrade conditions.

A Midcourse Assessment meeting organized by SHRP in Denver, CO, on August 1-3, 1990, was attended by more than 400 representatives of State highway agencies, research organizations, and the industry. SHRP's activities and progress of the research program were examined by the participants, and specific recommendations were made regarding the direction of the program.[9]

For a long time, good base design and good drainage under pavements was the accepted rule among pavement designers. The development of "rational" methods of pavement design in the 1950's and 1960's led to the belief that pavements could be built strong enough to resist damage without the benefits of good drainage.[10] That rationale let the designers increase the thickness and strength of pavements, while reducing drainage capabilities (capacity) of the base and subbase layers. The bases became also denser and stronger in order to be able to carry heavier loads during the construction and especially after the completion of the roads. Over the years, the inadequate

TABLE 14

U.S. EXPORTS OF CONSTRUCTION SAND AND GRAVEL[1] IN 1990, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	Sand	
	Quantity	F.a.s. value[2]
North America:		
Bahamas	1	12
British Virgin Islands	2	22
Canada	293	3,956
Dominican Republic	1	6
Guadeloupe	5	70
Mexico	74	2,157
Netherlands Antilles	11	96
Panama	3	279
Other	1	249
Total	391	[3]6,846
South America:		
Argentina	1	107
Colombia	12	401
Ecuador	1	22
Venezuela	6	308
Other	1	169
Total	21	1,006
Europe:		
Austria	1	11
Belgium	2	59
France	1	29
Netherlands	1	32
Switzerland	1	130
Other	1	388
Total	7	[3]651
Asia:		
Japan	2	350
Korea, Republic of	6	732
Philippines	1	25
Singapore	9	423
Taiwan	3	718
Other	1	169
Total	22	2,417
Oceania:		
Australia	13	361
New Zealand	2	48
Other	—	—
Total	15	[3]408
Middle East:		
Oman	1	59
Other	(4)	219
Total	1	[3]277
Africa:		
Gabon	1	36
Nigeria	10	151
Other	(4)	89
Total[3]	12	275
Grand total	468	[3]11,880

[1]Information on exports of gravel was not available for 1990.
[2]Value of material at U.S. port of export; based on transaction price, including all charges incurred in placing material alongside ship.
[3]Data may not add to totals shown because of independent rounding.
[4]Less than 1/2 unit.

drainage of pavement structures was identified as one of the primary causes of pavement distress and failure in today's highways.

Today, a different design approach is emerging. Rather than using impermeable dense-graded materials, several States started to use open-graded permeable bases that allow moisture to rapidly drain through the base and out from beneath the pavement structure. Permeable bases usually consist of open-graded crushed aggregate with very limited amount of fines and a longitudinal edge-drain system that collects the water from the permeable base. The permeable bases are used mostly under portland cement concrete pavements, but their use under asphaltic concrete pavement is increasing. There are two kinds of permeable bases in use: the untreated or unbound permeable bases that are dense-graded aggregate material with reduced amount of fines and the treated or bound with either asphaltic concrete or portland concrete bases. Many States have used the permeable base design method for some time, with California, Michigan, New Jersey, and Pennsylvania being the most advanced States. Performance data indicate that properly designed and constructed permeable bases virtually eliminate pumping, faulting, and cracking of pavements. Studies of pavements constructed on permeable bases in California suggest a minimum service life increase of 33% and 50%, respectively, for asphalt concrete and portland cement concrete pavements constructed on permeable bases.[11]

For the existing roads built on dense graded bases, a patented process for installing transverse drains under the joints of concrete pavements is being tested in Wisconsin.[12] The drains effectively remove free water from dense graded bases under the pavement joints, reducing or eliminating the pumping of fines and faulting of joints under heavy traffic. Drainage Technologies Inc., of Oconomowoc, WI, is the patent holder for the new drainage system.

At the suggestion of the National Pavement Association (NAPA), and in cooperation with the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA), a 14-day study tour of six European countries was organized in September 1990. Representatives of AASHTO, FHWA, NAPA, SHRP, The Asphalt Institute, and the Transportation Research Board visited Denmark, France, the Federal Republic of Germany, Italy, Sweden, and the United Kingdom. The objective of the tour was to exchange ideas and experience with European highway agencies and construction industry representatives regarding the design, production, and maintenance of asphalt pavements. The group members concluded that there is "a lot to learn from Europe about asphalt pavements and about pavement philosophy in general. European pavements are better than ours. The Europeans invest more in research, development, and deployment of new pavement technology. They build their pavement foundations better. They use innovative surfaces, such as Stone Mastic Asphalt, and mix in additives to a greater extent and with better results. And, the Europeans maintain their pavements to get the maximum life out of them."[13] A report summarizing the findings of the study group that also provides a plan for applying these findings in the United States was published by AASHTO.

Technology

A steep incline, high-capacity conveyor capable of operating uphill or downhill at angles of up to 70° on short or very long lifts was produced by Huwood, a United Kingdom conveyor manufacturer.[14] A troughed conveyor belt runs in parallel with a chain conveyor system. Attached to the chain are paddles shaped to the profile of the belt trough that propel the material and the belt up or down the incline. A single drive is used on the chain conveyor that allows the troughed belt to be manufactured from flexible, abrasion resistant, low tensile material. The rated operation capacity of the conveyor is 10,000 tons per hour. The conveyor will accommodate irregular-sized material, large lumps of fines, and abrasive as well as sticky or frozen materials. The conveyor is said to offer substantial cost benefits for bulk material transportation, especially in surface mine operations and stockyards.

Significant changes are taking place in the design and the use of conveyor systems and their accessories. Stationary or self-propelled conveyors are replacing in-quarry and pit-haul trucks because they provide increased productivity by moving large volumes of materials at a faster speed and lower cost. A new com-

TABLE 15

U.S. IMPORTS FOR CONSUMPTION OF CONSTRUCTION SAND AND GRAVEL, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1989		1990	
	Quantity	C.i.f. value[1]	Quantity	C.i.f. value[1]
Antigua and Barbuda	69	653	130	2,083
Australia	2	433	130	5,945
Bahamas	236	599	338	789
Barbados	—	—	8	103
Bermuda	—	—	1	11
British Virgin Islands	6	69	4	64
Canada	140	1,313	983	5,771
Dominica	14	96	6	50
Dominican Republic	—	—	1	24
Germany, Federal Republic of	19	4,839	7	4,875
Japan	54	285	43	491
Mexico	(2)	28	3	367
Norway	41	482	76	1,102
South Africa, Republic of	—	—	1	210
Taiwan	16	126	7	67
Turks and Caicos Islands	—	—	1	11
United Kingdom	1	99	3	429
Venezuela	—	—	1	8
Other	1	602	1	511
Total[3]	598	9,624	1,742	22,912

[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.
Source: Bureau of the Census.

puterized designing method for belt conveyor systems was developed by Don Suverkrup and John Cloes, mechanical engineering consultants of Bakersfield, CA.[15] Their computer program provides an improved method for producing the proper design of belt conveyors and accessories at a low cost. A review of the latest developments in conveyor systems and their accessories as well as their use was published by Rock Products.[16]

As the supply of aggregates from land-based resources becomes more restricted, European sand and gravel producers are placing more emphasis on offshore dredging of sand and gravel. To satisfy increased requirements for greater consistency of the products supplied, more sophisticated mining and processing methods are being used. For years, a common practice for offshore dredging was to do some onboard vessel screening of the dredged material. Recently, based on increased environmental concerns, some United Kingdom licenses started to prohibit onboard screening of dredged aggregates. To overcome this restriction, new excavating methods are being tested that will be more selective regarding the material being dredged. The USP Rox-Ann seabed classification system is a device that improves the efficiency of trailer-suction dredges.[17] The device works through reflected hydroacoustic signals that are able to determine the type of aggregate present in the seabed before the material is excavated. The dredging is therefore adjusted according with the information provided by the device.

Self-unloading vessels were developed and continue to thrive in the Great Lakes area. However, a new market for ocean-going self-unloaders transporting aggregates, cement, and other free flowing dry bulk commodities is developing. The main advantages provided by such vessels for transporting low-value/high-volume commodities are reduced handling costs, improved turnaround time, and capability to supply ports that are not equipped with high-capacity unloaders. These vessels are most cost effective if they perform short hauls and operate often in order to make full use of the installed equipment, but some are being used for long ocean hauls. Some new developments in the use of self-unloaders as well as reviews of some operations were published by Bulk International Journal.[18]

OUTLOOK

The demand for construction sand and gravel in 1991 is expected to be about 820 million tons, a 10% decrease from that of 1990. The slowdown of the economy that affected the construction industry in the second half of 1990 is expected to have an impact on the demand for construction sand and gravel in the first half of 1991. Gradual increases in demand for construction aggregates are anticipated after 1991, based on increased volume of work on the infrastructure expected to occur following the passage of the Surface Transportation Assistance Act of 1991. It is estimated that the demand for construction sand and gravel will reach 1 billion tons in 1995. The projected increases will be influenced by construction activity primarily in the public construction sector.

The release of the Department of Transportation comprehensive report on national transportation policy[19] indicates that a significant increase in the volume of work on the infrastructure should be expected in the next 5 to 10 years. The value of public construction work as part of the gross national product has declined constantly from about 3% in the 1950's and 1960's to less than 2% in the 1980's. If this trend begins to reverse in the 1990's, a significant increase in spending for public construction work could be expected that will dramatically alter the above forecasts.

Construction sand and gravel f.o.b. prices are not expected to increase significantly, even if the demand for construction aggregates rises over the above 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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[2]Langere, W. H. Natural Aggregates of the Conterminous United States. U.S. Geol. Surv. Bull. 1594, 1988, 33 pp.

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[8]Work cited in footnote 7.

[9]Work cited in footnote 6.

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[14]———. Hurise—New Generation Conveyor. International Bulk J. v. 10, No. 11, Nov. 1990, p. 73.

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INDUSTRIAL SAND AND GRAVEL

By Wallace P. Bolen

Mr. Bolen, a physical scientist, has been the commodity specialist for industrial sand and gravel since October 1988. Domestic survey data were prepared by Howard S. Sullivan, mineral data assistant; and the international production table was prepared by William Zajac, Chief, Section, International Data.

Probably no other nonmetallic mineral has more diversified uses than silica (industrial) sand, mainly because of its common occurrence around the world and its distinctive physical characteristics, including hardness, resistance to high temperature and chemical action, and relatively low price. Silica sand is the major component of common glasses, foundry molding and cores, abrasive blast sand, and hydraulic fracturing sand. Industrial sand and gravel is also important in ceramics, chemicals, and fillers for rubber and plastics, and also is utilized in golf courses, as a flux in smelting and chemical production, as filter media, and in many other uses.

DOMESTIC DATA COVERAGE

Production of industrial sand and gravel in 1990 decreased to 28.4 million tons, about 3% less than 1989's production. Production decreased for the first time in the past 4 years and was attributable to decreased silica usage for flat and specialty glasses, chemicals, ceramics, and roofing granules and fillers.

Exports of silica sand and gravel decreased about 44% in quantity, but the average value per ton, compared with that of 1989, increased 91%. Imports of industrial sand and gravel increased about 109% in quantity, and the associated value increased 57%. Domestic apparent consumption of industrial sand and gravel in 1990 was 27.3 million short tons, essentially the same as in 1989.

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 156 industrial sand and gravel operations surveyed, 149 (96%) reported to the U.S. Bureau of Mines. Their combined production represented about 99% of the U.S. total published in table 1. The production of nonrespondents was estimated mostly using employment data. Of the 156 operations, 154 (99%) were active and 2 idle.

BACKGROUND

One of the first industries to use silica sand was the glass industry. At least 4,000 years ago, long before iron was smelted, glassmaking was already a known craft. Although the place and date of the first manufactured glass are not known, the oldest known specimens of glass are from Babylon (ca. 2600 B.C.) and from Egypt (ca. 2500 B.C.), where the industry was well established by about 1500 B.C. Many varieties of glass were known during Roman times. Little is known of the glassmaking methods used in Europe from the fall of Rome until the 10th century, when stained glass was produced in Venice. After this, Venice remained the leader in fine glassware for the next four or five centuries. In the 17th century, a process for casting glass was invented in France, and later, England began to make flint glass, marking the beginning of modern glass technology.

Glassmaking was apparently the first industry to be transplanted from Europe to North America, first to Mexico and later to the British colonies. The first manufacturing establishment in what is now the United States was a glass factory at Jamestown, VA, built in 1608. The 1885 edition of "Mineral Resources of the United States," the predecessor of today's U.S. Bureau of Mines "Minerals Yearbook," reported a total of 317,000 tons of silica sand produced in 1884 in the United States, under "Glass Materials." In 1990, a total of 28.4 million tons of silica sand was produced in the United States for a variety of uses, of which 11.7 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,

TABLE 1

SALIENT U.S. INDUSTRIAL SAND AND GRAVEL STATISTICS[1]

(Thousand short tons and thousand dollars)

	1986	1987	1988	1989	1990
Sold or used:					
Sand:					
Quantity	26,940	27,380	27,207	27,819	26,956
Value	$354,460	$357,660	$376,202	$395,807	$420,871
Gravel:					
Quantity	484	631	1,272	1,385	1,450
Value	$4,853	$6,424	$11,796	$14,388	$15,284
Total industrial:[2]					
Quantity	27,420	28,010	28,480	29,205	28,406
Value	$359,300	$364,100	$388,000	$410,200	$436,200
Exports:					
Quantity	849	758	1,060	2,060	1,155
Value	$20,363	$21,253	$30,843	$78,308	$83,826
Imports for consumption:					
Quantity	88	104	43	35	73
Value	$1,014	$1,071	$1,918	$2,057	$3,148

[1]Puerto Rico excluded from all industrial sand and gravel statistics.
[2]Data may not add to totals shown because of independent rounding.

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. In the past 10 years, 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]

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 is 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.

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 gravel was used as the source material in the production of silicon and ferrosilicon and as a flux for the production of elemental phosphorus. Some gravel was also used as filtration media, mainly in municipal water treatment facilities.

Industry Structure

In 1990, 83 U.S. companies with 154 active operations produced silica sand and gravel. The individual industrial sand and gravel operations ranged in size from those producing about 1 million tons annually to those reporting less than 10,000 tons per year. Most of the production came from large operations that were mostly owned or operated by a small number of companies. In the past 10 to 15 years, there was a gradual trend toward larger operations, mostly because small plants were becoming less economical. The viability of small operations was dependent on demand in local markets, mining conditions, and the degree of processing required to supply the final product.

During the past 10 years, changes within the structure of the industrial sand industry occurred, primarily caused by mergers and acquisitions, some resulting from an influx of foreign capital, mostly from Europe.

Geology-Resources

U.S. resources of industrial sand 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 owned or controlled by domestic producers were estimated to total about 3 to 4 billion tons.

Although industrial sand reserve data for the rest of the world were not available, it could be assumed, on the basis of geologic evidence, that world reserves were sufficient to meet demand, even if not always at the locations where needed.

Industrial sand or silica sand was produced in the United States from a variety of geological formations ranging in age from late Precambrian to mid-Tertiary. About 70 stratigraphic units were known as having an economic potential for this industry. Lithologically, these deposits ranged from quartzites, sandstones with different degrees of cementation, quartz conglomerates, chert deposits, and quartz pegmatites to terrace sands and gravels and dune sands. Most of the high-quality industrial sand was produced from a few geological formations in the Eastern United States. Oriskany sandstone, or more precisely the Ridgeley formation of Early Devonian age, was one important source of silica sand. It extended from New York State to southern Virginia and eastern Ohio, but was being mined only in central Pennsylvania, northwestern Maryland, and northern West Virginia, where the formation was thick enough to be of commercial value. It was a hard, white orthoquartzite with medium to fine, angular and subangular, and well-sorted grains. The St. Peter sandstone of Middle Ordovician age, extending from Wisconsin and Minnesota through Iowa, Illinois, and east-central Missouri, was another major source of industrial sand. The best known center of production of silica sand from this formation was the Ottawa district of La Salle County, IL, where it was known as "Ottawa sand," and to a lesser degree in southern Wisconsin and east-central Missouri. It was a soft and poorly cemented high-purity orthoquartzite with coarse, rounded grains. The weak cement holding the silica grains together was mostly a light-colored clay.

In addition to the two formations just mentioned, the most important sources of industrial sand in the United States, numerous other deposits were also being mined for silica sand in different parts of the country. Included are the Jordan sandstone of Upper Cambrian age in Minnesota and Wisconsin, a primary source of hydraulic fracturing sand; the Raritan formation of Upper Cretaceous age in central New Jersey and the Cohansey sand of probable Miocene age in southern New Jersey; and the Tuscarora quartzite of Lower Silurian age in Pennsylvania and Virginia used for the manufacture of refractory bricks. Other deposits are the Sylvania sandstone of Devonian age in the Detroit area; the Oil Creek and McLish formations of Lower Ordovician age in Oklahoma, a southwestward extension of the St. Peter sandstone; and the Hickory sandstone of Cambrian age in central Texas that produced mostly hydraulic fracturing sand.

In the West, the most important sources of industrial sand were the Ione formation of Eocene age in northern California, the Silverado (Paleocene) and Tejon (Eocene) formations in southern California, and the Eureka quartzite of Middle Ordovician age in central California.

Just under 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 one-half of 1990 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.

Technology

Exploration.—A large number of geologic formations with economic potential as a source of industrial sand have been mapped and described in the literature over many years and were, therefore, well known. Consequently, detailed exploration and development work for new industrial sand operations was expected to occur on some of these formations. The qualities of a silica deposit necessary for a viable operation should include proper particle size, chemical composition, degree of cementation, and deposit uniformity. Also, the nature and amount of waste material and the economic feasibility of its removal and possible use or

disposal should be studied. The evaluation of the new deposit should also include an environmental impact study as required by most local or State agencies before authorizing a new mining operation.

If the raw material should prove to meet the requirements and adequate reserves are demonstrated, the development stage of the operation could be started. Economic feasibility and marketing studies should be performed by analyzing all factors important for any such mining operations. Included are the availability of power and water supply, mining and processing costs and requirements, and the condition of nearby roads and highways. Other factors include the proximity of rail haulage; the cost of compliance with local, State, and Federal regulations; and the proximity and density of local population as well as its attitude toward such a project.

Mining.—Most industrial sand was mined from open quarries, but a few underground operations existed, mostly because of an exceptionally thick overburden or environmental limitations. Surface mining methods and equipment varied with the type of the geologic formation, size and configuration of the deposit, production capacity, estimated life of the operation, and location of the deposit with respect to urban centers. The mining methods depended primarily on the degree of cementation of the rock, although most open pit mining operations included site clearing and removal of the overburden; mining of the silica rock or sand; processing of the material, including crushing, screening, and classification; and reclamation of the extraction area. Unconsolidated sands, such as the Cohansey of New Jersey, below the ground water level were dredged. Much of the St. Peter sandstone was first loosened by light blasting and then washed down by hydraulic jets or "monitors" into sumps, from which it was pumped to the processing plants. Harder rock such as the Oriskany sandstone required blasting and primary and secondary crushing before it could be processed.

Processing.—Processing of mined silica sand required specialized operations that varied considerably with the nature of the deposit and the physical and chemical requirements of the desired product. Depending on the degree of cementation, several stages of crushing were necessary to achieve the desired size reduction. Gyratory crushers, jaw crushers, impact mills, or roll crushers were used as primary or secondary crushers, and smooth rolls, media mills, autogenous mills, high-speed hammer mills, or fluid energy jet mills were used for grinding the product down to 50 microns and finer. Dry or wet screening was used to separate particles of sizes down to about 150 microns, and wet or air classifiers processed particles from 250 microns into the submicron range. Vibratory screens and gyratory screens, in addition to mechanical, hydraulic, or air classifiers, were used, depending on the size distribution required.

Research for the silica mining industry related not only to new methods that increased output and reduced production costs but also to health and safety problems as well as exploration, land management, and reclamation. Equipment manufacturers and some Government agencies were constantly working on improving exploration, mining, and processing plant technology.

Significant technological developments instrumental in maintaining adequate production at relatively stable real costs were mostly in the processing plant technology. The use of computerized systems in plant operation and quality control increased; this, along with improved mining and processing equipment, permitted the recovery of salable fractions that were previously considered uneconomical.

Recycling.—Recycling of silica sands was limited to some foundry sands, particularly those used for making cores and molds with no-bake resin-bonded sands, some abrasive and airblasting sands, and some scrap glass that substitutes for glass sand. International trends toward increased recycling of glass and foundries sands and innovative ideas on recycling other materials should influence increased recycling of silica products.

Byproducts and Coproducts

Small amounts of gold and silver were recovered occasionally as a byproduct or coproduct from some unconsolidated silica sand deposits. Also, during the processing of some silica resources, other minerals, including clays, feldspars, mica, and quartz crystals, were produced as byproducts and coproducts.

Economic Factors

Silica sand deposits are nonrenewable resources. New mining methods combined with advances in mineral processing that were introduced during the past decade have increased the number of silica deposits that can be commercially developed.

The industrial sand industry was very competitive, largely because silica sand is a relatively abundant mineral, with supply usually exceeding demand. The delivered price of the product, in addition to quality, was a very important element in any major transaction. The producer with an operation closest to the market had a significant advantage over competitors. Combining sophisticated (and therefore expensive) processing equipment backed by technical knowledge and solid sales expertise was important. For this reason, only a small number of large companies were able to compete successfully and succeed in the silica sand business and supply a wide variety of products. Smaller, less efficient operations became uneconomical as operating costs, as well as costs associated with meeting various Federal, State, and local regulations, continued to increase. The only alternatives they had were to either limit the range of products they supplied to close markets or go out of business.

Prices.—As a result of rapidly rising costs of labor, energy, and mining and processing equipment, 1990 constant dollar prices of industrial sand rose steadily between 1973 to 1983. From 1984 to 1990, 1990 constant dollar prices fluctuated in the 14.50 to 15.75 range. Prices should be expected to continue to fluctuate, although they should slowly rise as a result of the cost of compliance with more stringent environmental, land use, and safety regulations.

Costs.—Production costs for silica sand were determined to a large extent by the cost of labor, equipment, energy supply, water availability, and the additional burden of compliance with environmental and safety regulations. Production costs varied widely depending on the nature of the geologic deposit, the geographic location, and the type and number of products produced. Profits were relatively small for most producers, total production costs being close to the f.o.b. selling price per ton.

Tariffs.—There has been no tariff on imported silica sand containing 95% or more 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 of industrial sand and gravel were emission of particulate matter into the air, discharge of processing water, and noise abatement. Air pollution constituted a major problem in the processing plants, especially in the drying and packaging stages of finer products such as silica flour, silicosis being the major disease that can be contracted as a result of long-term exposure to silica dust. Because of the high cost of compliance with the environmental regulations designed to reduce this health hazard and possible long-term liabilities associated with it, some companies were no longer producing silica flour or did not plan to produce it in the future. Both wet and dry methods of dust control were used. The most important water pollutant was clay in suspension as a result of washing and screening silica sand. Because of the large quantities of water used to process silica sands and the need of compliance with stringent regulations the treatment of discharge water by the sand producer was expected to require increasingly sophisticated and expensive processing methods. Significant progress was made in reducing noise pollution, both inside and outside of the operations, including noise and vibration produced by blasting and movement of heavy trucks.

Sand producers had to obtain mining permits from the appropriate governmental agency, which sometimes also required an Environmental Impact Statement (EIS) and a reclamation plan that met its guidelines or regulations. More and more emphasis was being put by local communities on improving the overall appearance of the operating mines as well as on land reclamation after mining was completed. At the same time, industry and the communities had to recognize the time and costs required to protect the environment and the importance of agreeing on fair and realistic environmental standards. Many States, counties, and towns had zoning laws that regulated land use.

Most of the active silica sand quarries as well as the known deposits were on private land, which was either owned or leased on a long-term basis by the producers. These deposits contained high-quality silica sand and were in the best locations with respect to markets. Unlike the construction sand and gravel industry, the industrial sand industry was usually not significantly affected by increasing land values near populated areas.

Transportation.—Transportation costs for silica sand were often equal or considerably greater than the cost of the product at the processing plant. Because of the large variety and number of consumers of silica sand, long distance haulage was not uncommon. In 1990, the largest tonnage, 56% of all industrial sand, was shipped by truck because most users require a versatile and rapid delivery system. Substantial quantities, 40% of the total, were also shipped by rail, especially when large volumes were sent long distances. The remaining tonnage was shipped by barge or used at the mine.

ANNUAL REVIEW

Legislation and Government Programs

The Department of Labor's Mine Safety and Health Administration (MSHA) issued a proposed rule titled "Hazard Communication" on November 2, 1990. The rule would establish a MSHA standard requiring mine operators to assess the hazards of chemicals they produce or use and provide information to their employees concerning chemical hazards in regard to these chemicals. This hazard communication standard (HCS) would be similar to the Occupational Safety and Health Administration's HCS. The 41-page proposed rule covered approximately 1,000 chemical compounds and/or minerals and proposed exempting some mineral substances. However, "due to their higher degree of risk, MSHA is not considering including silica flour or certain industrial sands among the minerals exempted." The basis for not exempting silica was the report from the International Agency for Research on Cancer (IARC), in 1986, that there was limited evidence that silica is a carcinogen to humans.

Previous to this proposed rule, MSHA had already recommended that producers label silica products as a possible health hazard, but this rule would make this labeling mandatory. For larger producers, this rule would probably not add an unbearable or excessive cost, but for smaller producers, this rule could increase cost and affect their competitiveness.[4]

Production

The Midwest (East and West North Central regions) continued to lead the Nation in production with about 41% of the 28.4 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%.

Based on the 1990 census estimations on population, 1990 U.S. per capita industrial sand and gravel production was 0.11 ton. Per capita production by major geographic region was 0.23 ton in the Midwest, 0.12 ton in the South, 0.08 ton in the West, and 0.05 ton in the Northeast (Middle Atlantic and New England regions).

The five leading States in the production of industrial sand and gravel, in descending order of volume, were Illinois, California, Michigan, Texas, and New Jersey. Their combined production represented 45% of the national total. Significant changes within the five major producing States included Texas, where production increased 11%, and Michigan, where production decreased by almost 20%.

The U.S. Bureau of Mines canvassed 83 producers of industrial sand and gravel with 154 active operations. About 74% of the industrial sand and gravel was produced by 47 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., Manley Brothers of Indiana, Construction Aggregates Corp., Simplot Industries Inc., and Owens-Illinois Inc. Their combined production, from 58 operations, represented 70% of the U.S. total.

Green River Silica Co. in Hart County, KY, was purchased by Kentucky Aggregates of Glasgow, KY. Kentucky Aggregates will continue to produce sand for blasting, filtration, and golf courses.

TABLE 2

INDUSTRIAL SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY GEOGRAPHIC REGION

Geographic region	1989				1990			
	Quantity (thousand short tons)	Percent of total	Value (thousands)	Percent of total	Quantity (thousandd short tons)	Percent of total	Value (thousands)	Percent of total
Northeast:								
New England	154	1	$4,193	1	154	1	$3,755	1
Middle Atlantic	2,475	8	36,478	10	2,483	8	37,315	8
Midwest:								
East North Central	10,488	36	124,955	30	9,562	34	124,665	29
West North Central	1,881	6	27,108	7	1,948	7	31,688	7
South:								
South Atlantic	4,715	16	71,242	17	4,098	14	66,430	15
East South Central	1,446	5	16,571	4	1,533	5	17,761	4
West South Central	3,994	14	62,589	15	4,408	16	81,075	19
West:								
Mountain	1,315	5	17,657	4	1,477	5	19,803	5
Pacific	2,737	9	49,402	12	2,745	10	53,663	12
Total[1]	29,205	100	410,200	100	28,406	100	436,200	100

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

FIGURE 1

PRODUCTION OF INDUSTRIAL SAND AND GRAVEL IN THE UNITED STATES IN 1990, BY GEOGRAPHIC REGION

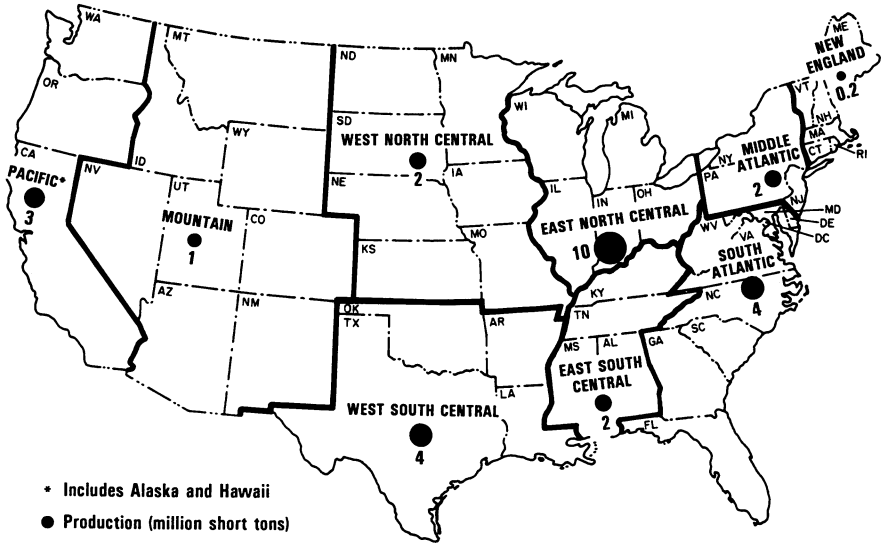


TABLE 3

INDUSTRIAL SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1989		1990	
	Quantity	Value	Quantity	Value
Alabama	805	8,092	878	9,075
Arizona	W	W	W	W
Arkansas	545	5,507	742	7,209
California	2,426	43,863	2,452	48,055
Colorado	W	W	W	W
Connecticut	W	W	W	W
Florida	681	7,768	520	7,024
Georgia	537	7,013	W	W
Idaho	459	5,037	552	6,234
Illinois	4,582	52,935	4,486	62,531
Indiana	W	W	W	W
Kansas	230	2,690	W	W
Kentucky	W	W	W	W
Louisiana	572	9,664	559	10,003
Maryland	W	W	W	W
Massachusetts	34	601	30	401
Michigan	2,865	24,577	2,310	19,285
Minnesota	W	W	W	W
Mississippi	W	W	W	W
Missouri	750	9,972	W	W
Montana	W	W	W	W
Nebraska	W	W	W	W
Nevada	718	W	607	W
New Jersey	1,797	26,138	1,762	26,190
New York	53	633	W	W
North Carolina	1,627	19,902	1,177	15,338
Ohio	1,394	24,662	1,349	24,205
Oklahoma	1,216	18,310	1,258	22,984
Pennsylvania	W	W	W	W
Rhode Island	W	W	W	W
South Carolina	842	16,635	844	15,972
Tennessee	W	W	W	W
Texas	1,661	29,107	1,849	40,880
Utah	3	60	2	42
Virginia	W	W	W	W
Washington	W	W	W	W
West Virginia	W	W	W	W
Wisconsin	1,514	22,399	W	W
Other	3,891	74,630	7,028	120,728
Total[1]	29,205	410,200	28,406	436,200

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

U.S. Silica, based in Berkeley Springs, WV, began operations at the former Card Silica Co., Harrison County, IN. In another transaction, U.S. Silica sold its McCulloch County, TX, operation to Texas Mining Co., a subsidiary of Oglebay Norton Co., Cleveland, OH. Texas Mining already operated a silica plant in McCulloch County, and this purchase adds to its reserves and increases the number of products it can market. With this latest purchase, Oglebay Norton now has five operations and has moved up to be the fifth largest producer of silica in the United States.

Unimin purchased Master Brothers Silica Sand Co. in Missouri from Bussen Quarries. Unimin now operates 17 silica operations in 13 States, further solidifying its position as the largest producer of industrial sand in the country.

Dravo Basic Materials Co. purchased the operations of R&S Materials Inc., in Macon County, AL. Dravo now operates two Alabama silica mines, both in Macon County.

Tyler Sand Co. of Tyler, TX, ceased operations after producing sand in the early months of 1990.

Bay City Silica Co., Bay City, WI, closed its silica mining operation.

Riverside Sand Co., Wallace, NC, discontinued production of sand for industrial sand markets and produced sand for the construction market only.

New industrial sand producers included in this report were G. W. Bryant Core Sands Inc., McConnellsville, NY; Huey Stockstill Inc., Picayune, MS; and Colorado Lien Co., Fort Collins, CO.

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 28.4 million tons of industrial sand and gravel sold or used, 41% was consumed as glassmaking sand and 22% as foundry sand. Other important uses were abrasive sand (8%) and frac sand (7%). Because some producers did not report a breakdown by end use, their total production as well as the estimated production for nonrespondents were included in "Other uses, unspecified," which represented about 4% of the U.S. total.

On the regional level, more than one-third of the glassmaking sand was

TABLE 4

INDUSTRIAL SAND AND GRAVEL PRODUCTION IN THE UNITED STATES IN 1990, 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	25	16.2	252	0.9
25,000 to 49,999	26	16.9	907	3.2
50,000 to 99,999	25	16.2	1,768	6.2
100,000 to 199,999	31	20.1	4,483	15.8
200,000 to 299,999	13	8.4	3,194	11.2
300,000 to 399,999	10	6.5	3,314	11.7
400,000 to 499,999	10	6.5	4,470	15.7
500,000 to 599,999	5	3.3	2,838	10.0
600,000 to 699,999	3	2.0	1,848	6.5
700,000 and more	6	3.9	5,333	18.8
Total	154	100.0	[1]28,406	100.0

[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 1990, BY GEOGRAPHIC REGION

Geographic region	Mining operations on land				Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable	No plants or unspecified		
Northeast:						
New England	4	—	—	—	—	4
Middle Atlantic	8	—	2	1	5	16
Midwest:						
East North Central	31	—	2	—	3	36
West North Central	7	—	—	—	4	11
South:						
South Atlantic	14	—	1	3	7	25
East South Central	13	—	—	—	3	15
West South Central	10	—	—	3	11	24
West:						
Mountain	9	1	—	—	1	11
Pacific	10	—	—	1	—	11
Total	106	1	5	8	34	154

produced in the South (37%), followed by the Midwest (31%) and the West (19%). Three-fourths of the foundry sand was produced in the Midwest (74%). About three-fourths of the hydraulic fracturing sand was produced in the Midwest (70%), and more than one-half of the abrasive sand was produced in the South (59%).

Northeast.—Cumberland County, NJ, continued to be the largest source for the glass and foundry sand markets in the region. Unimin, U.S. Silica, Morie, and Whibco Inc., all of which operated plants in the county, were among the largest producers of sand for these markets. U.S. Silica's plant in Huntingdon County, PA, also produced significant amounts of sand for the glass market. Morie's plant in Cumberland County and New Jersey Pulverizing Co.'s plant in Ocean County, NJ, produced a major percentage of the abrasive blast sand in the region.

Midwest.—Unimin's plants in LaSalle and Ogle Counties, IL; LeSueur and Scott Counties, MN; and Columbia County, WI, were among the leaders in producing sand for the glass, foundry, and frac sand markets. Fairmount Minerals, with operations in Geauga County, OH, and La Salle County, IL, was a major producer for the blast, foundry, and glass markets in the region. U.S. Silica's plants in St. Louis County, MO, and La Salle County, IL, and Badger Mining's plant in Jackson County, WI, were large producers for the glass and frac sand markets, respectively. Construction Aggregates Corp. in Ottawa County, MI, U.S. Silica in LaSalle County, IL, and Manley Brothers in Van Buren County, MI, were major producers of foundry sand in the region. Nugent Sand Co. Inc., in Muskegon County, MI, Badger Mining in Green Lake County, WI, and Sargent Sand Co. in Wexford County, MI, were also large producers for the foundry industry.

South.—Unimin and U.S. Silica Co. were two of the largest producers of sand for the glass and foundry markets. Unimin's major plants were in Frederick County, VA; Richmond County, NC; Pontotoc County, OK; and Izard County, AR. U.S. Silica's Bullock County, AL; Morgan County, WV; Johnston County, OK, and Limestone County, TX, operations were the major contributors for these markets. Morie's Tuscaloosa County, AL, and Marion County, GA, plants were large producers of foundry and glass sand, respectively. Huey Stockstill Inc., Pearl River County, MS, Cobb Industrial Corp., Red River Parish, LA, and Mid-State Sand and Gravel Co., Baywood and Baggett Parishes, LA, were the largest producers of blasting sand. W.R. Bonsal and Co., Anson County, NC, and Superior Products Inc., Chilton County, AL, produced the majority of the industrial gravel used in the processing of silicon and ferrosilicon. Oglebay Norton's Texas Mining Co., McCulloch County, TX, was the largest producer of frac sand in the region.

TABLE 6

INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1990, BY MAJOR END USE

Major end 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:															
Glassmaking:															
Containers	1,222	$17,084	$13.98	1,913	$15,754	$8.24	2,367	$30,736	$12.99	1,851	$32,692	$17.66	7,352	$96,266	$13.09
Flat (plate and window)	W	W	13.75	854	8,383	9.82	1,488	18,115	12.17	W	W	15.06	2,679	31,496	11.76
Specialty	W	W	16.33	395	5,778	14.63	W	W	16.97	12	203	16.92	747	11,650	15.60
Fiberglass (unground)	W	W	7.39	314	3,519	11.21	W	W	9.49	91	1,425	15.66	559	6,451	11.55
Fiberglass (ground)	—	—	—	W	W	36.00	W	W	35.10	W	W	23.50	391	13,684	35.00
Foundry:															
Molding and core	W	W	14.80	4,596	45,736	9.95	1,076	11,928	11.09	W	W	18.57	6,201	65,891	10.63
Molding and core facing (ground)	W	W	4.00	—	—	—	—	—	—	—	—	—	W	W	4.00
Refractory	W	W	20.00	113	1,508	13.35	W	W	27.83	3	73	24.33	132	1,995	15.11
Metallurgical:															
Silicon carbide	—	—	—	W	W	23.09	W	W	10.38	—	—	—	191	2,961	15.50
Flux for metal smelting	—	—	—	W	W	6.00	W	W	4.83	3	58	19.33	23	171	7.43
Abrasives:															
Blasting	218	4,518	20.72	329	6,387	19.41	1,351	24,788	18.35	400	9,555	23.89	2,298	45,248	19.69
Scouring cleansers (ground)	W	W	31.50	W	W	27.83	W	W	44.00	—	—	—	W	W	28.31
Chemicals (ground and unground)	84	2,136	25.43	282	2,973	10.54	238	4,111	17.27	46	790	17.17	651	10,010	15.38
Fillers (ground):															
Rubber, paints, putty, etc.	23	603	26.22	W	W	73.96	102	14,272	139.92	W	W	19.75	182	18,948	104.11
Silica flour	—	—	—	W	W	37.25	W	W	50.88	—	—	—	187	7,306	38.52
Ceramic (ground):															
Pottery, brick, tile, etc.	21	546	26.00	41	2,047	49.93	78	2,863	36.71	W	W	29.67	143	5,545	38.78
Filtration	106	1,815	17.12	61	1,574	25.80	175	2,780	15.89	25	815	32.60	367	6,985	19.03
Traction (engine)	W	W	2.52	130	1,283	9.87	59	668	11.32	W	W	18.23	314	2,879	9.17
Roofing granules and fillers	10	125	12.50	W	W	15.26	213	2,027	9.52	W	W	26.04	572	7,985	13.96
Hydraulic fracturing	—	—	—	1,281	33,636	26.26	W	W	23.11	W	W	27.63	1,839	46,655	25.37
Other uses, specified	849	11,358	13.38	888	20,775	23.40	1,622	38,154	23.52	870	16,136	18.55	XX	XX	XX
Other uses, unspecified[2]	W	W	28.53	W	W	23.36	495	6,839	13.82	411	7,292	17.74	1,212	21,756	17.95
Total[1] or average	2,625	40,810	15.55	11,355	153,741	13.54	9,264	157,280	16.98	3,712	69,039	18.60	26,956	420,871	15.61
Gravel:															
Metallurgical:															
Silicon, ferrosilicon	—	—	—	W	W	10.00	W	W	10.61	—	—	—	702	7,385	10.52
Filtration	12	260	21.67	W	W	50.00	W	W	10.10	—	—	—	75	1,106	14.75
Nonmetallurgical flux	—	—	—	—	—	—	W	W	8.75	W	W	8.81	599	5,272	8.80
Other uses, specified	—	—	—	154	2,611	16.95	775	7,986	10.30	W	W	8.68	XX	XX	XX
Total[1] or average	12	260	21.67	154	2,611	16.95	775	7,986	10.30	510	4,427	8.68	1,450	15,284	10.54
Grand total[1] or average	2,636	41,070	15.58	11,509	156,352	13.59	10,039	165,266	16.46	4,222	73,466	17.40	28,406	436,200	15.36

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.

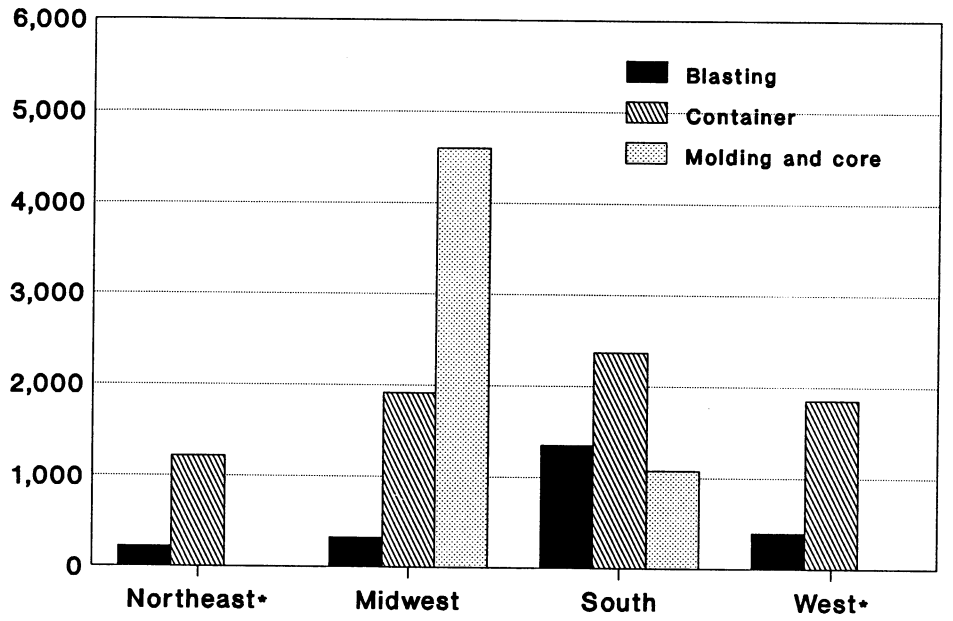
West.—Corona Industrial Sand Co., Owens-Illinois, Simplot Industries, and Unimin were the four largest producers of glass sand in the region, with major operations in Riverside County, CA, Amador County, CA, Clark County, NV, and Contra Costa County, CA, respectively. Corona Industrial Sand supplied the majority of sand for the sandblasting industry in the region. Simplot Industries also supplied a large portion of the foundry sand consumed.

Transportation

Of the total industrial sand and gravel

FIGURE 2

SAND USED IN SELECTED END USES, 1990



*Molding and core data withheld to avoid disclosing company proprietary data.

TABLE 7

TRANSPORTATION OF INDUSTRIAL SAND AND GRAVEL IN THE UNITED STATES IN 1990 TO SITE OF FIRST SALE OR USE

Method of shipment	Quantity (thousand short tons)	Percent of total
Truck	16,086	56
Rail	11,377	40
Waterway	774	3
Not transported	169	1
Total	28,406	100

produced, 56% was transported by truck from the plant to the site of first sale or use, down from 58% in 1989; 40% was transported by rail, up from 34% in 1989; 3% by waterway, unchanged from that in 1989; and only 1% was not transported, down from 5% in 1989. 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 1989, the average value, f.o.b. plant, of U.S. industrial sand and gravel increased about 9% to $15.36 per ton. Average unit values for industrial sand and industrial gravel were $15.61 and $10.54 per ton, respectively. Nationally, industrial sand used as fillers for rubber, paint, and putty, etc., had the highest value per ton ($104.11), followed by silica sand used in ceramics ($38.78), silica flour ($38.52), fiberglass (ground) ($32.06), scouring cleansers ($28.31), and frac sand ($25.37). Although the total tonnage of industrial sand, sold or used in 1990, decreased from that of 1989, the total value increased owing to substantial increases in average value for those smaller tonnage, higher average value end uses. The more traditional end uses, including glass, foundry, and blast sands, generally suffered from a decrease in demand and a subsequent drop in average value.

The average value per ton of industrial sand and gravel was highest in the West ($18.60), followed by the South ($16.98), the Northeast ($15.55), and the Midwest ($13.54). Glass sand average value per ton varied markedly, from $17.56 in the West to $18.35 in the Midwest. Tighter supplies and higher production and transportation 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 1989, decreased 44% to 1,155,000 tons, but the value increased 7% to $83.8 million. Of this, 70% went to Canada, 8% went to Mexico, 6% went to Japan, and the remainder went to numerous other countries throughout the world.

Imports.—Compared with those of 1989, imports for consumption of industrial sand increased 109% to 73,000 tons valued at $3.1 million. Of this, 96% came from Australia and 4% came from Canada. Small amounts of specially prepared silica sand from Belgium, Canada, France, the Federal Republic of Germany, Italy, Japan, Switzerland, and the United Kingdom sold for very high values per ton.

World Review

World production of industrial sand

TABLE 8

U.S. EXPORTS OF INDUSTRIAL SAND AND GRAVEL, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1989		1990	
	Quantity	F.a.s. value[1]	Quantity	F.a.s. value[1]
North America:				
Canada	1,054	11,374	806	16,565
Mexico	40	1,631	92	1,957
Panama	1	34	10	277
Other	5	672	2	305
Total[2]	1,100	13,709	910	19,105
South America:				
Argentina	(3)	137	1	188
Chile	4	275	10	705
Colombia	5	54	1	116
Ecuador	(3)	194	1	176
Peru	8	214	1	91
Venezuela	15	184	1	384
Other	6	386	(3)	37
Total[2]	39	1,445	14	1,697
Europe:				
Belgium	37	937	24	1,428
Finland	1	22	2	67
France	1	86	1	94
Germany, Federal Republic of	62	1,805	11	2,700
Italy	2	672	4	1,055
Netherlands	426	2,850	15	1,838
United Kingdom	90	2,116	40	872
Other	4	607	5	470
Total[2]	622	9,095	99	8,524
Asia:				
Indonesia	9	476	32	1,144
Japan	148	47,723	64	44,867
Korea, Republic of	50	1,687	5	1,872
Singapore	45	2,232	16	4,899
Taiwan	9	507	5	849
Other	8	700	4	445
Total[2]	270	53,324	125	54,076
Middle East and Africa:				
Ghana	—	—	1	31
Israel	(3)	43	2	84
Saudi Arabia	(3)	9	(3)	33
South Africa, Republic of	(3)	27	(3)	13
Other	2	235	(3)	83
Total[2]	2	314	3	244
Australia	25	356	(3)	165
Oceania	(3)	64	(3)	10
Grand total[2]	2,060	78,308	1,155	83,826

[1]Value of material at U.S. port of export; based on transaction price, including all charges incurred in placing material alongside ship.
[2]Data may not add to totals shown because of independent rounding.
[3]Less than 1/2 unit.

Source: Bureau of the Census.

and gravel, based on information usually provided by foreign Governments, was estimated to be 133.2 million short tons. The United States was the leading producer followed by, in descending order, the Netherlands, Argentina, France, and the Federal Republic of Germany. Most countries in the world had some production and consumption of industrial sand and gravel because of its basic uses in glass and foundries. However, because of variation in descriptions and usage for silica sand and gravel, it was difficult to get reliable information. Beyond those countries listed in table 10, many other countries, including the U.S.S.R. and other Eastern European nations, were believed to have had some type of silica production and consumption.

Current Research

Technological advancements and research breakthroughs are essential for the future of the silica industry because use of silica in traditional uses has stagnated at about current levels. Minimal or negative growth in the container and flat glass and auto foundries industries has forced silica producers to look for new markets for their products.

Although container and flat glass production will probably not increase much in the next decade, newer and novel uses of glass will likely help to increase silica demand. Recently, when Georgia-Pacific Corp. needed a new roof at its plant in Brunswick, GA, the solution was a fiberglass roof, the first of its kind. Although the cost of this type of roof may currently be greater than a concrete, steel, and/or wood roof, its advantages may outweigh the cost consideration. Georgia-Pacific chose this type of roof because they believed it will stand up to the corrosive effects of their papermaking process and still be able to support heavy loads.[5]

A process for using silica-glass to encapsulate toxic or industrial waste was reported in London by developer Dunston Ceramics. This use is similar to the use of silica-glass to hold radioactive waste as was reported in this publication in 1988. Using glass to essentially render waste harmless may provide a large market for silica should the process prove to be cost effective. The English company plans its first commercial plant in southern England.[6]

Other untraditional uses of glass that may have impact on the silica industry

TABLE 9

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

(Thousand short tons and thousand dollars)

Country	1989		1990	
	Quantity	C.i.f. value[1]	Quantity	C.i.f. value[1]
Australia	32	874	70	2,522
Canada	1	191	3	77
Germany, Federal Republic of	(2)	240	(2)	259
Japan	2	262	(2)	77
United Kingdom	1	60	(2)	62
Other	(2)	430	(2)	151
Total[3]	35	2,057	73	3,148

[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.

Source: Bureau of the Census.

include resins with continuous glass fibers, glass and glass-ceramic matrix composites, and glass-coated polyester. Continuous glass fibers in plastics are expected to see big growth by the year 2000.[7] Glass and glass-ceramic matrix composites can be manufactured at low cost. They offer high strength, stiffness, and overall performance, similar to that of resin matrix composites, but maintain these properties out to temperatures up to 1,200° C, ideal for high-temperature, high-stress applications.[8] Glass-coated polyester can provide barrier properties comparable to those offered by polyvinylidene chloride-coated polyester and others, and offers a more environmentally acceptable material.[9]

Corning Inc., Corning, NY, has increased optical fiber output by more than 50%. Corning feels that the market for fiber-optic material will grow substantially

TABLE 10

INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989	1990[e]
Argentina	11,452	9,974	r10,645	r9,434	9,900
Australia	2,305	2,602	2,170	e2,210	2,210
Austria	880	754	833	r903	890
Belgium	2,275	2,500	r2,698	e2,900	2,900
Brazil	3,019	2,829	2,880	e2,980	2,980
Canada	2,911	2,934	r3,094	r2,904	2,800
Chile[e]	330	330	330	330	330
Cuba	546	571	e610	e610	550
Denmark	2	e2	2	e2	2
Ecuador	r40	r16	e55	r113	80
Egypt[3]	e140	257	r152	r597	550
Finland	256	257	300	r311	310
France	5,878	8,236	e8,250	e8,250	8,250
Germany, Federal Republic of:					
Western states	7,228	6,755	6,386	r6,634	6,700
Greece[e]	r42	r42	r42	r39	39
Guatemala	25	34	35	e34	35
Hungary	572	696	714	e720	720
Iceland	4	5	e5	r e5	5
India	1,856	4,173	r3,239	r2,782	2,860
Ireland	7	6	7	e8	8
Italy[e]	4,630	4,740	4,740	4,960	4,740
Jamaica	14	22	14	17	418
Japan	4,327	4,291	4,630	4,826	44,884

See footnotes at end of table.

TABLE 10—Continued

INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989	1990[e]
Kenya	([5])	([e 5])	([e 5])	12	10
Korea, Republic of	1	1	2	r1	2
Malaysia	239	397	462	498	[4]757
Mexico	977	r1,094	r1,104	r1,341	[4]1,431
Netherlands	25,178	24,553	28,659	r28,271	[4]27,709
New Zealand	e55	e55	61	r113	110
Norway[e]	880	880	880	880	880
Pakistan	127	164	148	r200	190
Paraguay	r1,829	r2,087	r2,123	r2,137	2,100
Peru	5,343	8,833	e5,510	e5,510	5,510
Philippines	e165	185	281	r342	[4]691
Portugal[e]	6	6	6	6	6
South Africa, Republic of	1,824	2,135	2,216	2,405	[4]2,185
Spain	2,888	1,707	r2,668	e2,205	2,400
Sweden[e]	770	770	770	770	770
Tanzania	10	7	13	14	14
Thailand	169	169	267	r326	[4]465
Turkey	r382	438	r483	r e535	600
United Kingdom	4,528	3,599	r4,784	r4,828	4,630
United States (sold or used by producers)	27,420	28,010	28,480	29,205	[4]28,406
Venezuela	r385	r502	r502	r417	[4]183
Yugoslavia	2,939	2,379	2,231	e2,320	2,320
Zimbabwe	159	45	61	68	68
Total	r125,013	r130,042	r133,542	r133,973	133,198

[e]Estimated. [r]Revised.
[1]Table includes data available through June 15, 1990.
[2]In addition to the countries listed, Angola, Antigua and Barbuda, the Bahamas, China, Israel, New Caledonia, Panama, and the U.S.S.R., among others, produce industrial sand, but current, available information is not adequate to formulate estimates of production levels.
[3]Fiscal years beginning July 1 of that stated.
[4]Reported figure.
[5]Less than 1/2 unit.

during this decade as fiber-optic material replaces copper and coaxial cable in servicing television and telephone service in millions of homes. Corning also introduced a new fiber, Titan, that is a titanium-coated glass fiber that will be strong enough to withstand bending in small diameters. With advances in fiber-optics continuing, sales of silica for fiber-optic manufacturing should increase.[10]

OUTLOOK

Demand

The forecast range of total U.S. demand in the year 2000 was expected to be 30 to 41 million short tons for industrial sand and gravel. Probable demand was expected to be about 36 million tons, which corresponded with an average annual growth rate of 1.9%. 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 1984, annual demand for glass sand had fluctuated between 10.3 and 12.1 million tons. Sand consumed for container glass had decreased since 1987 mainly because some glass containers were being replaced by aluminum cans and plastic containers and also because the amount of glass being recycled was increasing. Additionally, many manufacturers of container glass were using thinner walls in glass containers, and this process had cut down the amount of sand used. Also, a new thinner and lighter safety glass was used in automobiles, and its use was growing. As a result of these contingency factors, demand for glass sand was expected to grow slowly until the year 2000. Probable demand for glass sand for the year 2000 was forecast to be 14 million tons, with a range of 12 to 16 million tons. The probable forecast indicated a modest annual growth rate of 0.8%.

Foundry Sand

The probable forecast for foundry

sands was expected to be 9.5 million tons, and the range was expected to be 9 to 11 million tons. The probable forecast indicated an average annual growth rate of 2.6%. 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.

Hydraulic Fracturing Sand

This end use showed a strong growth in 1990, surging to more than 1.8 million tons. The amount of hydraulic fracturing sand used in each oil and gas well increased, and this trend was expected to be maintained in the future. Therefore, demand was expected to grow for this end use. Probable demand for hydraulic fracturing sand for the year 2000 was expected to be 2.3 million tons, with a range of 1.7 to 2.7 million tons. The probable forecast indicated an annual growth rate of 4%.

Adequacy of Supply

Domestic production was expected to continue to meet more than 99% of demand through the year 2000. Imports, mostly from Australia and Canada, were expected to remain minor.

The United States was the largest producer and consumer of silica sand among the market economy countries and was self-sufficient in this commodity. Most of it was produced in the eastern part of the United States, where the largest deposits and major markets are. A significant amount of silica sand was also produced in the West and Southwest, mostly in California and Texas.

Because the unit price of silica sand was relatively low, except for a few end uses that required a high degree of processing, the location of silica sand deposits in relation to the market was an important factor that may work for or against a sand producer. Consequently, a significant number of relatively small operations supplied local markets with a limited number of products.

The constant-dollar price of domestic silica sand had fluctuated since 1983 and was expected to continue fluctuating because of strong competition among producers for retention of dwindling markets.

Possible Supply-Demand Changes

Several factors could affect supply-demand relationships for silica sand. Further increases in the development of substitute materials for glass and cast metals could reduce demand for glass sand and foundry sand but would increase demand for silica flour, which is used as a filler in plastics, and for glass fibers, which are used in reinforced plastics. Also, increased efforts to reduce waste and increase recycling could hinder glass sand demand. Although these 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.

Development of more efficient mining and processing methods are expected to continue. This will enhance development of lower grade silica sand deposits closer to markets but not presently mined. Such developments are expected to increase silica sand reserves.

[1]American Foundrymen's Society. Molding Methods and Materials. 1st ed., 1962, Des Plaines, IL, 619 pp.
———. Mold & Core Test Handbook. 1st ed., 1978, Des Plaines, IL, 388 pp.

[2]American Society for Testing and Materials. Standard Classification of Silica Refractory Brick. C 416-70 in 1984 Annual Book of ASTM Standards: V. 15.01, Refractories, Manufactured Carbon and Graphite Products; Activated Carbon. Philadelphia, PA, 1984, p. 140.
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[3]American Petroleum Institute. Recommended Practices for Testing Sand Used in Hydraulic Fracturing Operations. 1983, 13 pp.

[4]Federal Register. U.S. Mine Safety and Health Administration (Dep. Labor) Hazard Communication; Proposed Rule. V. 55, No. 213, Nov. 2, 1990, pp. 46400–46441.

[5]Engineering News Record (NY). Fiberglass Roof Experiment. V. 224, No. 8, Feb. 22, 1990, pp. 23–24.

[6]Industrial Minerals (London). Glass Shroud for Waste. No. 276, Sept. 1990, p. 89.

[7]Chemical Week (NY). Big Growth Ahead. V. 146, No. 23, June 13, 1990, p. 34.

[8]Materials Edge. Reflections on Glass. No. 17, May/June 1990, pp. 27–28.

[9]Modern Plastics. Environmental Packaging Issue Attracts Competition From Nonplastic Materials. V. 67, No. 5, May 1990, pp. 33–34.

[10]Pechter, K. Corning Boosts Fiber Output Capacity and Designs Tougher Fiberoptic Cable. Wall Street J. (NY), Mar. 20, 1990.

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TABLE 11

TIME-PRICE RELATIONSHIP FOR SILICA SAND

Year	Average annual price, dollars per ton, f.o.b. quarry	
	Actual price	Based on constant 1990 dollars
1970	$3.47	$10.86
1971	3.49	10.34
1972	3.81	10.77
1973	3.80	10.09
1974	4.83	11.76
1975	5.50	12.20
1976	5.70	11.88
1977	6.82	13.33
1978	7.65	13.93
1979	8.57	14.34
1980	9.98	15.31
1981	11.15	15.60
1982	12.03	15.82
1983	12.63	15.99
1984	12.92	15.78
1985	12.75	15.12
1986	13.16	15.21
1987	13.06	14.63
1988	13.83	14.99
1989	14.23	14.82
1990	15.61	15.61

TABLE 12

PROJECTIONS AND FORECASTS FOR U.S. INDUSTRIAL SAND, BY END USE, IN THE YEAR 2000

(Million short tons)

End use	1990	Year 2000		
		Forecast range		Probable
		Low	High	
Glass sand	11.7	12.0	16.0	14.0
Foundry sand	6.3	9.0	11.0	9.5
Hydraulic fracturing sand	1.8	1.7	2.7	2.3
Other	7.2	8.0	11.0	10.0
Total	27.0	30.7	40.7	35.8

TABLE 13

TEN-YEAR STATISTICAL DATA FOR INDUSTRIAL SAND SOLD OR USED BY U.S. PRODUCERS, BY SELECTED END USES

(Thousand short tons)

End use	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Glass[1]	12,078	12,252	9,436	11,341	10,293	10,993	11,873	12,141	12,293	11,728
Foundry[2]	9,948	7,118	6,670	7,239	5,143	5,777	[3]6,932	7,610	[3]7,085	[3]6,333
Silicon carbide	463	140	94	135	121	W	130	W	W	191
Flux for metal smelting	246	191	74	97	67	46	114	117	45	23
Abrasive[4]	1,958	2,208	1,950	2,030	1,681	1,947	[5]1,848	2,113	[5]2,287	[5]2,298
Chemicals	426	335	271	425	378	317	513	655	817	651
Fillers	284	192	141	200	158	267	394	225	227	369
Ceramics	179	226	179	184	150	198	225	280	238	143
Filtration	249	299	102	217	345	494	433	407	310	367
Traction (engine)	398	450	195	246	292	177	465	305	311	314
Roofing granules and fillers	162	517	296	289	403	261	392	575	790	572
Hydraulic fracturing	1,407	1,481	990	2,057	2,102	1,130	1,396	1,299	1,531	1,839

W Withheld to avoid disclosing company proprietary data.
[1]Includes container, flat, specialty, and fiber (sand and ground sand).
[2]Includes molding and core, molding and core facings (ground), and refractory uses.
[3]Excludes molding and core facings (ground).
[4]Includes blasting, sawing and sanding (1981–82, 1984–86), and scouring cleansers (ground).
[5]Excludes scouring cleansers (ground).

SELENIUM AND TELLURIUM

By Daniel Edelstein

Mr. Edelstein is a physical scientist (geologist) with more than 16 years of combined experience working for the U.S. Bureau of Mines in minerals processing research, process evaluation, and mineral commodities. He has been the selenium and tellurium commodity specialist intermittently for 7 years as well as a copper specialist. Domestic survey data were prepared by Evangeline J. Hemphill, mineral data assistant.

Domestic demand for both selenium and tellurium declined in 1990 owing to overall economic recession, weak demand for selenium in photoreceptors and pigments, and reduced demand for tellurium in ferroalloys. Domestic and world production of refined selenium increased, resulting in higher stock levels and a decline in price. Domestic and world production of tellurium fell in excess of the drop in demand, and estimated world stocks declined slightly. The price for refined tellurium, however, also declined slightly.

DOMESTIC DATA COVERAGE

Domestic data for selenium and tellurium are developed from a voluntary survey of the stocks, production, and shipments at the three known domestic producers of selenium and one producer of tellurium. Although all producers responded to the survey, some of the data are withheld to prevent disclosure of company proprietary data.

BACKGROUND

Geology-Resources

Selenium and tellurium are relatively rare elements, having estimated crustal abundances of 0.05 part per million and 0.5 to 10 parts per billion, respectively.[1] Selenium is frequently found in base metal sulfide minerals, where its similar crystallochemistry allows it to isomorphously replace sulfur in the crystal lattice. Tellurium is also found in close association with sulfur, as well as with selenium. However, unlike selenium, tellurium does not readily substitute in the sulfide lattice, but is found as discrete minerals or microsegregations in the host sulfide mineral.[2] Although native tellurium has been observed, the most frequent occurrence of tellurium is as a gold and/or silver telluride.

World reserves of selenium and tellurium are difficult to assess owing to limited knowledge of the selenium and tellurium content of the copper ores from which they are ultimately recovered. Tracing refinery production of selenium and tellurium to inground resources is complicated by trade in concentrates, blister and anode copper, as well as by trade in anode slimes and other nonferrous residues, including those generated from gold, lead, and zinc processing. A simplified estimate of selenium and tellurium reserves may be obtained by applying assumed recovery factors to world copper reserves as follows: selenium, 0.64 and 0.215 kilogram per ton of copper reserves, respectively, for Canada and the rest of the world; tellurium, 0.065 kilogram per ton of copper reserves. Total reserves of selenium and tellurium thus estimated were 80,000 tons and 22,000 tons, respectively. A higher recovery factor was applied to Canada owing to the unusually high selenium content of eastern copper reserves. The above estimates exclude resources of selenium and tellurium contained in gold, lead, and zinc reserves, which at times have served as sources of these materials.

Technology

Although more than 40 discrete selenium minerals have been identified, and slightly fewer tellurium minerals, their concentration in nature is insufficient to allow for economic recovery. Economic recovery of these elements is dependant upon their concentration during the processing of nonferrous ores. In the case of copper ores, the source of most of the world's selenium and tellurium, these metals accumulate along with the precious-metals values in the anode slimes generated during electrolytic refining. Decopperized anode slimes are treated by one of several chemical and pyrometallurgical process schemes, first to segregate the selenium and tellurium from the precious-metal residues, and secondly to refine the crude selenium and tellurium intermediates. In one process, decopperized slimes are roasted with soda ash to produce water-soluble selenates and selenides. If present, insoluble tellurium may be acid leached from the residue. A second method involves sulfatization treatment, where slimes are digested in sulfuric acid at elevated temperature to sulfatize the base metals and oxidize the selenium. Thin layer roasting of the slimes volatilizes the selenium dioxide, which is then precipitated upon cooling.

Most of the selenium and tellurium initially present in the sulfide ores is never recovered because circuits are optimized for recovery of copper in the concentration, smelting, and refining stages, and precious metals in the slimes processing circuits. In the case of selenium, only 25% to 60% of the selenium in the smelter feed is recovered in the blister, and only 30% to 80% of the selenium concentrated in the anode slimes is recovered, compounding losses as the processing progresses. Anode slimes typically average only 10% selenium and 2% tellurium, but may contain up to 30% and 8%, respectively.

ANNUAL REVIEW

Legislation and Government Programs

The Environmental Protection Agency (EPA) promulgated regulations, effective May 8, 1990, implementing the last of five Congressionally mandated prohibitions on the land disposal of hazardous wastes under the authority of the Resource Conservation and Recovery Act (RCRA). Selenium was one of the toxic elements covered by this

action. Despite being an essential micronutrient in the diets of humans and animals, selenium is considered toxic in high doses.

Under the new regulations, which become fully effective in May 1992, discharge standards for selenium and its compounds were based on what was perceived as the best demonstrated available technology (BDAT). In the case of selenium-containing nonwastewaters (solids), EPA believed vitrification was the BDAT technology for dispoal. Vitrification involves the dissolution of the waste into a molten slag or glass, which, upon cooling, forms a relatively impermeable solid. Since no data on vitrification of seleniun were available, standards were based on extrapolation of data for arsenic. Using the Toxicity Characteristic Leaching Procedure (TCLP) test, a maximum standard of 5.7 milligrams per liter selenium in the leachate was set. However, EPA believed that most wastes containing high levels of selenium would be processed for recovery of selenium because of its relatively high value.

For selenium-containing wastewaters, EPA determined that precipitation was the BDAT. Based on comments received, EPA set the standard for wastewater discharge at 1.0 milligram per liter selenium.[3]

Strategic Considerations

In August 1987, under contract to the Federal Emergency Management Agency, ASM International convened a panel of industry representatives to assess the quality and material form of minor metals for the National Defense Stockpile. In their report issued in 1989, the panel recognized important specialized military applications for high-purity selenium and tellurium in the manufacture of hardware for infrared imaging systems for night vision and navigation systems. These applications included germanium-arsenic-selenium glass for infrared optical components and cadmium-mercury-telluride infrared detectors. The panel concluded that domestic capacity for commercial and detector grades of tellurium were adequate to meet emergency requirements, but they recognized a potential for an emergency shortage of high-purity selenium for strategic uses. However, owing to the possibilities of conservation, the availability of selenium from domestic and Canadian sources, and the ability to substitute other materials in a number of metallurgical applications, the panel felt that the supply of selenium should be reasonably secure in an emergency and thus recommended against stockpiling of selenium. Government stockpiles of selenium, which exceeded 400,000 pounds in the 1960's when selenium rectifiers were of significant strategic importance, were liquidated by 1974.[4]

Issues

Selenium and tellurium and their compounds are considered toxic in large doses. Though there are no clear indications of long-term systemic effects among industrial workers, selenium and tellurium exposure is monitored and regulated by the Occupational Safety and Health Administration (OSHA), and EPA regulates their discharge in air, water, and solid wastes. The occurrence and toxicity of selenium in the environment from nonindustrial sources has been reported in considerable detail. Agricultural irrigation practice in the San Joaquin Valley of California and other arid regions of the Western United States leached selenium compounds from the soil. Selenium accumulated in the evaporation ponds and catch basins from agricultural drainage water. The high selenium levels in the water and aquatic vegetation had significant detrimental effect on waterfowl nesting in these areas. A second source of pollution, wastewater from oil refining, has been identified as a major source of selenium discharge into the Suissun and San Pablo Bay areas, east of San Franciso. Elevated levels of selenium found in Bay ducks and clams prompted the Regional Water Quality Control Board to issue guidelines limiting selenium discharge by at least six major oil refineries.

However, despite the detrimental effect to wildlife, a recent review indicates that there is little risk to humans from exposure to selenium even in the San Joaquin region. The exception to this would be the home gardener who consumed large amounts of vegetables grown on localized areas of high selenium content. Generally, selenium does not accumulate in enough quantities in the edible portion of food crops to significantly change a human's normal daily intake. Though selenium poisoning in humans from excessive uptake from crops grown in high selenium soils has been documented, it is considered rare and unusual. More common are diseases associated with deficiency in human dietary intake of selenium.[5] U.S. Department of Agriculture regulations allow a selenium supplementation level in "complete" animal feed of 0.3 part per million.

Production

Primary selenium was recovered in the United States at three electrolytic copper refineries: ASARCO Incorporated at Amarillo, TX; Phelps Dodge Refining Corp. at El Paso, TX; and Rio Tinto Zinc Corp. Ltd. at its Kennecott refinery at Magna, UT. Commercial-grade tellurium metal and tellurium dioxide were produced by Asarco. Selenium- and tellurium-containing anode slimes or residues generated at other domestic primary copper refineries were exported for processing. At least one of the domestic refineries may have processed tellurium-bearing residues generated during the refining of lead bullion.

Domestic production of refined selenium increased in 1990 to about the same level as in 1988. The increase in production, combined with a decline in domestic shipments, resulted in stocks of selenium increasing by about 50%.

Most domestic selenium production was as commercial-grade material, averaging a minimum of 99.5% selenium, and available in various forms, including shot, powder, and lumps, or as pigment-grade powder having a minimum 99.8% selenium content. There was no domestic production of high-purity selenium suitable for electronic applications. Selenium contained in scrap derived from the manufacture of photoconductor drums and from used photoreceptor drums was exported for processing. There was no domestic production of secondary selenium. Domestic production of refined tellurium declined slightly during 1990 in response to a decline in domestic demand. Stocks of tellurium rose slightly. Production of tellurium dioxide, used mostly in the rubber compounding industry, was discontinued during the year.

In addition to commercial-grade tellurium, Asarco produced some high-purity electronics-grade material (99.999% tellurium) at its refinery in Globe, CO. Detector-grade tellurium (99.99999% tellurium), suitable for use in infrared imaging devices, was produced by Cabot Corp., Boyerstown, PA.

There was no secondary production of tellurium. The U.S. Bureau of Mines, however, was conducting research on hydrometallurgical techniques to recover tellurium and cadmium from scrap generated in the production of infrared optic devices.[6]

Consumption and Uses

Selenium demand by end use can be divided broadly into five applications: elec-

tronic (includes photoconductor uses), glass and ceramics manufacturing, pigments, chemicals, and metallurgical. In electronics, the largest end-use market, high-purity selenium was used principally as a photoconductor on the drums of plain paper copiers. Other electronics uses include rectifier and photoelectric applications. In glass manufacturing, selenium was used principally as a decolorant in container glass and other soda-lime silica glasses. The addition of selenium under weak oxidizing conditions adds a pink color to the glass that combines with the green color imparted by ferrous ions to create a neutral grey color that has low perceptibility to the human eye. Selenium was also used to reduce solar heat transmission in architectural plate glass. Cadmium sulfoselenide red pigments have good heat stability and are used in ceramics and plastics.

Chemical uses of selenium included industrial, pharmaceutical, agricultural, and biological uses, such as rubber compounding chemicals, gun bluing, catalysts, antidandruff shampoos, animal feed supplements, and vitamin supplements for humans. In metallurgical applications, selenium was added to copper, lead, and steel alloys to improve machineability and casting and forming properties.

Domestic demand for selenium continued its 2-year slide owing to a decline in photoreceptor demand, weakness in the automotive industry, and environmental pressure to reduce the use of cadmium-containing materials. Demand for selenium by end use was estimated as follows: electronics, 35%; pigments and chemicals, 20%; glass manufacturing, 30%; and other, including agriculture and metallurgy, 15%.

Tellurium was used principally as an alloying element in the production of free-machining low-carbon steels, where additions of up to 0.1% tellurium, usually in conjunction with lead, greatly improve machineability. Similarly, the addition of tellurium to copper and other nonferrous alloys improves their machineability, strength, and corrosion resistance. Tellurium catalysts were used chiefly for oxidation of organic compounds, but were also used in hydrogenation, halogenation, and chlorination reactions. Tellurium chemicals were used as curing and accelerating agents in rubber compounding. Electronic semiconductor applications for high-purity tellurium included its use with selenium as a photoconductor in plain paper copiers, as an infrared sensing material in mercury-cadmium-tellurium (MCT) thermal imaging devices, and in thermoelectric and photoelectric devices. Tellurium alloys have been used in newly developed optical disk storage systems for computers.

Apparent domestic demand for tellurium and its compounds, as calculated from production, trade, and stock data, continued to decline in 1990. The decrease in apparent demand was largely attributed to reduced shipments to manufacturers of free-machining steels. Substitution of other free-machining alloys may have been stimulated by the environmental concerns over lead, which is used in conjunction with tellurium in some free-machining alloys. Though the price for tellurium remained relatively high throughout the year, supplies of tellurium were adequate. During the preceding several years, tight supplies and high prices may have encouraged substitution of other materials. Iron and steel products remained the largest end use, followed by nonferrous metals, chemicals, and other uses.

Markets and Prices

The merchant price for commercial-grade refined selenium, quoted by Metals Week on a weekly basis, declined slightly during the first half of the year before stabilizing at about $5.50 per pound. Prices in Europe were reported to have fallen below $5.00 per pound. Pigment-grade selenium, which traded at about a $0.50 per pound premium to commercial-grade material, was reported to be in tight supply during the fourth quarter of the year. Tightness was attributed by various sources to production difficulties at Japanese and Canadian producers and/or to merchant hording. Significant premiums, $10.00 to $20.00 per pound, were charged for higher purity forms of selenium.

The price for commercial-grade tellurium metal declined slightly, but remained near the high price established during 1988, more than triple the 1986 price. The yearend price quote for tellurium by the only domestic producer was $31 per pound. Concern over supply tightness, which had driven prices to record-high levels in 1988 and 1989, abated.

World Review

World production of refined selenium increased in excess of the corresponding increases in world copper mine and refinery production. In the United States, Kennecott instituted process improvements, and, in Japan, Mitsubishi Metals began production from a new precious-metals refinery at the end of 1989. In the Philippines, production increased significantly, possibly owing to increased dependance on imported copper concentrates, which may have had a higher selenium content.

According to shipment data compiled by the American Bureau of Metal Statistics (ABMS), demand for refined selenium declined by almost 7%, while world producer inventories of refined selenium rose by the same percentage. ABMS data reflect shipments and inventories from companies that accounted for about 75% of world production. The United States was the largest recipient of selenium, followed by the United Kingdom, Japan, Belgium, and the Netherlands. However, deliveries to European countries may not have reflected their ultimate point of consumption. In Europe, demand for selenium declined slightly, reportedly owing to the potential for a legislative ban on cadmium-base pigments. Conversely, a preference for glass containers for environmental reasons may have spurred a demand growth in this sector.

World production and consumption data for tellurium are limited. According to ABMS, which collected data from producers accounting for between 50% and 60% of estimated world production, production and shipments of refined tellurium declined sharply during 1990 and producer inventories fell slightly. However, supplies of tellurium were reported to be adequate, and it was likely that consumer and merchant inventories served to cushion demand.

More than 60 market economy countries reported mine production of copper and about 30 market economy countries reported electrolytic refined copper production from a total of more than 80 operating electrolytic refineries. However, only about 15 countries and 20 refineries reported recovery of primary selenium and about one-half that number reported tellurium production. Several primary refiners of selenium also recovered selenium from scrap, though breakout of their primary and secondary production is not well documented. Several companies, including International Recoveries Inc. in the Philippines, Shinko Chemicals Co. Ltd. and Asia Bussei Zairyo in Japan, and Mineral and Chemical Products Ltd. in the United Kingdom, were believed to produce selenium exclusively from secondary materials.

OUTLOOK

Though world production of selenium fluctuated greatly over the previous 10

years, its overall trend was flat; selenium production did not keep pace with the growth in copper mine output. Similarly, demand for refined selenium was also relatively stable. However, a production-demand imbalance existed, and a shortfall in production was met by a large drawdown of world inventories. According to ABMS data, by 1989, world inventories had fallen from their 1981 peak by almost 800 tons, more than 50%. In 1990, however, demand fell, production rose, and the slide in selenium inventories was halted. In recent years, major copper refiners throughout the world have been investing in new slimes treatment facilities. World capacity for refined selenium production has increased by more than 200 tons per year.

Demand for refined selenium declined in 1990 owing to environmental pressures and economic recession. Demand for selenium in its largest application, xerography, was expected to remain stable or even decline slightly as organic photoreceptors, particularly for color copying, gain market share. Pigment uses of selenium were also expected to experience weak demand owing to environmental constraints. Demand for use in glass manufacturing was expected to remain strong or even increase.

The U.S. Bureau of Mines forecasts a significant increase in world copper mine capacity for the next 5 years. Assuming that world demand for selenium remains stable and that new selenium refining capacity and increased mine production serve to maintain the 1990 level of refined selenium production, production of refined selenium is expected to meet or exceed world demand. Increased exports to China, which have become significant in recent years, and advances in solar and imaging technology could boost demand and lead to tight supplies.

Data on demand for and production of tellurium are incomplete. However, available data indicate that market economy country demand over the 1984-88 period was comparatively stable, averaging about 220 tonnes per year, but weakened in 1989 and 1990. World production of refined tellurium, according to ABMS data, has trended downward. Excess supply following a demand turndown in the early 1980's depressed prices and discouraged recovery of tellurium. In 1990, production fell in excess to the decline in demand, and inventories fell slightly.

The near-term outlook is for the continued tight balance between the supply and demand for tellurium. The high price for tellurium is expected to moderate future demand for tellurium in traditional metallurgical applications and stimulate the substitution of alternative materials. Demand for highpurity tellurium for use in thermal imaging and optical storage devices is expected to grow but not have significant impact on overall demand. If new thin-film technologies stimulate the demand for tellurium in electronic applications, such as solar energy conversion or thermoelectric power generation, supply pressures could increase. Though no significant new tellurium capacity is expected, additional resources, such as the gold telluride ores found in Fiji and Colorado, are potential new sources of tellurium.

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[3]Federal Register. Land Disposal Restrictions for Third Third Scheduled Wastes. V. 55, No. 106, June 1, 1990, pp. 22520-48435.

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TABLE 1

SALIENT SELENIUM AND TELLURIUM STATISTICS

(Kilograms of contained metal unless otherwise specified)

	1986	1987	1988	1989	1990
SELENIUM					
United States:					
Production, primary refined	W	W	285,633	253,427	286,755
Shipments to consumers	W	W	260,838	294,672	250,450
Exports, metal, waste and scrap	161,007	162,217	243,096	372,126	194,608
Imports for consumption	462,646	495,862	474,234	[1]417,095	[1]382,860
Apparent consumption, metal[2]	W	W	590,000	560,000	530,000
Stocks, yearend, producer[3]	W	W	W	W	W
Dealers' price, average per pound, commercial grade[4]	$5.70	$6.51	$9.84	$7.61	$5.82
World: Refinery production	[r 5]1,396,645	[r 5]1,407,655	1,699,574	[p]1,707,716	[e]1,788,747
TELLURIUM					
United States:					
Imports for consumption	30,721	26,700	76,890	[6]42,871	[6]34,012
Producer price quote, yearend, commercial grade	$10.00	$20.00	$35.00	$34.00	$31.00

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data.

[1]Includes unwrought and waste and scrap and selenium dioxide.

[2]Calculated using reported shipments, imports of selenium metal, and estimated exports of selenium metal, excluding scrap.

[3]Granlar selenium, a semirefined form of selenium, is included in stocks.

[4]Source: Metals Week. Calculated from published price ranges.

[5]Excludes the United States.

[6]Includes only unwrought and waste and scrap.

TABLE 2

U.S. EXPORTS OF SELENIUM METAL, WASTE AND SCRAP, BY COUNTRY[1]

Country	1988		1989		1990	
	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value
Belgium	48,299	$365,430	40,650	$658,524	11,794	$71,454
Benin	—	—	3,614	57,760	—	—
Brazil	—	—	362	22,640	2,396	88,633
Canada	2,110	54,872	9,766	161,518	44	1,195
Chile	—	—	2,040	29,908	1,590	18,143
Colombia	5,987	129,809	4,000	52,720	—	—
Djibouti	—	—	—	—	707	11,300
France	6,966	111,358	—	—	240	2,637
Germany, Federal Republic of	23,788	468,050	7,570	81,589	14,717	165,576
India	200	6,600	4,186	66,910	—	—
Italy	299	4,290	507	5,282	—	—
Japan	27,746	347,881	86,839	322,632	44,283	226,017
Korea, Republic of	4,049	64,717	998	29,887	450	10,000
Malaysia	2,654	42,426	—	—	—	—
Mexico	10,113	161,641	35,921	304,199	24,466	355,142
Netherlands	26,090	452,636	57,308	730,817	3,500	31,000
Senegal	—	—	1,664	22,130	—	—
Sierra Leone	—	—	11,035	21,749	—	—
Singapore	—	—	30,623	417,150	513	8,200
Spain	427	5,158	1,044	12,461	—	—
Tanzania	—	—	4,097	65,480	—	—
Uganda	—	—	2,891	46,200	—	—
United Kingdom	79,879	926,756	47,610	235,759	89,682	288,855
Venezuela	412	6,593	—	—	226	5,000
Zaire	—	—	16,808	44,973	—	—
Other	4,077	49,107	2,593	39,136	—	—
Total	243,096	3,197,324	372,126	3,429,424	194,608	1,283,152

[1]Under the Harmonized Tariff System begun in Jan. 1989, this category is listed as "selenium."

Source: Bureau of the Census.

TABLE 3

U.S. EXPORTS OF SELENIUM METAL, WASTE AND SCRAP, BY COUNTRY[1]

Country	1988		1989		1990	
	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value
Unwrought and waste and scrap:[2]						
Belgium	66,197	$2,087,313	73,654	$2,234,265	52,063	$1,962,260
Brazil	—	—	—	—	100	5,044
Canada	163,066	4,226,140	102,507	2,368,336	112,857	2,553,992
China	—	—	2,000	4,761	—	—
Finland	2,296	45,958	—	—	2,200	24,188
Germany, Federal Republic of	2,000	38,327	10,566	274,700	17,088	365,861
Hong Kong	—	—	2,268	78,600	—	—
Japan	57,358	1,456,867	65,266	1,517,688	51,307	1,102,083

See footnotes at end of table.

TABLE 3—Continued

U.S. EXPORTS OF SELENIUM METAL, WASTE AND SCRAP, BY COUNTRY[1]

Country	1988		1989		1990	
	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value
Unwrought and waste and Scrap[2]—Continued						
Korea, Republic of	1,000	$14,881	12,514	$188,780	7,999	$91,311
Netherlands	2,296	49,386	6,940	106,960	2,986	72,532
Peru	475	9,270	—	—	—	—
Philippines	18,275	291,962	12,910	143,243	30,153	321,908
Spain	—	—	10	1,070	—	—
Sweden	50	1,709	—	—	—	—
United Kingdom	100,854	1,640,007	69,631	1,173,918	82,684	1,619,921
Venezuela	—	—	920	10,103	—	—
Yugoslavia	—	—	40,320	491,760	18,315	166,948
Total	413,867	9,861,820	399,506	8,594,184	377,752	8,286,048
Selenium dioxide:						
Belgium	—	—	1,241	40,730	—	—
Canada	8	1,491	—	—	—	—
Germany, Federal Republic of	9,791	271,507	6,296	109,263	157	4,603
India	—	—	229	3,650	—	—
United Kingdom	1,527	54,250	9,823	186,431	4,951	62,713
Total[3]	11,325	327,248	17,589	340,074	5,108	67,316
Selenium salts:						
United Kingdom	125	5,325	—	—	—	—
Total	125	5,325	NA	NA	NA	NA
Sodium selenite:						
Belgium	2,300	58,825	—	—	—	—
Canada	4,600	144,119	—	—	—	—
Germany, Federal Republic of	19,819	61,619	—	—	—	—
Japan	184	19,798	—	—	—	—
United Kingdom	13,708	402,691	—	—	—	—
Total[3]	40,610	687,052	NA	NA	NA	NA
Other selenium compounds:						
Belgium	324	24,444	—	—	—	—
Germany, Federal Republic of	22	2,225	—	—	—	—
Italy	12	1,238	—	—	—	—
Japan	3	4,027	—	—	—	—
United Kingdom	7,946	226,418	—	—	—	—
Total	8,307	258,352	NA	NA	NA	NA
Grand total	474,234	11,139,797	417,095	8,934,258	382,860	8,353,364

NA Not available.

[1]Because of implementation of the Harmonized Tariff System in Jan. 1989, import and export categories for 1989 and 1990 are not necessarily comparable with those of 1988.

[2]Listed as "selenium" under the Harmonized Tariff System.

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

Source: Bureau of the Census, figures adjusted by the U.S. Bureau of Mines.

TABLE 4

U.S. IMPORTS OF CONSUMPTION OF TELLURIUM, BY CLASS AND COUNTRY[1]

Class and country	1988		1989		1990	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Unwrought and waste and scrap:[2]						
Australia	—	—	8,030	$256,379	—	—
Belgium	1,246	$73,622	5,485	463,840	4,638	$379,566
Canada	5,966	543,787	10,637	1,117,746	11,191	2,039,593
China	—	—	—	—	1,230	89,972
France	—	—	—	—	310	14,601
Germany, Federal Republic of	6	3,080	3,904	442,614	4,415	507,349
Hong Kong	321	13,760	—	—	—	—
Japan	15,044	705,514	1,802	209,261	1,110	162,572
Mexico	1,500	78,540	699	40,874	70	3,704
Netherlands	1,000	42,108	3,604	241,229	—	—
Philippines	13,700	302,033	240	15,121	—	—
Peru	—	—	—	—	1,072	70,452
United Kingdom	13,419	626,424	8,470	462,036	9,976	660,587
Total	52,202	2,388,868	42,871	3,249,100	34,012	3,928,396
Compounds:						
Canada	1,416	71,688	—	—	—	—
Germany, Federal Republic of	10,706	107,605	—	—	—	—
Japan	200	10,821	—	—	—	—
Netherlands	1,901	22,661	—	—	—	—
Switzerland	42	7,577	—	—	—	—
United Kingdom	645	37,564	—	—	—	—
Total	14,910	257,916	NA	NA	NA	NA
Salts:						
Germany, Federal Republic of	9,778	41,732	—	—	—	—
United Kingdon	—	—	—	—	—	—
Total	9,778	41,732	NA	NA	NA	NA
Grand total	76,890	2,688,516	NA	NA	NA	NA

NA Not available.

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export categories for 1989 are not necessarily comparable to those of previous years.

[2]Listed as "tellurium" under the Harmonized Tariff System, and grouped together with boron. However, imports of boron are thought to be very small relative to tellurium.

Source: Bureau of the Census.

TABLE 5

U.S. SELENIUM AND TELLURIUM IMPORT DUTIES

Tariff item	HTS No.	Most favored nation (MFN) January 1, 1991	Non-MFN January 1, 1991
Selenium	2804.90.0000	Free	Free
Selenium dioxide	2811.29.2000	do.	do.
Tellurium	2804.50.0000	do.	25.0% ad valorem

TABLE 6

SELENIUM: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Kilograms, contained selenium)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Belgium[e]	250,000	230,000	250,000	250,000	250,000
Canada[3]	345,000	300,000	321,000	270,000	[4]389,000
Chile	47,000	5,909	47,051	[e]47,000	50,000
Finland	5,693	[e]10,000	28,935	[e]25,000	25,000
Germany, Federal Republic of:					
Western states[e]	100,000	100,000	100,000	100,000	110,000
India	[e]4,800	4,026	5,103	4,261	4,300
Japan	426,567	481,109	471,020	470,028	[4]494,692
Mexico	23,000	29,000	13,000	20,000	18,000
Peru	12,035	[r]11,430	4,937	[e]5,000	5,000
Philippines[5]	82,000	72,000	58,000	55,000	70,000
Sweden	24,000	31,000	30,000	[e]30,000	30,000
United States	W	W	285,633	253,427	[4]286,755
Yugoslavia	54,400	66,362	60,812	[e]60,000	60,000
Zambia[6]	22,150	26,819	24,083	[e]25,000	25,000
Total	[r]1,396,645	[r]1,407,655	1,699,574	1,614,716	1,817,747

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]Insofar as possible, data relate to refinery output only; thus, countries that produced selenium contained in copper ores, copper concentrates, blister copper and/or refinery residues, but did not recover refined selenium from these materials indigenously, were excluded to avoid double counting. Table includes data available through May 29, 1991.

[2]In addition to the countries listed, Australia and the U.S.S.R. produced refined selenium, but output is not reported, and available information is inadequate for formulation of reliable estimates of output levels. Australia is known to produce selenium in intermediate metallurgical products and has facilities to produce elemental selenium. In addition to having facilities for processing imported anode slimes for the recovery of selenium and precious metals, the United Kingdom has facilities for processing selenium scrap.

[3]Excludes secondary production.

[4]Reported figure.

[5]Incomplete; data shown is for primary production at Philippine Associated Smelting and Refining Corp.

[6]Data for fiscal year beginning Apr. 1 of year stated.

TABLE 7

TELLURIUM: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Kilograms, contained tellurium)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Canada[3]	20,000	13,000	19,000	8,000	13,000
Japan	55,600	53,305	55,181	51,031	49,701
Peru	9,836	7,457	4,078	[e]5,000	[e]4,300
United States	W	W	W	W	W

[e]Estimated. [p]Preliminary. W Withheld to avoid disclosing company proprietary data.

[1]Insofar as possible, data relate to refinery output only; thus, countries that produced tellurium contained in copper ores, copper concentrates, blister copper and/or refinery residues, but did not recover refined tellurium, are excluded to avoid double counting. Table is not totaled because of the exclusion of data from major world producers, notably the U.S.S.R. and the United States. Table includes data available through May 29, 1991.

[2]In addition to the countries listed, Australia, Belgium, the Federal Republic of Germany, and the U.S.S.R. are known to produce refined tellurium, but output is not reported, and available information is inadequate for formulation of reliable estimates of output levels. Morever, the other major copper-refining nations such as Chile and Zambia may produce refined tellurium, but output in these nations is conjectural.

[3]Primary recoverable output.

SILICON

By Joseph Gambogi

Mr. Gambogi, a physical scientist with more than 8 years of Government and industry experience, has been the commodity specialist for silicon since 1988. Domestic survey data and trade data were prepared by Robin Johnson, mineral data 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 global silicon industry underwent further deterioration in 1990. Although demand was relatively strong, an abundance of supply caused prices to fall. Many producers were forced to curtail production and postpone expansion plans. Based on contained silicon, overall domestic production fell to 420,000 metric tons, while consumption increased to 585,000 metric tons. Imports of silicon products increased 38% compared with those of the previous year.

The metric system is the official system of measurement of most countries. The U.S. Bureau of Mines, in an effort to provide statistical data on silicon that are consistent with international usage, will henceforth report data in kilograms and metric tons unless otherwise noted. For comparison to previous years data, metric tons can be converted into short tons by multiplying the published number by 1.10231.

DOMESTIC DATA COVERAGE

Domestic production data for the silicon commodity are developed by the U.S. Bureau of Mines by means of monthly and annual voluntary surveys. The "Silicon Alloys" survey canvassed all of 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 are miscellaneous silicon alloys that contain silicon and other elemental alloys. 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 iron, calcium, and aluminum. 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) has published standards for ferrosilicon and silicon metal. 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 1990 was either 50%- or 75%-grade material, the majority being 50%-grade. The domestic silicon industry supplies nearly all of the 50%-grade material and about 70% of all ferrosilicon products. Miscellaneous silicon alloys consumed in the United States consist primary of magnesium ferrosilicon. Almost all ferrosilicon products are consumed by the iron and steel industries.

Metallurgical-grade silicon metal is used by the primary aluminum, secondary aluminum, and chemical industries. The products sold to these industries vary considerably in their specifications. The chemical and primary aluminum industries generally require more stringent specifications than those of the secondary aluminum industry. In addition, the chemical industry requires that the metal be ground into a fine powder rather than the lump form used by the aluminum industries.

Geology-Resources

The United States has an abundance of silica deposits for the production of ferrosilicon and silicon metal. For the production of these materials, 98% to 99% purity is preferred. However, trace amounts of aluminum and iron are also acceptable. Physically, the material should not contain fines and should not crumble easily.

Technology

Silicon metal and ferrosilicon are produced by the reduction of silica (SiO_2) to silicon (Si) in a submerged arc electric furnace. A typical charge consists of silica as beneficiated quartz or quartzite; coal, coke or charcoal as a reductant; wood

chips for porosity; and, when producing ferrosilicon, iron in the form of steel scrap or iron ore. During the furnace operation, raw materials are periodically charged into the top of the furnace, and the molten metal or alloy is periodically tapped at the bottom of the furnace and cast into chills or ingots. The material is then crushed to specific size requirements starting at about 20 centimeters down to 200 mesh.

Metallurgical-grade silicon metal is the starting material for high-purity silicon consumed by the electronics industry. First, silicon metal is used to produce an intermediate product such as silicon trichlorosilane (TCS). A vapor deposition process is then used to form a rod or boule of high-purity polycrystalline silicon (polysilicon) from the TCS. A single crystal boule is made from polysilicon by two methods. The Czochralski (CZ) method uses a seed crystal to grow a rod of single crystal silicon from a molten crucible of polysilicon. The Float Zone (FZ) method uses an induction coil to produce a molten zone within a rod of polysilicon. The coil starts at one end of the boule where a seed crystal starts the crystal growth. The coil moves slowly down the boule, allowing a single crystal to be formed. After being sliced into wafers, the silicon is used by the electronics industry to produce integrated circuits.

Byproducts and Coproducts

Silicon metal and ferrosilicon furnaces produce what is called a silica fume, silica dust, or microsilica. This material used to be considered of little or no value. However, microsilica is now used as an additive in a number of different products, including high-strength concrete. Research is ongoing to find additional uses for this material.

Economic Factors

. Production of silicon metal or ferrosilicon is extremely power intensive, requiring a power input of about 8,000 kilowatt-hours (kW·h) per ton of 75%-grade and 12,000 kW·h per ton of silicon metal. Power costs represent approximately one-third of operating costs for silicon producers. Subsequently, most new producers of silicon products have been located where favorable electrical power availability and cost situations exist. Norway has traditionally been a major producer and exporter of silicon products because of its vast hydroelectric power resources. More recently, Brazil, China, and Venezuela have emerged as major exporters of silicon products largely because of their low power costs.

ANNUAL REVIEW

Legislation and Government Programs

Amendments to the Clean Air Act were passed into law in November 1990. The new amendments were expected to have direct and indirect effects on the silicon industry. An indirect effect of the amendments was a predicted rise in the cost of electricity. The revised act limited the amount of sulfur dioxide emissions coal-base power utilities could produce. The cost of compliance incurred by the utilities was expected to be passed along to power consumers. The U.S. Bureau of Mines estimated that the requirements to limit sulfur dioxide emissions would increase the operational costs of certain silicon producers by up to 4.5 cents per pound. A more direct effect of the new amendments was that all ferroalloy producers were placed on a list of possible sources of toxic emissions subject to regulation by the Environmental Protection Agency. The impact of the toxic emissions regulation on the domestic silicon industry was not certain.

Under the authority of the Export Administration Act of 1979, the U.S. Department of Commerce (DOC) determined that foreign availability existed for certain types of high-purity polycrystalline silicon to controlled destinations, rendering existing controls to these destinations ineffective. Subsequently, export controls on certain grades of silicon to these destinations were removed.

Federal funding appropriated for photovoltaic research amounted to $34.3 million in 1990 compared with $35.5 million in 1989.

The U.S. Government provided partial funding for a consortium of semiconductor manufacturers known as Sematech. Sematech sponsored a number of programs aimed at improving silicon-base manufacturing technology.

Strategic Considerations

High-purity silicon is a strategic element of advanced electronic systems for commercial and military applications. Although the United States is a leader in the development of these systems, many of the components and devices within these systems are provided from foreign sources. Recent studies indicate Japan leads the United States in its share of world semiconductor chip production.

Issues

Domestic producers of silicon metal filed for antidumping and countervailing duties against imports of silicon metal from Argentina, Brazil, and China. The imports included silicon metal containing at least 96.00% but less than 99.99% silicon content. Semiconductor-grade silicon metal was not part of the petition. The petitioners charged that imports from Brazil were dumped at 30% to 54% margins under fair market value, while Argentina and China were dumped at 52% to 106% and 123% margins, respectively. In response to the petition, investigations were begun by the U.S. International Trade Commission (USITC) and the DOC. Preliminary determinations made by the USITC and DOC concluded that the imports were sold at less than fair value and materially injured or threatened the domestic silicon industry, thereby warranting further investigation. Final USITC and DOC determinations were scheduled for 1991.[1]

Production

Overall gross production of silicon products decreased 6% compared with that of 1989, based on silicon content. Production of silicon increased 4%, while production of ferrosilicon and miscellaneous alloys decreased 9%. Ferrous scrap used in the production of these products was estimated to be 235,000 tons.

Although in absolute terms prices did not fall as far as they did in 1989, the continued price slide caused several producers to cut back or discontinue production. Several captive producers permanently closed their operations, and one independent producer filed for protection under chapter 11 of the U.S. Bankruptcy Code.

Owing to poor market conditions, American Alloys Inc., New Haven, WV, curtailed its production of silicon products. The company reduced its ferrosilicon production by temporarily shutting down individual furnaces throughout the latter half of 1990. In December, the company also idled its only silicon metal furnace for a maintenance overhaul.

TABLE 1

PRODUCTION, SHIPMENTS, AND STOCKS OF SILVERY PIG IRON, FERROSILICON, AND SILICON METAL IN THE UNITED STATES IN 1990

(Metric tons, gross weight, unless otherwise specified)

Material	Silicon content (percentage)		Producers' stocks, Dec. 31, 1989[r]	Gross production	Net shipments	Producers' stocks, Dec. 31, 1990
	Range	Typical				
Silvery pig iron	5–24	18	W	W	W	W
Ferrosilicon	25–55	48	51,563	321,385	243,122	69,119
Do.	56–95	76	20,994	109,566	97,520	21,673
Silicon metal (excluding semiconductor grades)	96–99	98	8,716	145,744	133,460	13,746
Miscellaneous silicon alloys (excluding silicomanganese)	32–65	—	20,002	72,442	71,983	17,645

[r]Revised. W Withheld to avoid disclosing company proprietary data.

TABLE 2

PRODUCERS OF SILICON ALLOYS AND/OR SILICON METAL IN THE UNITED STATES IN 1990

Producer	Plant location	Product
Alabama Alloys Inc.	Dolomite, AL	FeSi.
American Alloys Inc.	New Haven, WV	FeSi and Si.
Applied Industrial Minerals Corp.	Bridgeport, AL	FeSi.
Dow Corning Corp.	Springfield, OR	Si.
Elkem Metals Co.	Alloy, WV	FeSi and Si.
Do.	Ashtabula, OH	FeSi.
Do.	Marietta, OH	Do.
Globe Metallurgical Inc.	Beverly, OH	FeSi and Si.
Do.	Selma, Al	Si.
Keokuk Ferro-Sil Inc.	Keokuk, IA	FeSi and silvery pig iron.
Reynolds Metals Co.	Sheffield, AL	Si.
Silicon Metaltech Inc.	Wenatchee, WA	FeSi and Si.
Simetco Inc.	Montgomery, AL	Si.
SKW Alloys Inc.	Calvert City, KY	FeSi.
Do.	Niagara Falls, NY	FeSi and Si.

Reynolds Metals opted to permanently close its silicon operations at its Listerville, AL, facility. However, the company continued to consume silicon for its magnesium production. After the closure, Reynolds met its requirements through open market purchases.

Union Carbide Chemicals and Plastics Co. sold its polysilicon operations to Advanced Silicon Materials Inc. The sale included two facilities in Moses Lake and Washougal, WA. The Moses Lake facility was one of the largest domestic producers of high-purity polysilicon in the world. The sale was not expected to affect production at the facility.

Globe Metallurgical Inc. cut its ferrosilicon and silicon metal production through a series of maintenance shutdowns. The shutdowns were at both the Beverly, OH, plant and the Selma, AL, plant.

Cominco American Resources Inc. stopped production of 50% ferrosilicon at its Glenbrook Nickel operations in Riddle, OR. The company decided to meet its ferrosilicon requirements through open market purchases.

Early in 1990, Elkem Metals Co. idled one of its two 45-megawatt (MW) ferrosilicon furnaces at its Ashtabula, OH, facility for maintenance repairs. The company planned to reopen the furnace in June. However, a transformer failure delayed the startup of the furnace for the remainder of the year. The furnace had produced 50%-grade ferrosilicon the previous year. Elkem also overhauled a 32-MW silicon metal furnace at its Alloy, WV, facility. The overhaul was made midyear and lasted for several months. In December, Elkem stopped ferrosilicon production at its Alloy plant. The company planned to continue silicon metal production at Alloy and enhance the plant's hydroelectric power capabilities.

Silicon Metaltech Inc. filed for protection from its creditors under chapter 11 of the U.S. Bankruptcy Code. The company was formed in 1988 when it purchased the Wenatchee, WA, facility from the M.A. Hanna Corp.

Northwest Alloys Inc. did not produce ferrosilicon or silicon metal in 1990. Northwest consumed ferrosilicon in its magnesium operations and had produced ferrosilicon in previous years. The company decided to purchase its requirements in 1990.

Consumption and Uses

Apparent consumption of silicon-containing ferroalloys and silicon metal was estimated to be 587,000 tons of contained silicon. Consumption of silicon metal was 195,000 tons, while consumption of ferrosilicon and miscellaneous silicon alloys was about 390,000 tons. Compared with that of 1989, consumption of silicon metal increased 13%, while consumption of ferrosilicon and other alloys increased 4%. Ferrosilicon and miscellaneous silicon alloys accounted for two-thirds of all the silicon materials consumed, based on silicon content.

The aluminum industry used silicon metal in the production of wrought and cast products, while ferrosilicon was used primarily as a deoxidizing and alloying agent in the production of iron and steel products. Metallurgical-grade silicon metal was also used as the basic raw material in the manufacturing of many chemical products and intermediates such as silicones and silanes. Silanes were used

TABLE 3

REPORTED CONSUMPTION, BY MAJOR END USE, AND STOCKS OF SILICON ALLOYS AND METAL IN THE UNITED STATES IN 1990[1]

(Metric tons, gross weight, unless otherwise specified)

	Silvery pig iron	Ferrosilicon[2]				Silicon metal	Miscellaneous silicon alloys[3]	Silicon carbide[4]
Silicon content (percent):								
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	—	45,610	—	26,659	(5)	(5)	1,559	(5)
Stainless and heat-resisting	—	89,221	—	39,875	(5)	263	2	—
Other alloy	(5)	36,247	—	36,850	(5)	(5)	445	(5)
Tool	—	(5)	—	1,710	(5)	(5)	—	—
Unspecified	22	187	—	130	674	12,000	1	166
Total[6]	22	171,264	—	105,224	674	12,263	2,008	166
Cast irons	18,925	141,332	1,173	20,113	465	W	20,997	13,909
Superalloys	—	W	—	260	W	103	—	W
Alloys (excluding superalloy and alloy steel)	W	3,653	—	W	W	92,429	21	—
Miscellaneous and unspecified	11	1,812	—	464	49	[7]93,295	—	3
Grand total[6]	18,957	318,061	1,173	126,062	1,188	198,089	23,023	14,080
Consumers' stocks, December 31	1,012	7,634	91	6,725	67	2,265	1,358	744

W Withheld to avoid disclosing company proprietary data; included in "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 of converted units.
[7]Primarily silicones, silanes, fumed silica, and other chemicals.

in the production of high-purity silicon for semiconductor devices, solar cells (photovoltaic cells), and infrared detectors. The U.S. Bureau of Mines did not collect data on electronic grades of silicon.

Markets and Prices

Although demand for silicon products was relatively high in 1990, prices of silicon products continued the downward trend that began in 1989. The downward pressure in prices was brought about largely by low-priced imports from China, Eastern Europe, South America, and the U.S.S.R. Several domestic companies curtailed their production in early 1990. However, global production outpaced demand, resulting in a continued soft market. In response to low priced imports, domestic producers in the United States filed an antidumping petition with the DOC and USITC. The petition alleged imports from Argentina, Brazil, and China were sold at less than fair value and materially injured the domestic silicon industry.

Table 4 shows the average import price of 50%- and 75%-grade ferrosilicon as well as silicon metal. Prices are posted in cents per pound of contained silicon. The import price of 75%-grade ferrosilicon started the year at 38.0 to 40.0 cents per pound, peaked midyear at 41.8 to 43.3, then fell to 36.0 to 36.5 by yearend. Silicon metal followed a similar curve starting at 53.0 to 55.0, with a midyear high of 57.0 to 58.0 cents per pound. The import price of silicon metal ended the year at 54.0 to 57.0 cents per pound.

Foreign Trade

U.S. imports of silicon products increased significantly in 1990 compared with those of 1989. In particular, imports of ferrosilicon categorized as "55% to 80% silicon, other" increased 45% based on gross weight. However, the total value

TABLE 4

TIME-PRICE RELATIONSHIP FOR SILICON PRODUCTS

(Cents per pound)

Year	Silicon metal	Ferrosilicon[2] 50%	Ferrosilicon[2] 75%
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

[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.	Most favored nation (MFN)[1]	Non-MFN[1]
Ferrosilicon, 55% to 80% Si:			
More than 3% Ca	7202.21.1000	1.1% ad valorem	11.5% ad valorem.
Other	7202.21.5000	1.5% ad valorem	11.5% ad valorem.
Ferrosilicon, 80% to 90% Si	7202.21.7500	1.9% ad valorem	9.0% ad valorem.
Ferrosilicon, more than 90% Si	7202.21.9000	5.8% ad valorem	40.0% ad valorem.
Ferrosilicon, other:			
Ferrosilicon, more than 2% Mg	7202.29.0010	Free	4.4¢/kg Si.
Ferrosilicon, other	7202.29.0050	Free	4.4¢/kg Si.
Silicon, more than 99.99% Si	2804.61.0000	3.7% ad valorem	25.0% ad valorem.
Silicon, 99.00% to 99.99% Si	2804.69.1000	5.3% ad valorem	21.0% ad valorem.
Silicon, other	2804.69.5000	9.0% ad valorem	45.0% ad valorem.

[1]Tariff effective Jan. 1, 1989.

for this category increased only 7%. Significant increases also occurred in ferrosilicon categorized as "Other," which included all ferrosilicon less than 55% silicon. Imports of "Other" ferrosilicon increased 40% by gross weight and 18% by total value. Overall imports of silicon metal products increased 54% based on gross weight. The U.S. net import reliance for ferrosilicon products jumped to 30% from 20% the previous year. The import reliance of silicon products was estimated to be 27% compared with 21% the previous year. The overall import reliance was estimated to be 29%.

U.S. exports of ferrosilicon increased 2% compared with that of 1989, based on gross weight. Meanwhile, the total value of ferrosilicon exports increased by 8%. In view of the soft global market, these figures demonstrate the domestic industry's trend toward higher value ferrosilicon products. Unlike ferrosilicon, silicon metal exports were affected by the soft global market. Although silicon metal exports increased 78% based on gross weight, the total value of these exports increased by only 10%.

World Review

During the past decade, the global industry has shifted a significant portion of its capacity from developed countries, such as the United States, to less developed nations with abundant resources. For example, producers in Brazil and China underwent huge capacity increases in the 1980's. However, in 1990, the market was in a state of oversupply, and many producers were forced to postpone expansion programs and cut back production. Many Brazilian producers were affected by not only the slow silicon market but also the economic troubles of their own country. Meanwhile, Eastern Europe and the U.S.S.R. joined China as suppliers of inexpensive material to the United States and the European Community. In response to requests by their domestic industry, the European Commission investigated and took action against dumping of silicon products into their market.

Argentina.—Despite poor market conditions, Silarsa, a joint venture between Axel Johnson Ore & Co. HAB and Stein Ferroaleaciones Sacifa, entered the silicon market. Silarsa began production of silicon metal at a new facility at Mendoza. The facility was reported to have a capacity of 6,500 metric tons per year (mt/yr), and most of the production was expected to be exported.

Australia.—Simcoa Pty. took control of Barrack Silicon Pty. and announced a suspension of plans to double the capacity at the company's silicon metal facility in Kemerton. The Kemerton facility, which started production late in 1989, produced more than 30,000 metric tons of material in 1990.[3]

Brazil.—Several factors combined to make 1990 a difficult year for the Brazilian silicon industry. These factors included a soft international market, a sharp increase in power rates, and a new economic policy by the Brazilian Government. As a result, many companies closed existing furnaces and halted plans for expansion. Companies that closed furnaces included Cia Industrial Fluminense, Cia Paulista de Ferro Ligas, Inonnibras, and RIMA Eletrometalurgica SA. Meanwhile, startups were delayed at Electrosiderúrgica Brasileira SA (Sibra) and Cia Paulista de Ferro-Ligas. Late in 1990, three Brazilian companies filed for "Concordata," which is similar to chapter 11 of the U.S. Bankruptcy Code.[4]

Owing to an inflation rate that reached almost 1,900% in 1989, the Brazilian Government instituted a new economic austerity plan in 1990. The new plan included the freezing of bank deposits, commodity prices, and wages. The plan's tight money policy had a detrimental effect on the domestic silicon industry by limiting bank loans that the industry used to help finance its export contracts. The Government also instituted a new 22% tax on electric power, and a 9.1% value added tax was placed on ferroalloys sold or exported. However, late in the year, the Government agreed to halve its tax on exports from the Minas Gerais State to 4.5%.[5]

In June, Cia Paulista de Ferro-Ligas stopped ferrosilicon production at its facility in Caxambu. The production capacity at Caxambu was estimated to be about 10,000 mt/yr.[6]

In mid-1990, Camargo Corrêa Metais halved its output of silicon metal. The cutback affected the company's plant in

TABLE 6

U.S. EXPORTS OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY

(Metric tons)

Grade and country	1989			1990		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
FERROSILICON						
Over 55% silicon:						
Australia	503	302	$413	984	590	$900
Canada	3,002	1,801	2,486	4,485	2,691	5,365
Germany, Federal Republic of	775	465	620	905	534	776
Korea, Republic of	6,890	4,839	5,906	1,427	1,021	1,264
Mexico	2,492	1,495	2,018	6,666	4,025	5,670
Other	r7,486	r4,481	r6,860	1,573	972	1,417
Total[1]	r21,149	r13,384	r18,303	16,039	9,833	15,392
Other ferrosilicon:						
Canada	10,161	5,080	8,008	14,025	7,012	10,912
France	1,064	532	861	1,436	718	1,134
Germany, Federal Republic of	1,307	653	1,032	2,245	1,122	1,773
Mexico	1,479	740	1,189	3,565	1,741	2,721
United Kingdom	7,273	3,636	5,756	5,832	2,896	4,735
Other	6,622	3,311	5,733	6,937	3,472	7,324
Total[1]	27,905	13,952	22,580	34,040	16,962	28,600
Total ferrosilicon[1]	49,054	27,336	40,883	50,079	26,794	43,993
SILICON METAL						
Over 99.99% silicon:						
Denmark	41	NA	3,191	51	51	3,965
Italy	89	NA	4,190	143	143	8,396
Japan	485	NA	27,235	504	504	27,894
Malaysia	200	NA	35,698	203	203	36,495
Mexico	4	NA	192	44	44	581
Other	94	NA	4,760	114	114	3,847
Total[1]	913	XX	75,266	1,059	1,059	81,178
99.00% to 99.99% silicon:						
France	70	NA	66	469	465	346
Mexico	145	NA	233	377	374	507
New Zealand	—	—	—	251	250	382
South Africa, Republic of	95	NA	116	326	323	371
Venezuela	1	NA	12	1,171	1,161	1,515
Other	873	NA	1,842	508	504	716
Total[1]	1,184	XX	2,269	3,103	3,077	3,837
Other silicon:						
Canada	517	NA	537	453	440	588
Czechoslovakia	—	—	—	378	367	562
Mexico	497	NA	1,501	1,756	1,696	2,400
New Zealand	260	NA	376	342	332	489
Venezuela	651	NA	768	337	328	477
Other	1,022	NA	3,357	1,552	1,491	2,698
Total[1]	2,947	XX	6,539	4,818	4,655	7,214
Total silicon metal[1]	5,045	XX	84,074	8,980	8,791	92,229

rRevised. NA Not available. XX Not applicable.

[1]Data may not add to totals shown owing to individual rounding of converted units.

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	1989			1990		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
FERROSILICON						
55% to 80% silicon, over 3% Ca:						
Argentina	1,078	639	$1,428	1,644	999	$1,563
Belgium	67	41	96	—	—	—
Brazil	15,355	9,525	20,879	14,978	9,425	18,484
China	—	—	—	257	146	266
France	2,835	1,731	4,354	2,659	1,591	4,358
Germany, Federal Republic of	110	71	306	1	1	2
Italy	733	455	1,027	1,992	1,216	2,565
Japan	188	142	439	—	—	—
Spain	54	31	78	—	—	—
Venezuela	—	—	—	567	425	655
Total[1]	20,421	12,636	28,607	22,099	13,802	27,893
55% to 80% silicon, other:						
Argentina	8,570	6,514	7,124	9,164	6,832	5,001
Australia	20	15	14	1,246	881	263
Brazil	14,090	10,361	11,527	42,635	31,897	24,775
Canada	18,332	13,839	15,211	18,089	13,694	10,668
China	1,375	930	899	4,074	2,985	1,703
Egypt	—	—	—	6,182	4,018	2,871
France	540	357	738	500	326	731
Germany, Federal Republic of	428	308	1,550	618	439	1,704
Iceland	12,561	9,584	7,202	—	—	—
Japan	71	46	205	215	144	615
Mexico	—	—	—	61	42	179
Norway	12,367	9,387	7,803	26,256	19,600	14,506
Venezuela	26,125	19,668	19,602	30,859	22,889	14,436
Yugoslavia	2,899	2,072	1,037	1,000	680	407
Zimbabwe	—	—	—	551	358	158
Total[1]	97,378	73,080	72,912	141,450	104,786	78,017
80% to 90% silicon:						
Brazil	14	11	13	—	—	—
France	9	8	22	—	—	—
Total[1]	22	19	35	—	—	—
Over 90% silicon:						
Brazil	2,500	2,309	2,705	100	94	59
China	110	101	119	—	—	—
Hong Kong	107	99	117	—	—	—
Japan	(2)	(2)	1	—	—	—
Total[1]	2,718	2,509	2,941	100	94	59
Magnesium ferrosilicon:						
Brazil	5,265	2,349	3,851	582	260	255
Canada	256	60	104	3,039	539	1,587

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	1989			1990		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
FERROSILICON—Continued						
Magnesium ferrosilicon—Continued						
China	70	23	110	134	47	213
France	—	—	—	105	57	138
Germany, Federal Republic of	1,034	353	1,848	446	240	1,572
Japan	28	11	57	108	48	222
Total[1]	6,653	2,796	5,970	4,415	1,191	3,987
Other ferrosilicon:						
Brazil	7,697	2,703	$1,967	9,338	3,926	$3,480
Canada	7,513	3,392	3,186	16,660	6,532	5,900
China	—	—	—	67	24	86
Egypt	—	—	—	978	460	205
Finland	1,022	488	573	—	—	—
France	421	174	465	83	34	137
Germany, Federal Republic of	65	19	75	—	—	—
Japan	33	15	69	49	23	99
Norway	910	464	375	1,300	663	670
U.S.S.R	33,042	16,062	14,457	41,445	19,596	14,113
Venezuela	—	—	—	900	433	286
Zimbabwe	—	—	—	100	42	63
Total[1]	50,703	23,318	21,166	70,920	31,733	25,038
Total ferrosilicon[1]	177,895	114,359	131,631	238,983	151,605	134,993
SILICON METAL						
Over 99.99% silicon:						
Belgium	—	—	—	(2)	(2)	2
Brazil	—	—	—	3	3	156
China	12	NA	133	—	—	—
Denmark	7	NA	396	6	6	401
Finland	(2)	NA	1	—	—	—
France	30	NA	1,174	18	18	984
Germany, Federal Republic of	481	NA	18,686	418	418	20,646
Ireland	—	—	—	1	1	45
Italy	190	NA	12,341	170	170	28,427
Japan	147	NA	2,284	90	90	2,138
Korea, Republic of	5	NA	112	3	3	386
Malaysia	3	NA	9	(2)	(2)	49
Netherlands	1	NA	7	—	—	—
Poland	—	—	—	(2)	(2)	6
Sweden	(2)	NA	2	(2)	(2)	1
Switzerland	—	—	—	(2)	(2)	1
Taiwan	—	—	—	(2)	(2)	7
U.S.S.R	—	—	—	(2)	(2)	17
United Kingdom	(2)	NA	7	(2)	(2)	17

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	1989			1990		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
SILICON METAL—Continued						
Total[1]	876	XX	35,152	709	709	53,284
99.00 to 99.99% silicon:						
Argentina	6,793	6,732	7,466	2,140	2,119	2,083
Australia	—	—	—	395	384	362
Brazil	11,273	11,181	12,610	24,367	24,160	23,363
Canada	6,686	6,628	6,970	7,105	7,028	8,945
China	4,574	4,532	5,172	19,292	19,126	15,546
Denmark	(2)	(2)	2	20	20	26
France	1,348	1,337	1,027	355	352	438
Germany, Federal Republic of	28	27	77	22	22	36
Hong Kong	1,474	1,458	1,700	1,492	1,475	1,267
Italy	91	90	56	—	—	—
Japan	108	107	144	19	19	20
Korea, Republic of	—	—	—	2	1	5
Norway	17	17	38	—	—	—
South Africa, Republic of	774	767	838	270	267	303
Spain	83	82	109	—	—	—
Sweden	37	37	66	16	16	50
Switzerland	—	—	—	201	199	162
Taiwan	167	165	163	134	133	102
Yugoslavia	—	—	—	1,309	1,296	1,274
Total[1]	33,452	33,160	36,438	57,139	56,617	53,982
Other silicon:						
Argentina	—	—	—	20	20	$15
Australia	—	—	—	60	44	69
Belgium	2	2	$31	3	2	23
Brazil	4,164	4,080	3,945	4,738	4,611	3,830
Canada	933	916	990	626	616	586
China	2,694	2,644	2,534	2,648	2,599	2,185
France	—	—	—	8	8	14
Germany, Federal Republic of	2	2	5	10	10	13
Hong Kong	759	721	856	368	363	294
Italy	3	3	10	2	2	10
Japan	74	72	128	36	35	60
Luxembourg	50	49	57	—	—	—
Norway	31	29	30	—	—	—
Sweden	3	3	21	—	—	—
Taiwan	100	99	112	—	—	—
United Kingdom	54	53	78	5	5	6
Venezuela	—	—	—	12	11	13
Total[1]	8,868	8,673	8,798	8,534	8,325	7,119
Total silicon metal[1]	43,196	42,709	80,388	66,383	65,651	114,385

NA Not available. XX Not applicable.
[1]Data may not add to totals shown because of individual rounding of converted units.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

the Para State, reducing output there from 32,000 mt/yr to 16,000 mt/yr.[7]

Electrosiderúrgica Brasileira SA (Sibra) announced it was constructing two 18-MW furnaces, but changed earlier plans to produce silicomanganese instead of ferrosilicon.[8]

Rima Electrometallurgia announced the closure of one of its three silicon metal furnaces in Minas Gerais. The company is one of the largest producers of silicon metal specializing in chemical-grade material. The closure reduced the company's silicon metal output from 24,000 mt/yr to 16,000 mt/yr.[9]

Late in the year, Electro Ila SA suspended plans to expand capacity at its Minas Gerais facility. The plant's capacity was estimated at close to 22,000 mt/yr of silicon metal. Ila og Lilleby Smelteverker increased its shareholding in Electro Ila from 49% to 75%. Metallur Mecanica SA was left with 25% of Electro Ila's shares. Elecro Ila produced 19,000 tons of metal in 1990 and marketed the material to Japan through Fesil KS.[10]

In contrast to the rest of industry, Italmagnesio SA expanded its capacity in 1990. The company completed construction of a 24-megavolt-ampere (MV·A) ferrosilicon furnace. The furnace followed the completion earlier in the year of a 6-MV·A furnace. The new additions doubled the company's ferrosilicon capacity to 90,000 mt/yr. Late in 1990, Italmagnesio was granted $90 million in finances by the Brazilian Government to help fund a series of projects, including the expansion of ferroalloy facilities, the building of hydroelectric facilities, and reforestation efforts.

Bhutan.—Marubeni Corp. signed an agreement as one of several partners in a joint venture called Bhutan Ferroalloys Ltd. The agreement called for plans to construct a 15,000-mt/yr ferrosilicon plant close to Bhutan's southern border with India. The company cited easy access to Asian markets, a nearby hydroelectric plant, and plentiful raw materials as reasons for constructing the plant at this location.[11]

China.—Once again China played a role in influencing the world market for ferrosilicon products. Although most of China's silicon products were sold in the Asian markets of Japan and Korea, China exported a significant quantity of material to the United States and European markets. Chinese ferrosilicon exports to Japan increased significantly, while exports of silicon metal fell slightly. Chinese production of silicon metal was estimated to be 130,000 tons in 1990.

China's Hanway Ferroalloys completed construction of a new facility in the Yunnan Province. The facility included three 6-MV·A furnaces capable of producing more than 12,000 tons of 75%-grade ferrosilicon. The company intended to export 80% of its production.

Canada.—In October, Dow Corning Corp., Midland, MI, held a groundbreaking ceremony for its 6-MW silicon metal pilot plant in Manitoba. When completed, the facility was expected to produce 2,000 mt/yr of silicon metal for use within the Dow Corp.[12]

European Community (EC).—In 1990, the EC took a series of actions to restrain dumping of silicon products into the European Community. Early in the year, the Commission completed a 19-month antidumping investigation of Norwegian ferrosilicon. However, in lieu of a punitive duty, the Commission accepted a proposal by Elkem AS for a minimum reference price. Later in the year, the Commission asked the main importers of Soviet material to abide by the same reference price. In August, the EC imposed a punitive duty on Chinese silicon imports into the EC. The duty was levied at 198 European Community Units (ECU's) per ton and made effective for a 5-year period. By yearend, the Commission decided to investigate dumping allegations of silicon metal imports from Brazil.[13]

Japan.—Imports of ferrosilicon into Japan increased significantly, rising from 407,000 tons in 1989 to about 494,000 tons in 1990. The rise in 1990 imports was attributed to the previous year's reliance on inventory built up in 1988. Chinese imports accounted for 158,000 tons of ferrosilicon imports. In April, Japan eliminated a 3% import duty on ferrosilicon.[14]

Norway.—Norwegian producers of silicon metal and ferrosilicon were faced with a difficult world market. In accordance with agreements made with the EC, producers were prohibited from supplying ferrosilicon below a minimum reference price. Meanwhile, their market share was assaulted in Europe and North America by low priced imports of ferrosilicon and silicon metal from China, Eastern Europe, and the U.S.S.R. Subsequently, producers cut back their production in 1990 and planned further cutbacks in 1991.

Elkem AS made several cutbacks in production. The company reduced output in three Norwegian plants: Bjolvefossen, Bremanger, and Thamshavn. Elkem also closed a furnace at its Icelandic plant. By shutting down one furnace at each plant during the fourth quarter of 1990, the company reduced its ferrosilicon output by about 20,000 mt/yr. Elkem also announced plans to close its Meraker facility.[15]

In October, Fesil KS planned to cut ferrosilicon output by 20% by reducing output at its Halfslund, Rana Metall, and Finnfjord facilities.[16]

Saudi Arabia.—United Gulf Industries Corp. announced plans to construct a 25,000-mt/yr ferrosilicon plant. The company planned to construct the plant in Jubail during the coming year.[17]

Sweden.—Kemanord Industrikemi AB closed its 14,000-mt/yr silicon metal furnace at its Ljungaverk plant. Kemanord was the only remaining producer of silicon in Sweden. Vargon Alloys AB, the only producer of ferrosilicon in Sweden, cut production in the last quarter of 1990.[18]

Venezuela.—Many of the expansion programs planned in 1989 were put on hold in 1990. However, the estimated $500 million Cefeca project was still underway. The Venezuelan Government, through the Corporacion Venezolana de Guayana (CVG), provided 20% of the funding. The balance of the funding was provided by Italmagnesio SA (8%), GT Administracion e Participacion SA (32%), and a group of private investors.[19]

Current Research

With assistance from the Electrical Power Research Institute Inc. (EPRI), Dow Corning Corp. continued with its development of a new smelting process to produce silicon metal. Dow started construction of a 6-MW furnace, which will be used to test its new process for making silicon metal. The new furnace is based on direct current (DC) electric power with a closed furnace hood design. Commercial producers traditionally used alternating current (AC) submerged arc furnaces with open or partially open furnace hoods. If successful, the new furnace

TABLE 8

WORLD PRODUCTION CAPACITY FOR SILICON-CONTAINING FERROALLOYS AND SILICON METAL IN 1990

(Thousand metric tons, contained silicon)

Country	Capacity
Argentina	37
Australia	58
Brazil	407
Bulgaria	(1)
Canada	94
Chile	7
China	830
Colombia	(1)
Czechoslovakia	(1)
Egypt	45
France	152
Germany, Federal Republic of:	
Eastern states	(1)
Western states	60
Hungary	(1)
Iceland	50
India	60
Italy	95
Japan	82
Korea, North	(1)
Korea, Republic of	18
Mexico	17
Norway	418
Peru	(1)
Philippines	18
Poland	(1)
Portugal	12
Romania	(1)
South Africa, Republic of	105
Spain	69
Sweden	38
Switzerland	(1)
Taiwan	10
U.S.S.R.	980
United States	468
Uruguay	(1)
Venezuela	48
Yugoslavia	135
Other	240
Total	4,553

[1]Included with "Other."

was expected to help reduce the consumption of electrode materials and electrical power in silicon operations.

Researchers at the Westinghouse Science and Technology Center, Pittsburgh, PA, produced a rod of single crystal silicon with impurities of only a few parts per 100 trillion. Silicon, with this level of purity, was developed for infrared detection in the space, defense, and environmental industries.

Researchers at Motorola Inc., Schaumburg, IL, and TRW Inc., Redondo Beach, CA, developed a computer chip capable of detecting and correcting for errors within itself. The chip was developed for use in aircraft, missiles, and satellites.[20]

IBM Corp. and Siemans announced they will jointly develop 64-megabit Dynamic Random Access Memory (DRAM) chips. The companies planned to market the chips by the mid-1990's. IBM also pursued agreements with Micron Technology and Cypress Semiconductor to develop a domestic source of 4-megabit DRAM chips based on IBM's design.[21]

OUTLOOK

Demand for silicon metal is driven by consumption in the aluminum and chemical industries. Consumption by these industries is expected to undergo slow growth during the next 5 years. The automotive sector will contribute to this growth through increased aluminum content within each vehicle as well as increased silicon content in individual aluminum castings. Consumption growth by the chemical industry is expected to be about 7% per year. The chemical industry consumes silicon metal to produce a wide variety of compounds such as silanes, silicone resins, and lubricants. However, specialty chemical products rather than traditional commodity products should be the driving force for consumption growth. Overall, consumption of silicon metal is expected to grow in excess of 5% per year for the next 5 years.

Ferrosilicon is consumed primarily by the iron and steel industries. The industries use ferrosilicon for both deoxidation of molten metal and as an alloying agent. The American Iron and Steel Institute studied the consumption of steel by industrialized countries and predicted an average decline of 0.1% per year from 1985 to 1995.[22] Consequently, domestic ferrosilicon consumption is expected to decline during the next few years. The passage of the latest amendments to the Clean Air Act into law has reinforced predictions for decreased consumption. Other factors that could influence consumption of ferrosilicon by the steel industry include technological changes and trade agreements.

Although many production cutbacks were made by many silicon producers in 1990, it is anticipated that additional capacity will be required to meet the growth in silicon metal consumption during the next 10 years. Any new capacity will be required to meet the increasingly stringent quality requirements of the aluminum and chemical industries. Therefore, the conversion of older ferrosilicon furnaces is not likely. The location of any new capacity will be in regions with favorable power availability and cost, such as South America, Norway, the Middle East, and selected locations within North America.

Prices for silicon products fluctuate with market demand. Higher demand for silicon metal by the chemical industry would put upward pressure on silicon prices. Meanwhile, the increased presence of China, Eastern Europe, and the U.S.S.R. in the ferrosilicon market coupled with a lack of strong demand by the steel industry should inhibit any attempts to raise ferrosilicon prices.

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SILVER

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Domestic silver production increased for the fourth consecutive year despite a lower price, reflecting the importance of byproduct silver production. Owing to the fact that much of the byproduct silver can be produced at a very low cost, continued low prices had little impact on byproduct silver producers. However, near yearend, the Candelaria Mine, one of the largest domestic primary silver producers, was closed. Company officials attributed the closure to the low silver price.

The Government continued to reduce its silver holdings. The U.S. Department of the Treasury, as required by Public Law 100-440, the Treasury and Postal Service Appropriations Bill, disposed of approximately 78 metric tons of its silver stocks during fiscal year 1990. The quantity of silver held in the National Defense Stockpile (NDS) also declined from that of the previous year. The domestic silver price, as quoted by Handy & Harman, fell to a 15-year low in 1990. The annual average price, $4.82 per troy ounce, marked the third consecutive year in which the average price had declined from that of the previous year. In December, the price fell below $4.00 per troy ounce for the first time since February 1976.

The domestic apparent demand for refined silver declined in 1990. Apparent demand measures both the quantity of silver required by domestic manufacturers and the quantity of silver demanded by U.S. investors. The decline in apparent demand was attributed by many analysts primarily to lower investor demand. Handy & Harman, in its 1990 review, estimated world silver consumption at about 17,700 tons, a decrease of more than 200 tons from the revised 1989 figure.

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 137 silver-producing lode mines to which a survey form was sent, 126 responded, accounting for an estimated 92% of the total U.S. mine production shown in tables 1, 2, 3, 4, 5, 6, and 7.

BACKGROUND

Silver has played an important role in peoples' lives since ancient times. Early people used silver for ornaments and utensils and as a substance that could be bartered for other goods and services. This concept of the "value" of silver eventually led to its use as the standard in monetary systems, such as that of the Roman Empire, and as a means of paying for international trade. Silver continued to be the standard for most currencies until the discovery of major silver deposits in Mexico and Peru. As more silver deposits were discovered in the 18th and 19th centuries, countries gradually abandoned silver as the standard for their currencies in favor of a gold standard.

Expanding industrial use of silver eventually led to the elimination of silver in U.S. coinage. In the early 1960's, the U.S. Department of the Treasury became a major supplier of silver to industrial consumers. The Treasury, however, had insufficient stocks both to meet industrial demand and to maintain an adequate supply of circulating silver coinage for a prolonged period. When the silver price reached $1.29 per ounce, the value of the silver in a silver dollar equaled $1 in currency. At silver prices greater than $1.29, the silver in a silver dollar would have been worth more than $1 in currency, and as a result, it could have been advantageous to melt silver dollars for their silver content, thereby decreasing the amount of circulating coinage. Similarly, if the silver price rose above $1.38 per ounce, the silver in dimes, quarters, and half-dollars would have been worth more than the coin's 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 1990.

Definitions, Grades, and Specifications

The purity of silver in bullion, coinage, jewelry, or other items is usually expressed by its "fineness," or parts per thousand. Pure, or "fine," silver is 1,000 parts fine or 100.0% silver. Sterling silver is 925 fine, or 925 parts (92.5%) silver and 75 parts (7.5%) copper. Domestic coin silver is an alloy that was used in minting coinage until 1964 and

contained 900 parts silver and 100 parts copper. Commercial silver bullion ranges from 999 to 999.9 fine. For any fineness of silver bullion, the principal impurities are gold or copper. Doré silver is unrefined silver bullion generally containing a variable percentage of gold as an impurity. Silver for the NDS is required to be 999 fine; free of slag, dirt, or other foreign material; and in bars weighing approximately 31 kilograms.

Products for Trade and Industry

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 are 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 ($1.00 per troy ounce) to more than $260 per kilogram ($8.00 per troy ounce). Underground mining is, in general, more expensive than surface mining.

U.S. tax laws permit silver-producing companies a depletion allowance of 15% for domestic operations and 14% for foreign operations. There are no tariffs on the importation of silver ores, concentrates, doré, scrap, or refined bullion. Tariffs on semimanufactured silver can be as high as 27.5% ad valorem for countries receiving most-favored-nation classification and can be as high as 110% ad valorem for imports from those countries classified as non-most-favored-nation, depending on the item.

Operating Factors

Silver mining is, in general, no more hazardous than other mining, but because of the depths reached in the Coeur d'Alene district, rock bursts there are relatively common. Temperatures are uncomfortable

at these depths, and air conditioning must be used in ventilation systems. Gains in productivity are difficult to achieve because the possibilities for mechanization are limited by the relatively narrow veins mined. In recent years, companies have attempted to increase productivity through modification of labor agreements to allow more flexibility in work assignments and compensation and by improved mining plans.

Although in most circumstances silver is not a toxic substance in other than very large doses, a standard has been established for worker exposure to airborne particulate silver. The Occupational Safety and Health Administration currently requires that the concentration of either silver metal or soluble silver compounds be less than 0.01 milligram per cubic meter of ambient air in workplaces.

Nearly all silver-bearing ores are processed after grinding by flotation or cyanidation. Pollution of downstream waters by fine solids from flotation plants is a problem that requires adequate ponding and retention of tailings. Disposal or stabilization of the accumulated tailings can be a problem at some mines. It can be partially solved in those deep mines where ground support is needed by pumping the tailings back into the mine. In cyanidation operations, extreme care must be exercised to avoid contamination of the ground water, nearby watercourses, or surrounding areas through losses of leach solution. As a result, the solution collection system for returning the leachant to the storage tanks and the system for monitoring water in the surrounding area must be adequate to prevent pollution.

Achieving adequate air pollution (sulfur dioxide) control and disposing of slag and other wastes (iron and silica) are the problems encountered in smelting silver ores. Refining presents little environmental concern because the bulk of noxious impurities are removed during the smelting step; however, spent solutions from electrolytic refining present a disposal problem because of toxic materials in the solutions.

ANNUAL REVIEW

Legislation and Government Programs

On July 16, the President signed Public Law 101-322, the Mount Rushmore Commemorative Coin Act, which authorized the U.S. Mint to produce 500,000 gold coins, 2.5 million silver coins, and 2.5 million copper-nickel-clad coins in honor of the 50th anniversary of the Mount Rushmore National Memorial. Each silver coin was to weigh 26.73 grams; consist of a 90% silver, 10% copper alloy; be legal tender; and have a $1.00 face value. The silver for the coin was to be obtained from the NDS. Issuance of the coins was limited to calendar year 1991. The price of each silver coin was to include a $7.00 surcharge, 50% of which was to be used to improve, enlarge, and renovate the memorial.

The 1992 Olympic Commemorative Coin Act, Public Law 101-406, was enacted on October 3. The law authorized the minting of not more than 500,000 gold coins, 4 million silver coins, and 6 million copper-nickel- clad coins. Each silver coin was to weigh 26.73 grams; consist of a 90% silver, 10% copper alloy; be legal tender; and have a $1.00 face value. The silver for the coin was to be obtained from the NDS. No coins authorized by this act were to be minted after June 20, 1993. The price of each silver coin was to include a $7.00 surcharge, all of which was to be paid to the United States Olympic Committee to support the training of U.S. athletes participating in the 1992 Olympic Games.

Production

Silver was produced from precious-metal ores at 118 lode mines and from base metal ores at 19 lode mines. In 1990, 18 mines each produced more than 30 tons of silver; their aggregated production equaled 76% of total domestic production. Silver was also produced at 16 placer operations. U.S. silver production in 1990, 2,170 tons, was the largest quantity produced in any year since 1941, when 2,211 tons was produced.

***Alaska*.**—In its first full year of operation, the Greens Creek Mine achieved full production and operated at its designed capacity of 900 tons of ore per day. During the year, approximately 350,000 tons of ore was processed and more than 238 tons of silver was recovered.[2] In addition to silver, Greens Creek also produced gold, lead, and zinc. Exploration resulted in a significant increase in proven and probable reserves, which were estimated at about 6 million tons with an average silver grade of about 470 grams per ton. At yearend, Greens Creek employed 265 workers.

The Red Dog Mine completed its first full year of operation. Despite some initial problems, Cominco Ltd. reported that more than 900,000 tons of ore with an average content of 112 grams of silver per ton was processed at the mine.[3]

***Idaho*.**—Hecla Mining Co. sold its 5% interest in the Coeur Mine to Coeur d'Alene Mines Corp. The sale, completed in the fourth quarter, increased Coeur d'Alene's holding in the mine to 45%. Other partners in the venture were ASARCO Incorporated, 50%, and Callahan Mining Corp., 5%. In 1990, the Coeur Mine reportedly produced about 66 tons of silver.[4]

Heap-leach operations at the DeLamar Mine were suspended in early 1990 owing to a ground stability problem. NERCO Minerals Co., owner of the mine, was able to stabilize the ground, and reportedly was assessing the situation at yearend. The heap-leach facility was constructed in 1987 to process DeLamar's low-grade ores and was expected to recover an additional 2 tons of gold and 44 tons of silver during its first 7 years of operation.

A project to increase DeLamar's mill capacity was begun in 1990 and completed in early 1991. Mill capacity was increased from 850,000 tons to 1.1 million tons per year. In addition to processing DeLamar ore, the mill will now be able to process ore from the nearby Stone Cabin Project. Stone Cabin, a gold-silver deposit, was under development by NERCO at yearend.

The mill capacity at the Galena Mine was increased through the addition of a lead-silver circuit. The new circuit allowed the treatment of lead-silver ore in addition to the mine's traditional silver-copper ore. For the year, the Galena Mine reportedly produced more than 95 tons of silver.[5]

Low silver prices were blamed for the closure of one of the six operating stopes at the Lucky Friday Mine in the fourth quarter. The closed stope reportedly contained the lowest grade ore. The need to close the stope occurred despite the cash-flow generated by the mine's byproduct copper, gold, lead, and zinc production and Hecla's reduction of operating costs. In 1990, Lucky Friday processed 134,000 tons of ore and recovered about 59 tons of silver.[6] At yearend, the mine employed 173 workers.

Silver production at the Sunshine Mine was 165 tons, an increase of about 16 tons from the previous year.[7] Continued declining silver prices combined with low prices for natural gas, Sunshine Mining Co.'s other principal product, resulted in the company reporting a net loss for the fifth consecutive year. As a result of the low prices, Sunshine developed a plan to restructure its debt during the summer. Included in the plan was the sale of its oil and gas assets and debt reduction. In early 1991, the sale of Sunshine's oil and gas proper-

ties was consummated, and the remainder of the plan was expected to be implemented.

The Thunder Mountain Mine, a small gold-silver heap-leach operation, was closed at yearend. Declining reserves and lower gold production were cited as reasons for the decision. The mine, in a federally designated wilderness area, was recognized throughout its operating life from 1986 to 1990 for its environmental stewardship. In 1990, the mine produced 183 kilograms of gold and 139 kilograms of silver.[8] Work planned for 1991 included land reclamation and dismantling of the mine's plant and equipment.

A new heap-leach facility was commissioned at Hecla's Yellow Pine Mine. The new facility enabled the mine to resume gold and silver production near midyear. The decision to build the facility followed the termination of an ore processing agreement with Pioneer Metals Corp. in 1988. Although no commercial gold or silver production was reported during 1989, ore continued to be mined and stockpiled. Company officials expected identified oxide reserves to be depleted in 1991. The feasibility of mining a sulfide deposit on the property was being investigated.

Montana.—At the Basin Creek Mine, Pegasus Gold Inc. completed construction of a new leach pad. The new pad was expected to solve a number of operating problems encountered since the mine was acquired in late April 1989. However, owing in part to discontinuities in the ore and lower than expected ore grades, Pegasus decided to suspend mining operations near yearend. In the fourth quarter, Pegasus wrote off the carrying value of the mine. During the year, Basin Creek produced about 1 ton each of gold and silver.[9] Although mining operations were suspended, leaching was expected to continue in 1991.

In September, Pegasus adopted a revised mining plan for the Montana Tunnels Mine. The new plan was expected to reduce the stripping ratio from 3.3:1 to 1.4:1. During 1990, 3.8 million tons of ore was treated. In addition to gold, lead, and zinc, the mine produced 37 tons of silver.[10]

Construction of a new leach pad was completed at the Zortman/Landusky Mine. The new pad had a capacity of more than 54 million tons of ore. In 1990, 3 tons of gold and 20 tons of silver were recovered by heap leaching at Zortman/Landusky.[11]

Asarco reported that the Troy Mine produced about 118 tons of silver.[12]

Nevada.—USMX Inc. purchased the Alligator Ridge Mine from NERCO and Kennecott Corp. near midyear. Prior to the sale, NERCO and Kennecott each held a 50% interest in the open pit heap-leach operation. Although identified reserves at the mine were exhausted in December 1989, leaching continued through 1990. USMX reportedly purchased other property along the Alligator Ridge geologic trend.

A new heap-leach facility began operation at the Battle Mountain Complex in early October. Battle Mountain Gold Co., which owned the complex, mined ore from three deposits, the Fortitude, the Labrador, and the Surprise. Ore from the Fortitude Mine was processed at the Fortitude mill, a carbon-in-pulp cyanide leach facility. Ore from the Labrador and Surprise Mines was in general a lower grade material than the ore mined at Fortitude and was leached at the new heap-leach facility. It was expected that unless new millable ore deposits were discovered, heap leaching would provide an increasing amount of the company's precious-metals production at the Battle Mountain Complex. The Fortitude Mine was expected to be depleted in 1993. The company reported that during 1990, 14 tons of silver and 8 tons of gold were produced by the Battle Mountain Complex.[13]

Mining operations were suspended at the Candelaria Mine in November. NERCO, the mine's owner, cited the low silver price as the reason for the closure. Reportedly, the silver price had declined to near Candelaria's cost of production. Although mining was suspended, leaching was expected to continue in 1991, with an expected silver output of approximately 62 tons. During 1990, Candelaria produced about 151 tons of silver, an increase of 15 tons from that of the previous year.[14]

At the McCoy/Cove Mines, operations at the 6,800-ton-per-day mill were halted for 3 months following the reoccurrence of bird deaths at the mill's tailings pond. Near mid-September, construction of a new mill-effluent treatment facility was completed, and operations resumed. No additional bird kills were reported. Echo Bay Mines Ltd., owner and operator of the mines, cited an additional benefit provided by the new treatment facility. Following the startup of the new facility, the mill was able to resume using the correct amount of cyanide reagent, resulting in improved gold and silver recoveries. In 1990, the aggregated production from the McCoy and Cove deposits was about 8 tons of gold and 62 tons of silver.[15]

Silver production at the Paradise Peak Mine increased owing in part to the mining of the higher grade silver core of the ore body. During the year, about 1.3 million tons of ore was milled and an additional 700,000 tons was heap leached to produce 6 tons of gold and 170 tons of silver.[16]

At its Rochester Mine, Coeur d'Alene Mines handled more than 6 million tons of ore. Heap leaching at the open pit mine resulted in the recovery of almost 2 tons of gold and about 149 tons of silver.[17]

Silver production at the Wind Mountain Mine increased by 60% to more than 17 tons.[18] Officials at Amax Gold Inc. attributed the increase primarily to improved productivity.

Homestake Mining Co. ceased operations at its Wood Gulch Mine following the depletion of minable ores. The open pit heap-leach operation produced gold and some byproduct silver. Reclamation of the mine site was begun and was expected to be completed in late 1992.

Other States.—A project begun by Cyprus Minerals Co. in 1989 to increase the milling capacity of the Bagdad Mine in northwestern Arizona was completed. A fifth grinding line was added to the existing mill, increasing the capacity of the sulfide ore concentrator by about 20,000 tons per day to about 69,000 tons per day. At its Sierrita Mine, also in Arizona, Cyprus reported improved productivity following the acquisition of new larger haul trucks and a power shovel.

At the White Pine Mine in Michigan, projects were begun to increase the mine's productivity and lower its operating costs. Metall Mining Corp., which acquired the mine in mid-1989, instituted a revised mining plan. As part of the new plan, additional headings were developed to increase production. Metall also began replacing some of White Pine's aging equipment. By yearend, 56 pieces of equipment, including drill jumbos, load-haul-dump units, and bolters, were replaced. This modernization program was expected to continue in 1991. For 1990, the White Pine Mine milled 4.6 million tons of ore and recovered 34 tons of silver.[19]

At the Escalante Mine, in Iron County, UT, the milling of stockpiled ore was completed near midyear, and the mill was placed on care-and-maintenance status. Mining operations had been halted near the end of 1988 when the ore body was mined out. As part of its reclamation of the site, Hecla refilled a canal used for dewatering the mine, reseeded the surface area, and filled the access portal. In 1990, the mine recovered about 24 tons of silver.[20]

Consumption and Uses

Apparent U.S. demand for silver in 1990, calculated as refinery production from primary materials and from old scrap plus net imports of refined bullion, was 4,006 tons. Included in the apparent demand calculation was the amount of silver absorbed by investors, as well as the amount of silver required by the domestic fabricating 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, photooffset 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.

Stocks

Total accountable stocks at yearend 1990 had increased by about 500 tons over those of yearend 1989. Continued buildup of stocks held by futures exchanges more than compensated for declines in industry and Government-held stocks and accounted for all of the increase in accountable stocks. Some analysts explained the continued stock buildup as a normal consequence of the slowdown in the U.S. economy combined with a lack of investor demand. A few analysts, however, pointed to the stock buildup as an indication that perhaps in industrialized countries such as the United States, silver was losing its status as a precious metal, and hence, the lack of investor demand.

The quantity of Government-held silver continued to decline. The U.S. Mint used NDS silver for various coinage programs, and a portion of excess Treasury Department stocks were sold through Government-sponsored auctions held in October 1989 and January, May, and July 1990. Since 1985, Government-held stocks have declined by more than 1,600 tons, almost all of which has been used in various Government coinage programs.

Markets and Prices

The domestic silver price, as quoted by Handy & Harman, decreased, continuing the declining trend of the previous 3 years. The price began the year at $5.21 and was $4.18 at yearend. Analysts attributed the continued weak price primarily to an abundant silver supply combined with a lack of investor demand. Silver prices declined steadily throughout the year except for a brief rally in August following Iraq's invasion of neighboring Kuwait. Notable was the brevity of the rally considering that the Iraq-Kuwait conflict continued through yearend. The price decline resumed in mid-August. In December, the price fell below $4.00 per troy ounce for the first time since February 1976.

As with the domestic price, the London spot price decreased and 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 1990 at $5.21 per troy ounce and ended the year at $4.19. The low and high prices of $3.95 and $5.36 occurred on December 17 and February 20, respectively. The average for 1990 was $4.83.

The amount of silver represented by the futures contracts traded on the Commodity Exchange Inc. (COMEX) decreased in 1990 to 608,635 metric tons. In the previous year, futures contracts representing 680,640 metric tons of silver had been traded on COMEX. At the Chicago Board of Trade,

the quantity of silver corresponding to the futures trading volume decreased from 8,295 tons in 1989 to 5,912 tons in 1990. Silver futures trading volume declined from 422 tons to 342 tons on the Mid-America Commodity Exchange.

Foreign Trade

U.S. silver exports increased in 1990 for the sixth consecutive year, probably owing in part to the lower domestic silver price and increased domestic production. The countries recording the largest increases in receipt of U.S. silver exports were Canada and Japan, with increases of about 208 tons and 359 tons, respectively. In the case of Canada, most of the increased shipments were in the form of silver-bearing waste and scrap materials. The increased shipments to Japan, however, were for the most part in the form of refined bullion. The largest decrease in U.S. silver exports from the previous year was in shipments of doré and precipitates to Switzerland—approximately 58 tons.

Although U.S. silver imports for consumption remained essentially the same as in 1989, the quantity of silver imported from Canada and Mexico declined by 70 tons and 424 tons, respectively. In the case of both countries, the decreases were in the form of refined bullion. However, increased shipments of 167 tons from Peru, 124 tons from Taiwan, and 126 tons from the United Kingdom were able to keep U.S. total silver imports essentially unchanged.

World Review

The data in table 13 were rated production capacity in mines as of December 31, 1990. Rated capacity was defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

A decline in Peruvian production was more than offset by increased silver production in Australia, Canada, and the United States. As a result, world silver production increased slightly in 1990. It was believed that, as in the United States, the increased silver production in Australia and Canada was attributable to increased byproduct production. In Australia, mining plans were modified at a number of mines to increase gold output in 1990, as a new Australian tax on gold production was to come into effect in 1991. Consequently, Australian silver production also increased. The lower Peruvian production was attributed to labor unrest and the country's economic problems.

Worldwide, gold continued to be the primary metals exploration target, although reported tight copper and zinc supplies were believed to have resulted in increased interest in these metals. As with gold, most copper and zinc deposits contain some silver that can be recovered as a byproduct. As in previous years, Oceania and countries bordering the Pacific Ocean continued to be the most active exploration areas.

In its 1990 review, Handy & Harman estimated world silver consumption at about 17,700 tons, a decrease of about 200 tons from the revised 1989 figure.[21] Of the total, 16,900 tons was used in industrial applications, essentially unchanged from that of the previous year. The quantity of silver used for coinage decreased from that of about 1,100 tons in 1989 to about 800 tons in 1990.

Canada.—The Ansil Mine in Quebec completed its first full year of operation. The mine began commercial production in July 1989. In addition to copper, gold, and zinc, the mine recovered 10 tons of silver during 1990.[22]

Construction of LAC Minerals Ltd.'s Bousquet No. 2 Mine was completed, and the mine commenced commercial operations on October 1. Ore from the mine was trucked to LAC's Est-Malartic mill, where copper, gold, and byproduct silver were recovered using flotation.

Production at the Dome Mine in Ontario declined. Lower ore grade was a contributing factor in the reduced production. Additionally, unionized workers struck the mine for about 6 months, from May to November, following the expiration of their contract. To reduce operating costs at Dome, Placer Dome Inc. reorganized the mine's operations, resulting in a significant reduction in the number of employees.

Silver production at the Equity Silver Mine in British Columbia was about 229 tons, an increase of about 11 tons from that of the previous year.[23] Improved recoveries and higher ore grades were cited as the reasons for the increased production. Production was expected to decline in each of the next 2 years owing in part to lower ore grades and reserve depletion. The mine was expected to close in late 1992.

Workers at Brunswick Mining and Smelting Corp. Ltd.'s No. 12 Mine began a strike in early July. Issues included wages, work practices at the mine, and pension and health benefits. Near mid-July, the company began operating the mine at about 25% of its normal rate using staff personnel. At yearend, the strike remained unsettled.

At the Samatosum Mine, approximately 150,000 tons of ore was milled during the mine's first full year of operation. During 1990, the mine produced about 166 tons of silver.[24] Samatosum, an open pit mine in British Columbia, began commercial production in July 1989. In addition to silver, the mine also produced copper, gold, lead, and zinc.

Cominco Ltd. closed the Sullivan Mine at the end of January. Company officials attributed the decision to a combination of declining zinc prices, high operating costs resulting from the need for increased ground support at the mine's lower levels, and changes in the ore at these levels. In July, a new 27-month contract was negotiated with Sullivan's unionized workers. As part of the attempt to improve the mine's productivity, the new contract incorporated a new incentive plan. From August to November, the company made various improvement to the mine and mill. The mine was reopened in November. Employment at Sullivan declined from 727 at yearend 1989 to 655 at yearend 1990.[25]

At the Valley Mine in British Columbia, Highland Valley Copper Co. produced about 31 tons of silver, an increase of more than 9 tons from that of the previous year when operations were disrupted by a 15-week strike.[26] In February, the Bethlehem mill was permanently closed. Bethlehem, which last operated in 1989, was placed on standby that year following the opening of the Highland mill.

Other Countries.—Construction of a second roaster was completed at the El Indio Mine in Chile, and the construction of a third roaster was begun. The additional roasting capacity was expected to reduce the penalties imposed by smelters on some of El Indio's concentrates owing to its high arsenic content. In 1990, El Indio milled about 1 million tons of ore and recovered almost 7 tons of gold and 44 tons of silver.[27]

The Real de Angeles Mine in Mexico increased its silver production to about 294 tons.[28] The increased production was attributed to mill modifications and an in-

crease in hauling capacity. About 5.4 million tons of ore with an average silver content of 59 grams per ton was milled at Real de Angles during the year.

At the Porgera Mine, in Papua New Guinea, construction of the underground mine and a new processing facility were completed in August. The processing plant had a capacity of 1,650 tons per day and began commercial production in early September. The plant used carbon-in-pulp technology to recover gold and silver. According to company reports, tailings from the operation were being stored so that they could be processed through a pressure oxidation circuit currently under construction to recover additional gold and silver. Construction of the pressure oxidation circuit was expected to be completed in late 1991.

OUTLOOK

The increasingly dominant component of domestic silver supply is its recovery as a byproduct of the processing of other nonferrous metals such as copper, gold, lead, and zinc. Most nonferrous ores contain some silver, which is either concentrated when the ore is processed or recovered with the principal product. Once it is concentrated or separated from the principal product, the additional cost to recover the silver is relatively minor. As a result, the revenue generated by the recovered silver is often an important component in many mines' finances, especially during periods of declining prices for the principal product.

A drop in the U.S. mine production of silver could have been expected given the declining silver price and a U.S. economic recession. However, U.S. mine production did not decrease; instead, it increased for the fourth consecutive year in response to an increase in byproduct silver production. As a result of this relative independence of silver supply and price, it is expected that during the period 1991-93, domestic silver mine production will remain near 2,000 tons per year.

Worldwide, silver mine production is expected to remain near the 1990 level of 15,100 tons.

Future industrial demand for silver is harder to forecast owing to the lack of data. As in 1989, some analysts believed that the consumption of silver by domestic manufacturers increased, while other analysts believed that the consumption decreased. It is believed that during the period 1991-93, industrial silver demand will remain essentially unchanged from that of 1990. Worldwide, silver demand is expected to grow slightly as potential new markets are opened and countries such as those in Eastern Europe develop the means of earning the foreign exchange needed to purchase products containing silver.

[1]Heyl, A.V., W. E. Hall, A. E. Weissenborn, H. K. Stager, W. P. Puffett, and B. L. Reed. Silver. Ch. in United States Mineral Resources, ed. by D. A. Brobst and W. P. Pratt. U.S. Geol. Survey Prof. Paper 820, 1973, 2 p. 596.
[2]Hecla Mining Co. 1990 Annual Report, 36 pp.
[3]Cominco Ltd. 1990 Annual Report, 64 pp.
[4]Coeur d'Alene Mines Corp. 1990 Annual Report, 32 pp.
[5]ASARCO Incorporated. 1990 Annual Report, 42 pp.
[6]Work cited in footnote 2.
[7]Sunshine Mining Co. 1990 Annual Report, 20 pp.
[8]Work cited in footnote 4.
[9]Pegasus Gold Inc. 1990 Annual Report, 48 pp.
[10]Work cited in footnote 9.
[11]Work cited in footnote 9.
[12]Work cited in footnote 5.
[13]Battle Mountain Gold Co. 1990 Annual Report, 49 pp.
[14]NERCO Inc. 1990 10K Report, 41 pp.
[15]Echo Bay Mines Ltd. 1990 Annual Report, 64 pp.
[16]FMC Gold Co. 1990 Annual Report, 31 pp.
[17]Work cited in footnote 4.
[18]Amax Gold Inc. 1990 Annual Report, 40 pp.
[19]Metall Mining Corp. 1990 Annual Report, 44 pp.
[20]Work cited in footnote 2.
[21]Handy & Harman. The Silver Market, 1990. 75th Annual Review, 31 pp.
[22]Kerr Addison Mines Ltd. 1990 Annual Report, 28 pp.
[23]Placer Dome Inc. 1990 Annual Report, 64 pp.
[24]Work cited in footnote 22.
[25]Work cited in footnote 3.
[26]Work cited in footnote 3.
[27]LAC Minerals Ltd. 1990 Annual Report, 56 pp.
[28]Work cited in footnote 9.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

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Other Publications

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Metals Week, New York.
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The Silver Institute Letter, pub. bimonthly by the Silver Institute, Washington, DC.
The Silver Market, compiled by Handy & Harman, New York.

TABLE 1

SALIENT SILVER STATISTICS

		1986	1987	1988	1989	1990
United States:						
Mine production	metric tons	1,074	1,241	1,661	2,007	2,170
Value	thousands	$188,846	$277,063	$349,339	$354,971	$336,006
Refinery production:						
Domestic and foreign ores and concentrates	metric tons	1,319	1,415	1,474	1,718	1,611
Secondary (old scrap)	do.	762	810	852	735	433
Exports:						
Refined	do.	314	350	444	430	736
Other	do.	467	493	555	850	1,112
Imports for consumption:						
Refined	do.	3,899	2,114	2,260	3,062	2,698
Other	do.	607	431	497	241	646
Stocks, December 31:						
Industry	do.	550	471	480	544	534
Futures exchanges	do.	5,042	5,279	5,862	7,795	8,636
Apparent demand, refined[1]	do.	5,666	3,989	4,142	5,085	4,006
Coinage	do.	234	469	275	r264	265
Price, average per troy ounce[2]		$5.47	$7.01	$6.54	$5.50	$4.82
Employment[3]		2,200	1,800	2,300	2,800	2,600
World:						
Mine production	metric tons	r13,034	r13,844	14,333	p14,760	e15,108
Consumption:[2]						
Industry and the arts	do.	15,399	15,443	16,671	r16,889	16,942
Coinage	do.	526	933	799	r1,082	793

eEstimated. pPreliminary. rRevised.

[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]Handy & Harman.

[3]Mine Safety and Health Administration.

TABLE 2

MINE PRODUCTION OF RECOVERABLE SILVER IN THE UNITED STATES, BY STATE

(Metric tons)

State	1986	1987	1988	1989	1990
Alaska	W	(1)	1	W	W
Arizona	140	114	152	171	173
California	5	4	15	21	21
Colorado	20	27	27	W	23
Idaho	349	W	340	439	436
Missouri	45	37	45	53	35
Montana	148	185	192	194	220
Nevada	199	379	608	625	708
New Mexico	W	58	93	78	48
Oregon	—	W	W	W	W
South Dakota	W	W	3	4	6
Utah	73	W	W	185	147
Other States[2]	r94	r436	r185	r239	354
Total[3]	1,074	1,241	1,661	2,007	2,170

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

MINE PRODUCTION OF RECOVERABLE SILVER IN THE UNITED STATES, BY MONTH

(Metric tons)

Month	1986	1987	1988	1989	1990
January	115	99	116	143	199
February	101	97	114	139	173
March	102	105	131	166	188
April	99	103	126	160	178
May	90	99	129	176	183
June	86	101	142	174	184
July	84	110	142	175	183
August	81	107	152	185	187
September	82	109	152	179	167
October	82	105	157	168	179
November	74	100	150	170	179
December	78	106	150	173	168
Total[1]	1,074	1,241	1,661	2,007	2,170

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

TABLE 4

TWENTY-FIVE LEADING SILVER-PRODUCING MINES IN THE UNITED STATES IN 1990, IN ORDER OF OUTPUT

Rank	Mine	County and State	Operator	Source of silver
1	Greens Creek	Admiralty Island, AK	Greens Creek Mining Co.	Zinc ore.
2	Paradise Peak	Nye, NV	FMC Gold Co.	Gold ore.
3	Sunshine	Shoshone, ID	Sunshine Mining Co.	Silver ore.
4	Candelaria	Mineral, NV	NERCO Metals Inc.	Do.
5	Rochester	Pershing, NV	Coeur Rochester Inc.	Gold ore.
6	Troy	Lincoln, MT	ASARCO Incorporated	Copper ore.
7	Bingham Canyon	Salt Lake, UT	Kennecott-Utah Copper Co.	Do.
8	Galena	Shoshone, ID	ASARCO Incorporated	Silver ore.
9	Red Dog	NW Arctic, AK	Cominco Alaska Inc.	Zinc ore.
10	Coeur	Shoshone, ID	ASARCO Incorporated	Silver ore.
11	Lucky Friday	do.	Hecla Mining Co.	Lead-zinc ore.
12	McCoy and Cove	Lander, NV	Echo Bay Mining Co.	Gold ore.
13	Sierrita	Pima, AZ	Cyprus Sierrita Corp.	Copper ore.
14	DeLamar	Owyhee, ID	Nerco DeLamar Co.	Gold ore.
15	Montana Tunnels	Jefferson, MT	Montana Tunnels Mining Inc.	Zinc ore.
16	Mission Complex[1]	Pima, AZ	ASARCO Incorporated	Copper ore.
17	White Pine	Ontonagon, MI	Copper Range Co.	Do.
18	Tyrone	Grant, NM	Phelps Dodge Corp.	Do.
19	Bagdad	Yavapai, AZ	Cyprus Bagdad Copper Co.	Do.
20	Escalante	Iron, UT	Hecla Mining Co.	Silver ore.
21	Continental	Silver Bow, MT	Montana Resources Inc.	Copper ore.
22	Zortman-Landusky	Phillips, MT	Pegasus Gold Inc.	Gold ore.
23	Wind Mountain	Washoe, NV	Amax Gold Corp.	Do.
24	Morenci	Greenlee, AZ	Phelps Dodge Corp.	Copper ore.
25	Fortitude and Surprise	Lander, NV	Battle Mountain Gold Co.	Gold ore.

[1]Includes Eisenhower, Mission, Pima, and San Xavier Mines.

TABLE 5

SILVER PRODUCED IN THE UNITED STATES, BY STATE, TYPE OF MINE, AND CLASS OF ORE

Year and State	Placer (metric tons of silver)	Lode					
		Gold ore		Gold-silver ore		Silver ore	
		Metric tons	Metric tons of silver	Metric tons	Metric tons of silver	Metric tons	Metric tons of silver
1986	(1)	r39,707,049	120	788,434	56	5,040,027	493
1987	(1)	62,044,114	221	W	W	7,944,696	432
1988	(1)	108,310,781	372	W	W	9,573,505	674
1989	W	r155,188,564	528	W	W	4,450,703	524
1990:							
Alaska	(1)	W	W	—	—	—	—
Arizona	(1)	1,085,469	W	W	W	—	—
California	W	18,134,695	W	—	—	—	—
Colorado	—	24,606,696	W	W	W	—	—
Idaho	—	W	W	—	—	W	W
Illinois	—	—	—	—	—	—	—
Kentucky	—	—	—	—	—	—	—
Michigan	—	—	—	—	—	—	—
Missouri	—	—	—	—	—	—	—
Montana	—	15,089,794	26	—	—	—	—
Nevada	W	367,984,488	547	W	W	W	W
New Mexico	—	W	W	—	—	—	—
New York	—	—	—	—	—	—	—
Oregon	W	—	—	—	—	—	—
South Carolina	—	W	W	—	—	—	—
South Dakota	—	6,846,661	6	—	—	—	—
Tennessee	—	—	—	—	—	—	—
Utah	—	4,457,618	12W	W	W	158,578	24
Washington	—	W	W	—	—	—	—
Total	W	457,296,182	679	W	W	W	W
Percent of total silver	W	XX	31	XX	W	XX	W

	Lode					
	Copper ore		Other[2 3]		Total[4]	
	Metric tons	Metric tons of silver	Metric tons	Metric tons of silver	Metric tons	Metric tons of silver
1986	r 5161,063,941	5345	r7,401,691	59	r214,001,141	1,074
1987	201,434,248	477	W	W	279,753,709	1,241
1988	222,306,768	485	W	W	350,639,851	1,661
1989	r230,558,434	529	W	W	r407,094,891	2,007
1990:						
Alaska	—	—	W	W	W	W
Arizona	149,921,652	164	W	W	151,030,556	173
California	—	—	—	W	18,134,695	21
Colorado	—	—	W	W	25,000,495	23
Idaho	—	—	W	W	W	436
Illinois	—	—	—	W	—	W
Kentucky	—	—	W	W	W	W
Michigan	W	W	—	—	W	W
Missouri	—	—	7,471,102	35	7,471,102	35

See footnotes at end of table.

TABLE 5—CONTINUED

SILVER PRODUCED IN THE UNITED STATES, BY STATE, TYPE OF MINE, AND CLASS OF ORE

	Lode					
	Copper ore		Other[2 3]		Total[4]	
	Metric tons	Metric tons of silver	Metric tons	Metric tons of silver	Metric tons	Metric tons of silver
1990—Continued						
Montana	W	W	W	W	37,109,897	220
Nevada	W	W	157,584	8	372,412,290	708
New Mexico	W	W	—	—	30,231,997	48
New York	—	—	W	W	W	W
Oregon	—	—	—	—	—	W
South Carolina	—	—	—	—	W	W
South Dakota	—	—	—	—	6,846,661	6
Tennessee	—	—	W	W	W	W
Utah	W	W	—	—	W	147
Washington	—	—	—	—	W	W
Total	240,620,259	492	W	W	719,153,536	2,170
Percent of total silver	XX	23	XX	W	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 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.
[4]Data may not add to totals shown because of independent rounding.
[5]Includes copper-zinc ore and silver recovered from copper-zinc ore.

TABLE 6

SILVER PRODUCED IN THE UNITED STATES BY CYANIDATION[1]

(Metric tons)

Year	Leaching in vats, tanks, and closed containers[2 3]		Leaching in open heaps or dumps[4]	
	Ore treated	Silver recovered	Ore treated	Silver recovered
1986	r18,005,513	233	r25,151,850	113
1987	r22,886,885	280	r45,269,732	254
1988	r26,601,197	302	r86,863,178	456
1989	r37,688,487	r300	r120,365,867	r490
1990	132,689,247	290	326,163,458	550

rRevised.
[1]May include small quantities recovered by leaching with thiourea, by bioextraction, and by proprietary processes.
[2]Including autoclaves.
[3]May include small quantities recovered by gravity methods.
[4]May include tailings and waste ore dumps.

TABLE 7

LODE SILVER PRODUCED IN THE UNITED STATES, BY STATE

(Metric tons)

	Amalgamation		Cyanidation		Smelting of concentrates			Smelting of ore		Total ore processed [1,2]	Total silver recovered[2]
	Ore treated	Silver recovered	Ore treated	Silver recovered	Ore concentrated	Concentrate smelted	Silver recovered	Ore smelted	Silver recovered		
1986	r684,970	(3)	r43,157,363	346	r169,976,452	r3,794,572	717	r182,356	9	r214,001,141	1,074
1987	W	W	r68,156,617	534	r211,426,725	4,459,843	696	W	W	279,753,709	1,240
1988	1,512	(3)	r113,464,375	758	r236,934,759	4,943,949	884	r239,205	19	350,639,851	1,661
1989	W	W	r158,054,354	790	r248,850,352	5,164,847	1,195	W	W	r407,094,891	2,007
1990:											
Alaska	—	—	W	W	W	W	W	—	—	W	W
Arizona	—	—	W	W	149,921,652	2,648,257	164	W	W	151,030,556	173
California	—	—	W	W	W	W	W	—	—	18,134,695	21
Colorado	1,230	(3)	W	W	W	W	W	318	(3)	25,000,495	23
Idaho	—	—	W	W	1,222,240	138,475	W	—	—	W	436
Illinois	—	—	—	—	—	W	W	—	—	—	W
Kentucky	—	—	—	—	W	W	W	—	—	W	W
Michigan	—	—	—	—	W	W	W	W	W	W	W
Missouri	—	—	—	—	7,471,102	594,301	35	—	—	7,471,102	35
Montana	—	—	15,062,280	23	22,047,306	217,278	197	311	(3)	37,109,897	220
Nevada	—	—	372,102,525	698	W	W	W	W	W	372,412,290	708
New Mexico	—	—	—	—	W	W	W	W	W	30,231,997	48
New York	—	—	—	—	W	W	W	—	—	W	W
South Carolina	—	—	W	W	—	—	—	—	—	W	W
South Dakota	—	—	6,846,661	6	—	—	—	—	—	6,846,661	6
Tennessee	—	—	—	—	W	W	W	—	—	W	W
Utah	—	—	4,616,195	37	W	W	W	W	W	W	147
Washington	—	—	1,476,843	10	W	W	W	—	—	W	W
Total	1,230	(3)	458,852,705	840	260,212,391	6,249,955	W	87,210	W	719,153,536	2,170

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Total," where applicable.
[1]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.
[2]Data may not add to totals shown because of independent rounding.
[3]Less than 1/2 unit.

TABLE 8

U.S. REFINERY PRODUCTION OF SILVER

(Metric tons)

Raw material	1986	1987	1988	1989	1990
Concentrates and ores:					
Domestic and foreign	1,319	1,415	1,474	1,718	1,611
Old scrap	762	810	852	735	433
New scrap	1,448	1,316	1,505	1,495	1,185
Total[1]	3,529	3,541	3,832	3,948	3,229

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

TABLE 9

YEAREND STOCKS OF SILVER IN THE UNITED STATES

(Metric tons)

	1986	1987	1988	1989	1990
Industry	550	471	480	544	534
Futures exchanges	5,042	5,279	5,862	7,795	8,636
Department of the Treasury	1,052	1,229	1,201	997	840
Department of Defense	78	75	81	81	31
National Defense Stockpile	3,960	3,517	3,310	2,973	2,830

TABLE 10

U.S. SILVER PRICES

(Dollars per troy ounce)

Period	Low		High		Average
	Price	Date	Price	Date	
1986	4.87	May 20	6.20	Jan. 27	5.47
1987	5.36	Jan. 7	10.20	Apr. 27	7.01
1988	6.01	Nov. 21 and Dec. 29	7.99	July 21	6.54
1989	5.02	Sept. 15	6.17	Jan. 23	5.50
1990:					
January	5.19	Jan. 3	5.34	Jan. 12	5.24
February	5.10	Feb. 27	5.39	Feb. 7	5.28
March	4.91	Mar. 28	5.14	Mar. 1 and 8	5.06
April	4.89	Apr. 30	5.17	Apr. 5	5.05
May	4.99	May 8 and 9	5.22	May 24 and 25	5.07
June	4.77	June 26	5.07	June 6	4.91
July	4.80	July 10	4.96	July 3	4.86
August	4.80	Aug. 31	5.22	Aug. 14	4.98
September	4.74	Sept. 3 and 4	4.90	Sept. 24	4.79
October	4.10	Oct. 29	4.69	Oct. 4	4.36
November	4.08	Nov. 29	4.28	Nov. 7	4.16
December	3.93	Dec. 18	4.17	Dec. 31	4.06
Average and date	3.93	Dec. 18	5.39	Feb. 7	4.82

Source: Handy & Harman daily quotation.

TABLE 11

U.S. EXPORTS OF SILVER, BY COUNTRY[1]

Year and country	Ores and concentrates		Wastes and scrap		Doré and precipitates		Refined bullion		Total[2]	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
1986	8,840	$1,630	401,715	$72,729	56,148	$11,436	314,440	$56,785	781,142	$142,581
1987	472	150	425,325	96,738	67,286	16,294	349,610	79,123	842,693	192,305
1988	25,450	1,416	475,481	99,797	53,733	10,844	443,831	94,029	998,495	206,086
1989	607	166	770,788	145,340	78,664	15,478	430,110	77,812	1,280,169	238,797
1990:										
Austria	—	—	—	—	—	—	877	187	877	187
Belgium	13,143	2,058	108,693	17,677	—	—	86	12	121,922	19,747

See footnotes at end of table.

TABLE 11—Continued

U.S. EXPORTS OF SILVER, BY COUNTRY[1]

Year and country	Ores and concentrates		Wastes and scrap		Doré and precipitates		Refined bullion		Total[2]	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
1990—Continued										
Brazil	—	—	2,281	$638	—	—	—	—	2,281	$638
Canada	54	$16	349,154	56,097	5	$1	80,420	$14,165	429,632	70,279
China	—	—	876	131	—	—	—	—	876	131
Egypt	—	—	—	—	—	—	727	176	727	176
France	—	—	150,666	23,522	2,299	387	1,997	391	154,962	24,300
Germany, Federal Republic of	—	—	60,234	8,017	2,871	489	23,230	4,732	86,335	13,238
Hong Kong	—	—	16,709	2,252	—	—	38	7	16,747	2,259
Italy	—	—	3,204	493	—	—	324	60	3,528	553
Japan	—	—	207,797	19,767	—	—	515,327	82,167	723,124	101,934
Korea, Republic of	81	15	907	136	—	—	9,253	1,496	10,241	1,646
Mexico	7,913	1,768	864	129	—	—	—	—	8,777	1,897
Netherlands	292	77	329	78	—	—	183	26	803	180
Singapore	—	—	6	4	—	—	31,269	5,128	31,275	5,132
Sweden	—	—	26,334	4,169	—	—	—	—	26,334	4,169
Switzerland	—	—	19	19	537	213	2,295	390	2,850	623
United Kingdom	—	—	147,171	25,617	7,471	1,264	64,081	9,848	218,723	36,729
Uruguay	—	—	—	—	—	—	4,729	869	4,729	869
Venezuela	—	—	936	184	—	—	—	—	936	184
Other	380	61	1,245	266	—	—	1,156	239	2,779	566
Total[2]	21,861	3,994	1,077,421	159,194	13,184	2,353	735,993	119,892	1,848,458	285,434

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export data may not be comparable with previous years' data.
[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 SILVER, BY COUNTRY[1]

Year and country	Ores and concentrates[2]		Wastes and scrap		Doré and precipitates		Refined bullion		Total[3]	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
1986	171,556	$30,926	58,066	$10,854	377,638	$68,590	3,899,300	$688,296	4,506,560	$798,183
1987	83,401	18,019	105,881	22,514	242,017	53,858	2,113,765	460,235	2,545,064	554,627
1988	191,324	35,508	60,470	12,995	245,122	52,840	2,260,049	476,181	2,756,964	577,524
1989	7,013	2,301	90,753	96,254	142,739	27,943	3,061,548	578,781	3,302,054	705,278
1990:										
Argentina	—	—	9,159	350	—	—	—	—	9,159	350
Brazil	—	—	—	—	—	—	1,030	166	1,030	166
Canada	382	255	69,253	28,777	15,648	2,545	1,042,523	172,535	1,127,806	204,112
Chile	—	—	767	134	195	29	51,963	8,381	52,926	8,544
China	—	—	10,227	6,789	—	—	4,647	787	14,874	7,576
Denmark	—	—	29,520	108	—	—	—	—	29,520	108
Dominican Republic	—	—	102	82	19,094	3,273	—	—	19,196	3,355
Germany, Federal Republic of	1	7	52,306	1,597	—	—	20,073	3,347	72,379	4,952
Hong Kong	—	—	1,249	206	—	—	—	—	1,249	206

See footnotes at end of table.

TABLE 12—Continued

U.S. IMPORTS FOR CONSUMPTION OF SILVER, BY COUNTRY[1]

Year and country	Ores and concentrates[2]		Wastes and scrap		Doré and precipitates		Refined bullion		Total[3]	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
1990—Continued										
Italy	—	—	168	$55	—	—	2,375	$326	2,543	$381
Malaysia	—	—	24,513	2,466	—	—	—	—	24,513	2,466
Mexico	89,756	$22,930	6,458	1,252	1,247	$207	1,250,474	200,386	1,347,935	224,775
Netherlands Antilles	—	—	12,375	335	—	—	—	—	12,375	335
Peru	—	—	7	213	857	139	253,214	39,037	254,078	39,389
Philippines	—	—	14,457	1,499	9,550	2,244	122	22	24,129	3,765
Switzerland	64	11	3,391	11,344	—	—	16	8	3,470	11,362
Taiwan	—	—	124,429	1,534	—	—	—	—	124,429	1,534
United Kingdom	—	—	146,367	1,887	—	—	—	—	146,367	1,887
Uruguay	—	—	—	—	1,440	230	70,444	12,237	71,883	12,467
Other	—	—	2,904	27,794	417	72	1,047	147	4,368	28,014
Total[2]	90,202	23,203	507,649	86,421	48,449	8,741	2,697,926	437,380	3,344,229	555,744

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export data may not be comparable with previous years' data.
[2]Includes silver content of base metal ores, concentrates, and matte imported for refining.
[3]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13

WORLD ANNUAL SILVER PRODUCTION CAPACITY,[1] DECEMBER 31, 1990

(Metric tons)

	Rated capacity
North America:	
Canada	1,380
Mexico	2,420
United States	2,130
Other	160
Total	6,090
South America:	
Chile	520
Peru	2,050
Other	420
Total	2,990
Europe:	
Poland	1,060
Spain	370
U.S.S.R.	1,500
Other	890
Total	3,820
Africa	750
Asia:	
Japan	360
Other	680
Total	1,040
Oceania:	
Australia	1,120
Other	70
Total	1,190
World total	15,880

[1]Includes capacity at operating plants as well as at plants on standby basis.

TABLE 14

SILVER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Algeria[e]	4	4	4	4	4
Argentina	66	60	79	83	80
Australia	1,023	1,119	1,118	1,075	[3]1,273
Bolivia	95	142	232	267	280
Brazil[e 4]	[r]58	[r]61	61	60	60
Bulgaria[e]	28	28	28	28	28
Burma	[r]14	26	9	7	[3]7
Canada (shipments)	1,088	1,375	1,443	1,262	[3]1,380
Chile	500	500	507	545	[3]633
China[e]	90	100	110	125	125
Colombia[5]	6	5	7	7	7
Costa Rica[e]	(6)	(6)	(6)	(6)	(6)
Czechoslovakia[e]	(6)	(6)	(6)	(6)	(6)
Dominican Republic	41	36	40	23	[3]22
Ecuador[e]	(6)	(6)	(6)	(6)	(6)
Fiji	1	1	1	1	1
Finland	37	44	31	31	31
France	26	25	24	22	20
Germany, Federal Republic of:					
Eastern states[e]	41	41	40	39	35
Western states	28	31	[e]31	[e]31	30
Ghana[e]	(6)	1	1	1	1
Greece	54	52	61	[re]60	62
Greenland	12	13	[e]14	[e]15	—
Honduras	54	23	58	50	36
India	35	38	41	35	38
Indonesia	47	50	58	74	[3]67
Ireland	8	7	6	7	7
Italy[5 7]	[r]56	[r]82	92	96	98
Japan	351	281	252	156	[3]150
Korea, North[e]	50	50	50	50	50
Korea, Republic of	157	209	227	239	[3]238
Malaysia	14	[r]16	11	13	13
Mexico	2,303	2,415	2,359	2,306	[3]2,346
Morocco	[r]79	[e]44	226	237	236
Namibia	108	[r]103	117	108	90
Nicaragua	[e]1	1	[e]1	1	1
Papua New Guinea	56	61	70	94	130
Peru	1,926	2,054	1,552	[e]1,840	[3]1,725
Philippines	54	52	52	48	50
Poland	829	831	1,063	1,003	1,000
Portugal	1	1	1	1	1
Romania[e]	25	23	23	25	25
Saudi Arabia[e]	—	—	4	11	11
Solomon Islands	—	—	(6)	(6)	(6)
South Africa, Republic of	222	208	200	182	[3]161
Spain	327	350	353	[re]450	500
Sweden	[r]263	[r]254	208	228	220
Taiwan	13	10	8	6	6

See footnotes at end of table.

TABLE 14—Continued

SILVER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Tunisia[e]	[3]2	2	2	2	2
Turkey[e]	7	9	23	[r]29	32
U.S.S.R.[e 5]	1,500	1,510	[r]1,520	[r]1,520	1,400
United States	1,074	1,241	1,661	2,007	[3]2,170
Yugoslavia[5]	177	165	139	133	[3]105
Zaire	34	37	74	77	75
Zambia[8]	[r]26	[r]28	24	[r e]25	25
Zimbabwe	26	25	22	22	22
Total	[r]13,034	[r]13,844	14,333	14,760	15,108

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Recoverable content of ores and concentrates produced unless otherwise specified. Table includes data available through June 21, 1991.

[2]In addition to the countries listed, Botswana produces silver (probably 1 kilogram or less per year) and Austria and Thailand may produce silver, but information is inadequate to make reliable estimates of output levels.

[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): 1986—20 (estimated); 1987—20 (estimated); 1988—22 (estimated); 1989—22 (estimated); and 1990—22 (estimated).

[5]Smelter and/or refinery production.

[6]Less than 1/2 unit.

[7]Includes production from imported ores.

[8]Year beginning Apr. 1 of that stated.

SLAG—IRON AND STEEL

By Cheryl Cvetic Solomon

Ms. Solomon, a physical scientist with 5 years U.S. Bureau of Mines experience, has been the commodity specialist for iron and steel slag since 1990. Domestic survey data were prepared by Barbara McNair, mineral data assistant.

Iron and steel slags are byproducts of the iron and steel industry and provide an important source of raw materials for construction and road building. Slags are used in road bases, asphalt concrete aggregates, concrete aggregates and products, glass manufacture, mineral wool, railroad ballast, sewage treatment, and soil conditioning.

In 1990, the Federal Environmental Protection Agency (EPA) permanently retained iron and steel slags in the Bevill amendment, or mining waste exclusion, under the Resource Conservation and Recovery Act (RCRA). Iron and steel slags are, therefore, not subject to Federal regulation as hazardous wastes.

Research during the year emphasized the use of granulated slag, particularly in cement. The Australasian Slag Association was formed in Sydney, Australia, to expand the already considerable use of slag in the Australian and Asian markets.

Domestic consumption of iron slag showed a moderate increase when compared with that of 1989, while the consumption of steel slag stayed at the increased level that it had reached in 1989.

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. Slag quantities are given in short tons except where otherwise indicated.

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 a 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. 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.

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 it 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.

When added to cement, granulated slag enhances the properties of ordinary cement. For example, it will increase the resultant concrete's durability in a marine environment, where concrete is subjected to sulfate attack.

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. Different types of steel slag are generated from the open hearth, basic oxygen, and electric arc furnaces.

Owing to skid resistant properties of both blast furnace and steel furnace slag, many State agencies or State departments of transportation have specified slag for use in any asphalt surface application having a high volume of traffic. The State of Illinois specifies the use of either blast furnace or steel furnace slag for road construction.[1] In the Greater Chicago area, the use of steel furnace slag is presently specified in these applications. The State of Indiana presently specifies that at least 50% of the coarse aggregate portion of the asphalt mix be blast furnace slag.[2]

Industry Structure

In general, most slag processors operate under contracts of 3 to 10 years with steel companies. The services the slag processors typically offer to the steel mill industry are hauling and transport of the slag away from the mill site, processing of the slag, and recovery and distribution of metallics and nonmetallics. Because slag hauling and processing facilities are capital intensive, the slag processors usually try to negotiate a long-term initial contract with the steel company to recover the capital investment. Subsequent contracts may be shorter.

Depending upon the specific situation at the mill site, the slag processor may assume ownership of the slag at the point of discharge or process for a fee and/or market the finished product and pay royalties to the steel company on sales. Some steel companies may allow the processor to share in royalties on these sales. Although there are many variations in the way a particular slag processor and steel mill will set up their agreement, two possible options are considered here. The slag company may be paid to haul and transport the slag, process it, and market the finished product. The steel company, in turn, receives a royalty on the completed sale and a purchase discount on material recycled to the mill. Secondly, in a minority of the contracts, the slag processor takes ownership of the material and pays little or no royalties to the mill. In this situation, the slag processor would be assuming 100% of the site development and capital costs, including facilities for screening, metallic separation, and crushing and heavy equipment, such as slag pot haulers, to move the material around.

Technology

The slag pelletizer was developed by National Slag Ltd. in Hamilton, Ontario, as a means of bringing very high gas emission levels typical of the "pit foaming" process under control.[3] Pelletized slag is produced by expanding molten blast furnace slag under water sprays and then passing the flow of this pyroplastic material over a spinning drum on which fins are mounted. The fins break up the slag, which then forms into pellets owing to surface tension. While previous expanding processes have been of the batch type, this is a continuous process so that gaseous emissions are effectively diluted by generation over a long period of time. Because of this rapid cooling, the pelletizer can be thought of as an "air granulator."

National Slag Ltd. now has licensed the process in many countries, including Australia, England, France, Japan, Sweden, and the United States. Currently, in Canada, about 400,000 metric 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.

Operating Factors

Until recently, in Canada and the United States, portland cement was relatively cheap, and there was no incentive for the ready-mixed concrete industry to use alternative cementing materials.[4] Environmental concerns combined with high energy costs have forced cement companies to seek alternative cementing materials that can partially replace portland cement in concrete. In the construction industry, the search for less expensive types of binders has led to the utilization of ground granulated blast furnace slag, among other byproducts, to partially replace high energy consuming portland cement in concrete.

ANNUAL REVIEW

Legislation and Government Programs

On January 23, 1990, the EPA published its final ruling concerning retaining iron and steel slags permanently under the Bevill exclusion of RCRA until the EPA completed a required report to Congress and made a regulatory determination.[5] As in the September, 25, 1989, proposal, the Agency evaluated the 20 mineral processing wastestreams by applying the high-volume and low-hazard criteria using a multistep process. The first step entailed applying the high-volume criteria to the available waste generation data. Mineral processing wastes generated above the volume criteria thresholds (an average rate of 45,000 metric tons per facility for nonliquid wastes) passed the high-volume criterion. In the second step, the Agency evaluated each of the 20 wastes with respect to the low-hazard criterion using the relevant waste characteristics. EPA considered a waste to pose a low hazard only if the waste passed both a toxicity test (Method 1312) and a pH test. Finally, the results of the first two steps were consolidated.

In July 1990, the EPA released its Report to Congress on Special Wastes From Mineral Processing (RTC).[6] RCRA required the EPA Administrator to determine whether regulation of iron and steel slags as hazardous wastes under subtitle C, along with 19 other mineral processing wastes, was warranted. This was to be done within 6 months after publication of the report. The Agency accepted public comments until October 1990. These were to be used in the final regulatory determination. No comments were received opposing the RTC recommendation that regulation under subtitle C for those wastes is inappropriate, and the EPA was expected to conclude in 1991 that regulation under RCRA subtitle C is unwarranted for iron and steel slag wastes.

Production

American Aggregates, of Dayton, OH, a building material company with sand and gravel, limestone, and slag operations in the Michigan, Indiana, and Ohio area was acquired in February 1990 by CSR Australia. CSR Australia is a leading Australian building and construction materials company with operations in Australia, New Zealand, North America, and Europe. Construction materials include aggregates, sand, cement, premixed concrete, and asphalt.

C.J. Langenfelder & Son Inc., a general contracting company based in Balti-

more, MD, acquired the Maryland Slag Co. from the Arundel Corp. in September 1990. Langenfelder is involved in site and civil work, such as construction, roads, tunnels, and landfill. Arundel Corp. was to market the blast furnace slag products for Langenfelder.

Harsco Corp., of Camp Hill, PA, established a wholly owned subsidiary company to process slag and reclaim metal in Yugoslavia through its Heckett Div., based in Butler, PA. (See Yugoslavia in the World Review section of this report.)

In 1990, Koch Minerals Co., a division of Koch Industries of Wichita, KS, began the construction of a granulation facility to process all slag production from the Weirton Steel No. 1 blast furnace in Weirton, WV. Work was also begun on a facility to grind these granules into cement. Koch's grinding and granulation plant was to begin operations in 1991.

Koch Minerals was also contracted by USX to process slag at the USX Gary, IN, works in 1990. This included air-cooled and expanded slag from five furnaces. In addition, Koch signed an agreement to install a granulation plant at the USX No. 13 blast furnace and then to process the slag granules into cement. Koch planned to start up the granulation and grinding facilities by late 1991.

The Levy Co. of Portage, IN, was involved in many projects utilizing slag. Levy used 67,000 short tons of blast furnace slag to construct a breakwater for the Hammond Marina, Hammond, IN. Levy also completed construction of the Beta Steel slab finishing plant, in Portage, IN, in proximity to Bethlehem Steel. The project employed 40,000 cubic yards of concrete aggregate, 90% of which was pumped.

The Standard Slag Co., Eastern Div., based in Coraopolis, PA, supplied more than one-half million tons of slag for the new Greater Pittsburgh International Airport. Standard was using air-cooled slag coarse aggregate extensively to construct the airport. Slag was being used in runways, taxiways, bridges, and tunnels for the new landside and airside terminals. The entire project is expected to be completed by 1992.

Standard Slag also built a new plant at Browns Reserve in West Mifflin, PA, a slag bank where there is in excess of 16 million tons of blast furnace slag. It is estimated that 700 to 800 thousand tons of slag per year will be obtained from this reserve to keep up with the demand for slag. The slag was produced during the time period of the mid-1920's to the mid-1960's.

Based on American Iron and Steel Institute data, domestic production of iron and steel slag remained essentially unchanged. Sales and consumption of iron and steel slag, however, increased moderately when compared with the level of the previous year. The value of blast furnace slag increased compared with that of 1989, reflecting its use as a substitute for natural aggregates, which in certain geographic locations may be in short supply.

Consumption and Uses

Commercial use of slag reduces cost and landfill requirements for the iron and steel industry. Slag, in its use as a synthetic mineral fiber, has a unique cost-performance relationship that makes it a preferred raw material in industrial applications and as a building material.

Sales of slag products generally reflect demand from the construction industry. The Department of Commerce reported that value of new construction in 1990 declined slightly (2% decline estimated) compared with that of 1989.[7] The value of highway and street construction increased from 1989 to 1990.

Air-cooled blast furnace slag continues to be the predominant form of iron slag processed in the United States, accounting for more than 90% of blast furnace slag sales in 1990. The most significant increase in 1990 in end use for air-cooled slag was as concrete aggregate. Air-cooled blast furnace slag is used in road base, asphaltic concrete aggregate, fill, mineral wool, and glass manufacture. (See table 5 for related data). Mineral wool is used in ceiling tile in commercial and residential buildings and in various thermal and acoustical insulation applications.[8] Mineral wool exhibits low thermal shrinkage and high melting point, which makes it ideal as a fire-resistant material.

Granulated and expanded blast furnace slag accounted for the remainder of the iron slag that was sold or consumed in the United States. Consumption of combined expanded and granulated slag decreased by 15% from that of 1989 to 1,450,000 tons valued at $26,448,000. Granulated slag was predominantly used in the manufacture of cement and expanded slag in the manufacture of lightweight concrete blocks.

Reported steel slag consumption increased slightly compared with that of 1989 (see table 6). It is reported by some slag companies that 90% of steel slag produced is being used. Steel slag used in asphaltic concrete and concrete aggregate increased moderately from that of 1989.

TABLE 1

IRON AND STEEL SLAGS SOLD OR USED[1] IN THE UNITED STATES

(Thousand short tons and thousand dollars)

Year	Blast furnace slag									
	Air-cooled		Expanded[2]		Total iron slag[3]		Steel slag		Total slag[3]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1986	13,501	58,899	1,879	33,851	15,380	92,750	5,689	17,883	21,068	110,633
1987	14,447	65,943	1,774	33,750	16,221	99,693	5,013	15,787	21,234	115,480
1988	14,242	69,415	1,658	32,139	15,900	101,554	5,714	18,058	21,614	119,614
1989	13,783	66,574	1,706	29,143	15,489	95,717	7,376	24,056	22,865	119,772
1990	15,147	77,863	1,450	26,448	16,597	104,311	7,552	22,268	24,149	126,578

[1]Value based on selling price at plant. Includes estimated value data for several operations.
[2]Includes granulated to avoid discount 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 short tons and thousand dollars)

Region and State	1989				1990			
	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, Michigan	W	W	W	W	W		W	W
Ohio	2,818	15,728	W	W	W	W	W	W
Total	W	W	8,819	41,572	9,413	44,733	10,006	48,882
Middle Atlantic:								
Maryland, New York, West Virginia	1,351	7,234	W	W	W	W	W	W
Pennsylvania	2,591	14,999	W	W	2,691	17,991	2,891	20,628
Total[2]	3,942	22,323	W	W	W	W	W	W
Undistributed[2]	7,023	28,523	6,670	54,145	3,043	15,139	3,701	34,802
Grand total[3]	13,783	66,574	15,489	95,717	15,147	77,863	16,597	104,311

W Withheld to avoid disclosing company proprietary data; included in "Total and Undistributed."
[1]Value based on selling price at plant.
[2]Includes Alabama, California, Colorado, Kentucky, Texas, Utah, and that indicated by symbol "W."
[3]Data may not add to totals shown because of independent rounding.

Transportation

Most slag is used within about a 30-mile radius of its source. Transportation costs make slag uncompetitive with natural aggregates when transportation distances exceed about 30 miles. Some slag may be delivered over greater distances to areas that do not have other natural aggregates for use in construction and roadbuilding.

Of all the iron and steel slag products sold in 1990, 87% traveled by truck, with an average marketing range of 30 miles; 5% traveled by waterway, with an average range of 251 miles; and 3% traveled by rail, with an average range of 176 miles. The remaining 5% was used at the plant where it was processed (see table 4).

Markets and Prices

The average price, f.o.b. plant, for all iron blast furnace slag was about $6.28 per ton, a slight increase over that of 1989 (see table 7). The price of air-cooled blast furnace slag increased from $4.83 to $5.14 per ton in 1990. Granulated and expanded slag price information was withheld to avoid disclosing company proprietary data. The unit value for steel slag decreased by 10% from that of 1989 to $2.95 per ton.

Foreign Trade

Statistics developed by the U.S. Department of Commerce, Bureau of the Census, indicated that approximately 148,026 tons of granulated blast furnace slag was imported into the country during 1990. The breakdown was as follows: 137,006 tons from Belgium valued at $1,243,002, 11,000 tons from Australia valued at $89,622, and 20 tons from France valued at $5,662. Japanese imports also reportedly entered into the country through the Port of Los Angeles, CA, and 100,000 tons of Canadian imports reportedly entered into the country primarily through Detroit, MI, Cleveland, OH, and Baltimore, MD. The Canadian imports may be, in fact, expanded or pelletized slag.

World Review

Australia.—The Australasian Slag Association, based in New South Wales, Australia, was formed in 1990 by a group of leading steel, cement, quarrying, and slag processing companies in Australia, Japan, New Zealand, Singapore, and the United Kingdom. The slag industry in Australia processes and markets approximately 4 million tons of slag per year. The association's goal is to increase public awareness of the properties and value of slag products and thus to widen the use of slag.

Blue Circle Southern Cement of Sydney, Australia, grinds slag produced by Australian Steel Mill Services in ball mills for use in cement. Blue Circle used the blast furnace slag in the Sydney Harbour Tunnel to improve cement properties in the concrete subject to sulfate attack. Sydney Harbour Tunnel's submerged concrete tunnel segments were built in 1990. The segments contain approximately 200,000 tons of high-quality, sulfate-resistant concrete, made possible by the addition of blast furnace slag. Installation of the sections was planned for Sydney Harbour in 1991.

BHP Steel in Newcastle, Australia, contracted with Steelstone Pty. Ltd. to process and remove basic oxygen furnace slag for the next 10 years. Steelstone was first to recover metallics for recycling in steelmaking and the sinter plant and then to produce and market road construction aggregate. Steelstone is a joint venture of South Coast Equipment Pty. Ltd. of Port Kembla and the Slag Reduction Co. (SRC) of Rotherham, both of which specialize in steel mill services. Although the use of basic oxygen furnace slag as a roadmaking material is new to Australia, SRC has been turning processed and graded steel slag into coated roadstone

TABLE 3

PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1990

Company	Plant location	Slag source				Blast furnace slag type
		Iron	Steel			
		Blast furnace	Basic oxygen furnace	Open hearth	Electric arc furnace	
Alexander Mill Services	Prospect, PA				X	—
American Aggregates	New Miami, OH	X				Air-cooled.
Do.	Middletown, OH	X				Do.
Blue-Circle Atlantic Inc.	Sparrows Point, MD	X				Granulated.
Buffalo Crushed Stone	Buffalo, NY	X				Air-cooled.
Dunbar Slag Co. Inc.	Wheatland, PA	X	X	X		Do.
Fountain Sand and Gravel Co.	Pueblo, CO	X				Do.
Fritz Enterprises Inc.	Lorain, OH	X				Do.
Gascola Slag Co.	Penn Hills, PA			X		—
Heckett Co.	Emeryville, CA				X	—
Do.	Fontana, CA		X			—
Do.	Bourbonnais, IL				X	—
Do.	Chicago, IL	X				Air-cooled and expanded.
Do.	Sterling, IL				X	—
Do.	Indiana Harbor, IN		X			—
Do.	Ashland, KY	X	X			Air-cooled.
Do.	Coalton, KY				X	—
Do.	Newport, KY				X	—
Do.	Owensboro, KY				X	—
Do.	Kansas, MO				X	—
Do.	Jackson, MS				X	—
Do.	Charlotte, NC				X	—
Do.	Canton, OH				X	—
Do.	Mansfield, OH				X	—
Do.	Warren, OH		X		X	—
Do.	Butler, PA				X	—
Do.	Fairless Hills, PA			X		—
Do.	Johnstown, PA				X	—
Do.	Natrona Heights, PA				X	—
Do.	Georgetown, SC				X	—
Do.	Geneva, UT	X		X		Air-cooled.
Do.	Kent, WA				X	—
Do.	Seattle, WA				X	—
Hempt Bros. Inc.	Steelton, PA			X		—
International Mill Service	Fort Smith, AK				X	—
Do.	Pueblo, CO		X		—	
Do.	Claymont, DE				X	—
Do.	Tampa, FL				X	—
Do.	Atlanta, GA				X	—
Do.	Cartersville, GA				X	—
Do.	Alton, IL				X	—
Do.	Chicago, IL	X	X		X	Air-cooled.
Do.	Granite City, IL		X			—
Do.	Huntington, IN				X	—
Do.	Laplace, LA				X	—
Do.	Baltimore, MD				X	—
Do.	Jackson, MI				X	—
Do.	Monroe, MI				X	—
Do.	St. Paul, MN				X	—

TABLE 3—Continued

PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1990

Company	Plant location	Slag source				Blast furnace slag type
		Iron	Steel			
		Blast furnace	Basic oxygen furnace	Open hearth	Electric arc furnace	
International Mill Service—Continued	Kansas City, MO				X	—
Do.	Perth Amboy, NJ				X	—
Do.	Newport, MN				X	—
Do.	St. Paul, MN				X	—
Do.	Riverton, NJ				X	—
Do.	Marion, OH				X	—
Do.	Middletown, OH		X			—
Do.	Mingo Junction, OH		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.	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.	Plymouth, UT				X	—
Do.	Weirton, WV		X			—
C. J. Langenfelder & Son Inc.	Sparrows Point, MD		X			—
Do.	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		X	Do.
Do.	East Chicago, IN	X				Air-cooled.
Do.	Gary, IN			X		—
Maryland Slag Co.	Baltimore, MD	X				Air-cooled.
Koch Minerals	Gary, IN	X				Air-cooled and expanded.
Sheridan Corp.	Lebanon, PA	X				Do.
The Standard Slag Co.	Granite City, IL	X				Air-cooled.
Do.	Cleveland, OH	X				Do.
Do.	Lordstown, OH	X				Granulated.
Do.	McDonald, OH	X				Air-cooled.
Do.	Mingo Junction, OH	X				Do.
Do.	Warren, OH	X				Do.
Do.	Weirton, WV	X				Do.
Do.	West Mifflin, PA	X	X	X		Do.
Do.	West Alliquippa, PA	X	X	X		Do.
Do. (Brown Reserve)	West Mifflin, PA	X				Do.
Stein, Inc.	Cleveland, OH		X		X	—
Do.	Lorain, OH		X		X	—
St. Louis Slag Products Co.	Granite City, IL	X				Air-cooled.
Vulcan Materials Co.	Alabama City, AL	X	X			Do.
Do.	Fairfield, AL	X	X			Do.
Warner Co.	Bala-Cynwyd, PA	X				Air-cooled and expanded.
Waylite Corp.	Bethlehem, PA	X				Do.

TABLE 4

SHIPMENTS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1990, BY METHOD OF TRANSPORTATION

Method of transportation	Quantity (thousand short tons)
Truck	21,127
Waterway	1,189
Rail	701
Not transported (used at plant site)	1,132
Total	24,149

since the 1930's. BHP began work on the slag utilization project in 1986. Between 200,000 and 250,000 tons of slag produced annually at the steelworks was expected to be absorbed by the process.

Steel Cement Ltd. was formed in 1989 by Independent Cement & Lime Pty. Ltd. (45%), Ube Industries Ltd. (26%), Adelaide Brighton Cement Investments Ltd. (20%), and AICIA Pty. Ltd. (9%) with the intent of using Australian granulated blast furnace slag in cement production and other areas. In 1990, Steel Cement shipped 11,000 tons of the granulated blast furnace slag to Hawaii to be used as fertilizer for cane fields as its first export.

South Africa, Republic of.—Iscor granulated 152,000 tons of slag at Pretoria Works for use in cement, 548,000 tons at Vandervijlpark (63% for cement), and 576,000 tons at Newcastle (37% for cement). The Republic of South Africa experienced a severe depression in the construction and mining industries in 1990 and did not use all of its available capacity for granulating slag. Iscor's steel slag production in Pretoria was 142,000 tons in Vanderbijlpark and 190,000 tons in Newcastle. The concept of utilizing blast furnace slag to produce cementitious material was first researched in the Republic of South Africa in the 1950's. After successful trials on Iscor slags, Building Binders Ltd. was formed to exploit this technology, and a plant was built in 1955 at Vanderbijlpark adjacent to the Iscor works. The business progressed rapidly and, in 1962, the three major South African cement companies—Pretoria Portland Cement, Blue Circle, and Anglo Alpha—acquired the shares of the company, and the name was changed to Slagment Ltd. Based on the success of this venture, a second plant was

TABLE 5

AIR-COOLED BLAST FURNACE SLAG SOLD OR USED IN THE UNITED STATES, BY USE[1]

(Thousand short tons and thousand dollars)

Use	1989		1990	
	Quantity	Value	Quantity	Value
Asphaltic concrete aggregate	1,673	8,771	2,136	12,049
Concrete aggregate	1,394	8,043	1,780	10,405
Concrete products	412	2,586	474	2,557
Fill	1,651	5,119	1,558	5,844
Glass manufacture	W	W	W	W
Mineral wool	510	3,285	581	3,614
Railroad ballast	248	1,285	397	2,024
Road base	7,276	32,981	7,667	36,827
Roofing, built-up and shingles	92	1,027	78	726
Sewage treatment	W	W	W	W
Soil conditioning	W	W	W	W
Other[2]	527	3,474	494	3,817
Total[3]	13,783	66,574	15,147	77,863

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 short tons and thousand dollars)

Use	1989		1990	
	Quantity	Value	Quantity	Value
Asphaltic concrete aggregate	969	3,835	1,066	3,153
Fill	1,374	5,057	1,005	3,510
Railroad ballast	213	670	227	621
Road bases	3,141	9,169	3,182	8,901
Other[2]	1,679	5,325	2,071	6,081
Total[3]	7,376	24,056	7,552	22,268

[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

Year	Iron blast furnace slag				Steel slag	Total slag
	Air-cooled	Granulated	Expanded	Total iron slag		
1986	$4.36	W	$12.57	$6.03	$3.14	$5.25
1987	4.56	W	W	6.15	3.15	5.42
1988	4.87	W	W	6.39	3.16	5.48
1989	4.83	W	W	6.18	3.26	5.24
1990	5.14	W	W	6.28	2.95	5.24

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 1990, BY USE

(Dollars per short ton)

Use	Iron blast furnace slag						Steel slag	
	Air-cooled		Granulated		Expanded			
	Average	Range	Average	Range	Average	Range	Average	Range
Asphalt concrete aggregate	5.64	2.44-10.00	—	—	—	—	2.96	0.46- 4.75
Cement manufacture	W	W	W	W	—	—	—	—
Concrete aggregate	5.85	2.50-10.00	—	—	—	—	—	—
Concrete products	5.39	3.90-10.00	—	—	—	—	—	—
Fill	3.75	1.46- 7.25	—	—	—	—	3.49	.15-10.00
Glass manufacture	W	W	—	—	—	—	—	—
Lightweight concrete aggregate	—	—	—	—	W	W	—	—
Mineral wool	6.22	4.41-10.25	—	—	—	—	—	—
Railroad ballast	5.34	3.88- 8.00	—	—	—	—	—	—
Road bases	4.80	2.73- 8.00	W	W	—	—	2.80	.39- 5.72
Roofing, built-up and shingles	9.29	4.00-12.86	—	—	—	—	—	—
Sewage treatment	W	W	—	—	—	—	—	—
Soil conditioning	W	W	W	W	—	—	W	W
Other	4.16	1.93- 7.37	—	—	—	—	2.84	.35- 5.59

W Withheld to avoid disclosing company proprietary data.

built in 1966 at Pretoria. After this, Slagment increased production from the initial 65,000 tons per year to 600,000 tons per year. In 1985, the third plant was built near the Newcastle ironworks, and today the three plants have a production capacity of 1.5 million tons per year of cementitious slag material. The Newcastle plant was subsequently sold to one of Slagment's major customers, Natal Portland Cement,which now manufactures the product under license to Slagment.

U.S.S.R.—Approximately 88% of the slags produced in the U.S.S.R. is utilized. Blast furnace slags amounted to more than 41 million tons. Of that amount, about 25 million tons was granulated, 16 million tons was used as building stone, and 85,000 was used as mineral wool. Steel slags accounted for a little more than 9 million tons. Of these, 375,000 tons is used as slag-lime fertilizer and a little more than 7 million as building stone.[9] Slag was used mainly in the production of cement, concrete, and in slag wool and in road construction and agriculture. According to U.S.S.R. economic indicators, including price, labor, and cost of production, slag industries were profitable.

The Cherepovets works in the U.S.S.R. produces granulated blast furnace slag.[10] The granulating complex processed slag from the Krivorozhstal steelworks. The granulators grind and crush the molten slag, as well as hydraulically transport, dewater, and collect the granulated slag from the blast furnace without the use of cinder cars.

United Kingdom.—Appleby Group, South Umberside, continued to increase its penetration into the cementitious market in spite of the recession in industry. The Group has made major inroads into the concrete, glass, and abrasives markets. Frodingham, the largest company in the Appleby Group, produced ground granulated blast furnace slag for use as a cement extender. It was the first such producer in the United Kingdom.

Appleby has invested in high-pressure roller crushers to increase production. The environmental concerns in the United Kingdom have pushed iron manufacturers toward production of granulated and away from air-cooled blast furnace slag. This trend is likely to continue.

Yugoslavia.—Harsco Corp., of Camp Hill, PA, established a 100%-owned company for metal reclamation and slag processing in Yugoslavia through its Heckett Div. Designated Heckett Yugoslavia Ltd., the new company was one of the first U.S.-funded projects to begin operations in Yugoslavia since the liberalization of foreign investment laws by the Yugoslavian Goverment in 1989. The new company entered into a long-term contract for slag processing and metal recovery at the Metalurski Kombinat Smederevo (MKS) steel plant in Smederevo in the Republic of Serbia near Belgrade.

Current Research

Current research was dominated by that done on granulated blast furnace slag. A study at the Canada Centre for Mineral and Energy Technology (CANMET) of the Energy, Mines and Resources Canada reviewed the use of granulated blast furnace slag in concrete in Canada.[11] Three areas were covered: mixture proportions and properties of fresh concrete incorporating slag, mechanical properties of concrete incorporating slag, and durability of concrete incorporating slag. The mixture proportions of granu-

lated blast furnace slag to be used in concrete depend upon the specific job. As an example, granulated slag would replace 25% to 50% by weight of cement if the goal were to conserve cement in concrete operations. However, if the purpose were to increase concrete durability, such as sulfate resistance, then the slag content would be at least 50% of the total cementitious material. Because each slag has a unique chemical composition, glass content, and fineness, it is necessary to perform exploratory investigations with the cement, aggregates, and chemical admixtures to be used in each specific project.

The mechanical properties of concrete incorporating slag are highlighted by the compressive strength development of slag concrete. Compressive strength development, as well, depends upon the type, fineness, activity index, and the proportions of slag used in concrete mixtures. Other factors that affect the performance of slag in concrete are the water-to-cementitious materials ratio and the type of cement used.

The increased durability of portland cement concrete incorporating slag results primarily from a finer pore structure and reduced contents of easily leached calcium hydroxide in the hardened cement paste. Also, the dilution of the reactive component of the portland cement by the replacement of cement by slag contributes to increased resistance of slag concretes to sulfate attack.

Several studies completed at CANMET in 1990 illustrate the above areas. The amount of slag replacing cement has been limited in the past by the relatively slow strength development of the slag. The studies have shown that, in slag concretes, strength development can be accelerated by the addition of alkali activators such as lime, sodium hydroxide, sodium carbonate, sodium silicate and, in general, salts of weak acids and strong bases. The purpose of the study was to formulate the proportioning of concrete mixtures made with ground-granulated blast furnace slag activated with sodium silicate and to determine their properties and durability.[12] Six concrete mixtures were made using ground-granulated blast furnace slag, sodium silicate, lime, crushed limestone, natural sand, and a hydrocarbon air-entraining admixture. Among the conclusions, it was found that the sodium silicate-to-slag ratio was an important factor affecting the properties of fresh and hardened concrete and that the compressive strengths were comparable to or higher than those of portland cement concrete with equivalent water-to-cement ratio and workability.

In another study at CANMET, mechanical properties of slag, abrasion resistance, and chloride-ion permeability of concrete incorporating ground-granulated blast furnace slag from northern Ontario were investigated.[13] Nine concrete mixtures were made with the water-to-cementitious materials ratio of the mixtures ranging from 0.45 to 0.70. The percentage of slag used as a replacement by mass for the portland cement varied from 0% to 50%. Among other findings, the strength development characteristics of the slag concrete indicated that granulated blast furnace slag can be satisfactorily used as a partial replacement for portland cement in concrete.

Engineers at the Department of Civil Engineering ADFA in Australia investigated the possibility of using slagment (65% cement and 35% slag) instead of plain cement to manufacture structural-grade concretes.[14] The strength development of three grades of plain cement concretes, portland blast furnace slag concretes, and concretes in which 15% and 35% of slagment was replaced by fly ash (ternary blends) were tested. They found that low and medium-strength slagment concretes reaching 20 and 35 megapascals gave higher strength than those cast with plain cement. However, the addition of fly ash to slagment generally decreased concrete strength. In addition, the results suggest that the strength of the slagment concretes are less affected by lack of curing than the strength of the plain cement concretes.

Slag-blended cements have been used to improve the sulfate resistance of concrete in Europe for decades. However, they had not been widely used in North America because slags had limited availability. There were also concerns that not all slags performed equally because of variations in slag composition, reactivity, and fineness from different sources. In addition, until the 1970's in Canada and the United States, portland cement was not expensive, and there was no reason to find substitutes for it. Thus, in Canada in 1976, with higher energy costs renewing interest in slag, a research program was begun at McMaster University to monitor concrete and mortar specimens incorporating Canadian slag. Research continued at Trow Ltd. and then at the University of Toronto, and the results of a 10-year study of slag exposure to sulfate solutions were published.[15] The major finding was that replacement of a 50 percent by mass of normal portland cement by slag provided equivalent or better sulfate resistance than sulfate-resistant portland cement. Sulfate resistance was found to decrease with increasing slag aluminum oxide content and to improve with reduced slag permeability and reduced slag calcium hydroxide content, among other factors. The results of the study are based only on particular pelletized slags ground to a specific fineness.

Researchers at the University of Sherbrooke, Sherbrooke, Quebec, Canada, studied the microstructural development of a very high strength concrete containing 10% silica fume, 30% slag replacement for cement, and a high-range water-reducing admixture.[16] Chemical and mineral additives traditionally have been used to improve the properties of fresh and hardened concrete and to reduce costs by replacing cement with low-cost industrial byproducts. The concrete displayed high early strength and reached 94 MPa at 28 days. Past experience has shown them to be very efficient components in the production of very high strength concrete. The benefits of blended elements incorporating slag for high-strength concrete production have been illustrated during the construction of Nova Scotia Plaza.[17]

Portland cement containing 50% to 80% blast furnace slag has higher resistance to seawater attack and to alkali-silica reactions and a better development of strengths than portland cement. The Laboratory of Metal Engineering and Mineral Geochemistry, Ecole Superieure Energie et Materiaux, Universite d'Orleans, France, investigated the influence of the nature of solid and aqueous solutions on the composition of the hydrated slag.[18] To understand the properties of cement and concrete containing slag powders or sands, the researchers determine the structure, composition, and origin of the hydrated layers grown after different reaction times. Two synthetic glassy slags with high aluminum and magnesium contents were hydrated at 40° C at time periods ranging from 4 hours to 150 days in water and alkaline solutions. Glassy slags in alkali media were more highly reactive than in water.

Researchers at the Regional Research Laboratory in Assam, India, have investigated the activation of low-lime, high-

alumina granulated blast furnace slag by anhydrite to prepare supersulfated slag cement.[19] The latent hydraulic property of granulated blast furnace slag is advantageously used in making various cementitious binders by activating it with different activators, such as ordinary portland cement. The hydraulic activity of a slag depends mainly on its glassy phase content and chemical composition. In general, the higher the glassy phase, the lime and alumina contents, the higher is the hydraulic property of the slag. Ordinary portland cement clinker (commercial grade) and slag procured from the Rourkela steel plant were ground separately in a laboratory ball mill. The researchers concluded that the optimum quantity of anhydrite required to make supersulfated slag cement from a low-lime (26%), high-alumina (27%) Indian blast furnace slag is in the range of 15% to 20%. The enhancement of strength characteristics in the latter stages of hydration was attributed to the formation of calcium-silicate hydrates.

The King Fahd University of Petroleum and Minerals has investigated the long-term corrosion-resisting characteristics of concrete incorporating slags or pozzolans.[20] They investigated the corrosion-resisting characteristics of concrete samples made with a blast furnace slag cement, two Class F fly ashes, a natural pozzolan, and a preblended portland-fly ash cement. Specimens were immersed in 5% sodium chloride solution for a period of more than 5 years, and the corrosion activity was evaluated by monitoring the half-cell potentials and measuring the corrosion rate of embedded steel using a linear polarization resistance technique. The investigators concluded that the corrosion rate of steel in concrete made with blast furnace slag cement is lower than in the other concretes tested.

Investigators at the Building Research Station have studied the hydration behavior of refractory aluminous cement and ground-granulated blast furnace slag over a range of temperatures.[21] Commercial high-alumina cements (HAC) show a reduction in compressive strength when kept in a hot and humid atmosphere over a prolonged period of time. It has been claimed that the strength loss suffered by HAC under hot and humid conditions can be counteracted by the addition of sufficient quantities of ground-granulated blast furnace slag to the cement. When kept in hot water over a long period of time, the 1:1 cement plus slag mixture has not shown any reduction in strength. The researchers concluded that there are chemical interactions between the cement and the granulated blast furnace slag that form sulfate hydrates and accompanying gel material. These inhibit the formation of the hydrate phase that is responsible for reduction in strength of HAC concrete.

Ground-granulated blast furnace slag is recognized as giving specific qualities to the composite-cement concrete making it superior to concrete made from portland cement alone. The Department of Mechanical and Process Engineering at the University of Sheffield, England, studied the engineering properties of slag concrete when 50% to 70% by weight of portland cement was replaced by slag.[22] The study emphasized that adequate drying should be an essential specification when slag is incorporated in concrete. Prolonged drying of inadequately cured slag concrete can adversely influence its long-term durability owing to internal microcracking and loss of elastic modulus.

The U.S.S.R. studied the reduction of dust and gas emissions from slag forming mixtures used in continuous casting.[23] Introduction of effective means of recovering waste products was investigated. It was discovered that the basic components of the gas emissions are the flourine and carbon compounds, the quantity of which, depending upon the mixture, composes from 1.8 to 10.4 milligrams per gram of mixture. When using granulated slag, the dust emissions are insignificant.

OUTLOOK

The use of granulated slag is expected to increase owing to environmental and cost considerations. Using granulated slag reduces energy costs that would be higher when using portland cement. As more companies decide to granulate slag, more slag may be used in cement, and less may be available for use as an aggregate in building and construction. Granulated slag production capacity may exceed demand as the amount of slag consumed approaches an upper limit for slag use in cement. On the other hand, in some areas of the country, there may be shortages of blast furnace slag because of blast furnace shutdowns. There may also be shortages in steel slag as a result of an expected downturn in the steel industry in 1991.

The slag industry is expected to pursue markets in traditional areas such as building and road maintenance and resurfacing as well as to seek nontraditional niches. The use of slag and fly ash as a substitute for open graded fill is one such nontraditional area. Slag used in ways other than as replacement for natural aggregates will represent a new area for slag to be used in the future. Slag industry demand, both for cement and aggregate end use, depends upon the construction industry, which in turn depends on general economic conditions.

Events of the past few years have indicated that there continues to be foreign interest in acquiring U.S. slag companies and that the total number of U.S. slag companies may decrease as consolidation occurs. Downstream integration of the industry continues, with increased emphasis in the United States in marketing slag in higher value end uses such as in cement. Iron slag processors are increasingly part of larger companies having captive markets in the aggregate, cement, and construction markets.

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[1]Illinois Department of Transportation. Standard Specifications for Road and Bridge Construction. State of Illinois. July 1988, p. 625.

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[3]Malhotra, V. M. Use of Granulated Blast-Furnace Slag in Concrete in Canada—A Review. Energy, Mines and Resources Canada. Paper in Proceedings of the Latin American Seminar on Utilization of Blast-Furnace Slag in Concrete, Buenos Aires, Argentina, June 1991, 23 pp.; available from Canada Centre for Mineral and Energy Technology (CANMET), Ottawa, Ontario, Feb. 1991.

[4]Work cited in footnote 3.

[5]Federal Register. U.S. Environmental Protection Agency. Mining Waste Exclusion. V. 55, No. 15, Jan. 23, 1990, pp. 2322-2354.

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SODA ASH

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 12 years of U.S. Bureau of Mines experience, has been the commodity specialist for soda ash since 1979. Domestic survey data were prepared by Carleen Militello, mineral data assistant; and international data tables were prepared by William Zajac, Chief, Section of International Data.

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 Stat. 339) and the United States was an original signatory party to the 1875 Treaty of the Meter (20 Stat. 709), the United States has been the only industrially developed nation that has not universally converted to the metric system from the English system of measurements. While foreign trade of soda ash increases and foreign participation in U.S. joint ventures continues, communicating information with an international standard of measurement becomes more important.

DOMESTIC DATA COVERAGE

Domestic production data for soda ash are developed 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.

Soda ash consumption by end use was collected quarterly from the industry. Trade statistics are obtained from the U.S. Department of Commerce, Bureau of the Census. The export data collected by the Census Bureau may not correspond to the export data provided by the soda ash producers in the quarterly survey of soda ash sales. This discrepancy between the export data is because Census data reports the transaction on the date the cargo physically departed from the U.S. port whereas soda ash producers consider a shipment as exported when it leaves the plant. Overland transit time between the plant and port and any carryover export inventory are not taken into consideration.

Soda ash, also known chemically as sodium carbonate, is the 11th largest inorganic chemical in terms of production of all domestic inorganic and organic chemicals, excluding petrochemical feedstocks. Although soda ash is not a common

TABLE 1

SALIENT SODA ASH STATISTICS

(Thousand metric tons and thousand dollars)

	1986	1987	1988	1989	1990
United States:					
Production[1]	7,655	8,066	8,738	8,995	9,156
Value[1]	$553,517	$593,685	$644,973	$764,146	$836,188
Production, Wyoming trona	12,008	12,582	13,713	14,774	14,665
Exports[2]	1,859	2,018	2,238	2,648	2,392
Value[2]	$241,238	$253,200	$286,945	$365,469	$346,693
Imports for consumption	96	136	121	129	146
Value	$15,023	$18,334	$15,999	$17,396	$20,495
Stocks, Dec. 31: Producers'	267	235	261	221	287
Consumption:					
Apparent	5,980	6,217	6,595	6,516	6,844
Reported	NA	6,100	6,494	6,469	6,527
World: Production	r29,360	r30,203	r31,269	r31,939	e32,429

eEstimated. rRevised. NA Not available.

[1]Includes natural and synthetic. Natural only, and soda liquors and mine water converted to soda ash equivalent in 1987 and thereafter; 63,469 tons in 1987, 73,365 tons in 1988, 95,027 tons in 1989, and 111,894 tons in 1990.

[2]Export data for 1986–88 were adjusted by the U.S. Bureau of Mines to reconcile data discrepancies among the Bureau of the Census, the American Natural Soda Ash Corp, and Statistics Canada.

household term, it is used in many consumer products found in virtually every home—glass, soap and detergents, paper, textiles, and food. 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.

BACKGROUND

In 1990, soda ash represented about 2.2% of the total $38 billion nonfuel mineral industry that was surveyed by the U.S. Bureau of Mines. The average U.S. citizen consumes about 18,140 kilograms (40,000 pounds) of new minerals in the form of consumer goods each year. Based on the 1990 U.S. population of almost 250 million, the 1990 per capita consumption of soda ash was 26 kg (58 lbs), compared with copper, 8 kg (18 lbs); aluminum, 17 kg (38 lbs); salt, 156 kg (345 lbs); cement, 328 kg (724 lbs); and iron and steel, 348 kg (767 lbs). If an infant were born in 1988, he or she would require 1,940 kg (4,344 lbs) of soda ash in his or her lifetime, based on an average life expectancy rate of 74.9 years.

Natural soda ash was probably first obtained as evaporite incrustations along the edges of alkaline lakes in Lower Egypt. It was used about 3,500 B.C. to make ornamental glassware, as evidenced by many of the early Egyptian glass artifacts. The Egyptians also mixed lime and soda ash to make caustic soda. The caustic soda was combined with silicate minerals obtained from the Sinai Desert. This made a soluble silica, which was added to aluminum-rich Nile River silt, producing a silica-aluminate cement mortar with superior bonding properties. In the Old Testament, it was referred to as neter but has also been known as natrium, kali, trona, and natron. Until the 18th century, soda ash was obtained mainly by burning seaweeds and marine plants, leaching the soluble material from the ashes, and evaporating the solutions to dryness. About 12 metric tons (13 short tons) of ash yielded 1 metric ton of sodium carbonate and 14 kilograms (30 pounds) of iodine as a byproduct. The final material was very impure but could be used in the manufacture of glass and soap and detergents. Pliny, a Roman historian, listed soda ash in the manufacture of glass, as a medicine for colic pains and skin eruptions, and for making bread in the first century A.D.

In 1791, Nicolas Leblanc, a French chemist, developed a process for making soda ash from "salt cake" (from salt and sulfuric acid), coal, and limestone. The French Revolution interfered with its development, and Leblanc's 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 17 synthetic Solvay plants that was in operation by 1939 in the United States and, ironically, the last one to close. The Solvay process gained in popularity over the years and is now the basic method used throughout the world for making synthetic soda ash.

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 270 metric tons (300 short 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 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 gram 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 Société Nationale Elf Aquitaine of France bought Texasgulf Chemical Co., to 37% in 1990. Five of the six U.S. companies have either Australian, French, Japanese, or Korean partners. FMC Wyoming Corp. remains the only U.S. producer without any foreign ownership.

Geology-Resources

The definitions of resources, reserves, and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals." Briefly, "resources" describe the quantity of ore present, regardless of grade or ease of extraction. The "reserves" are the portion of the resource that are economic to mine using the current technology and value of the commodity.

There are more than 60 identified natural sodium carbonate deposits in the world, the largest of which is the trona deposit in southwest Wyoming. Although several of these deposits have been quantified, most are economically insignificant or too remote to be commercially developed. Table 4 lists the countries with known soda ash deposits. All soda ash deposits can be classified in one of five modes of occurrences. In decreasing order of economic importance, they are: buried, surface or subsurface brines, crystalline shoreline or bottom crusts, shallow lake bottom crystals, and surface efflorescences.

The trona found in the Green River Formation in southwest Wyoming is an excellent example of a buried trona deposit. The Wilkins Peak Member contains 42 beds of trona, 25 of which have a thickness of 0.91 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

TABLE 2

U.S. PRODUCERS OF SODA ASH IN 1990

Company	Plant nameplate capacity (million tons)		Plant location	Source of sodium carbonate
	Metric tons	Short tons		
FMC Wyoming Corp.	2.59	2.85	Green River, WY	Underground trona.
General Chemical (Soda Ash) Partners[1]	2.09	2.30	do.	Do.
North American Chemical Co.[2]	1.18	1.30	Trona, CA	Dry lake brine.
Rhone Poulenc of Wyoming[3]	1.78	1.96	Green River, WY	Underground trona.
Tenneco Minerals Co.[4]	1.13	1.25	do.	Do.
T.g. Soda Ash Inc.[5]	1.18	1.30	Granger, WY	Do.
Total	9.95	10.96		

[1]A joint venture between General Chemical Corp. (51%) and Australian Consolidated Industries International (49%).
[2]Acquired Nov. 30, 1990, from Kerr-McGee Chemical Corp., with Oriental Chemical Industries of Korea as partner (27%).
[3]Joint venture between Rhone-Poulenc Basic Chemicals Co. of France (51%) and Union Pacific Resources Co. (49%).
[4]Owned by Texasgulf Inc., subsidiary of Societe Nationale Elf Aquitaine of France (100%).
[5]Formed a joint venture with Asahi Glass Co. of Japan in Feb. 1990. The partership provides Asahi with 20% of the full nameplate capacity of the operation when the 600,000 tons expansion is completed in late 1992.

TABLE 3

SODA ASH SUPPLY-DEMAND RELATIONSHIPS[1]

(Thousand metric tons)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
WORLD PRODUCTION											
United States	7,507	7,513	7,093	7,681	7,721	7,721	7,655	8,066	8,738	8,995	9,156
Rest of world	20,839	20,501	19,714	20,210	21,513	20,514	21,705	22,137	22,531	22,944	23,273
Total	28,346	28,014	26,807	27,891	29,234	28,235	29,360	30,203	31,269	31,939	32,429
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
U.S. production capacity	8,727	9,398	10,124	10,124	10,124	10,124	9,580	9,512	9,512	9,580	9,950
Wyoming trona ore production	11,708	11,301	9,826	10,442	10,618	10,726	12,008	12,582	13,713	14,774	14,665
Domestic sources	7,507	7,513	7,093	7,681	7,721	7,721	7,655	8,066	8,738	8,995	9,156
Imports	16	11	16	18	15	51	96	136	121	129	146
Industry stocks, Jan. 1 [2]	62	121	239	294	279	292	355	267	235	261	221
Total U.S. supply	7,585	7,645	7,348	7,993	8,015	8,064	8,106	8,469	9,094	9,385	9,523
Distribution of U.S. supply:											
Industry stocks, Dec. 31[2]	121	239	294	279	292	355	267	235	261	221	287
Exports	993	953	1,006	1,484	1,495	1,584	1,859	2,017	2,238	2,648	2,392
Industrial demand[3]	6,472	6,453	6,048	6,230	6,228	6,125	5,980	6,217	6,595	6,516	6,844
U.S. DEMAND PATTERN[4]											
Glass (total)	3,494	3,357	3,176	3,130	3,085	3,084	3,152	3,343	3,390	3,294	3,177
Container	2,516	2,383	2,268	2,177	2,087	1,996	1,951	2,107	2,128	1,961	1,909
Flat	559	504	454	522	544	635	680	821	852	907	851
Fiber	175	236	200	209	227	249	272	249	246	241	228
Other	244	234	254	222	227	204	249	166	164	185	189
Chemicals	1,294	1,288	1,179	1,270	1,406	1,361	1,179	1,238	1,445	1,412	1,573
Soaps and detergents	453	454	454	562	544	544	590	684	718	781	835
Pulp and paper	227	191	249	181	227	318	181	63	111	114	132
Water treatment	227	227	209	209	272	272	227	72	110	92	91
Flue gas desulfurization	NA	NA	NA	NA	272	159	181	183	200	208	207
Distributors	NA	NA	NA	NA	NA	NA	NA	349	373	380	376
Other[5]	777	936	781	878	422	387	470	168	148	188	136
Total U.S. consumption[6]	6,472	6,453	6,048	6,230	6,228	6,125	5,980	6,100	6,495	6,469	6,527
Undistributed[7]	—	—	—	—	—	—	—	117	100	47	317
Total U.S. primary demand[6]	6,472	6,453	6,048	6,230	6,228	6,125	5,980	6,217	6,595	6,516	6,844
VALUES[8]											
Average annual value:											
Dollars per short ton	89.85	91.19	88.35	76.95	67.00	67.82	65.29	66.78	66.96	77.07	82.85
Dollars per metric ton	99.04	100.52	97.39	84.82	73.85	74.76	71.97	73.61	73.81	84.96	91.33

NA Not available; included in "Other."

[1]Natural and synthetic except where noted.

[2]Natural soda ash only for 1980, and 1987 and thereafter: natural and synthetic from yearend 1981–86.

[3]Also known as apparent consumption (production + imports-exports ± stock changes) and is equal to "Total U.S. primary demand."

[4]Estimated consumption for 1980–86 was based on industry sources; reported consumption 1987 and thereafter were from quantitative and qualitative quarterly surveys of producers' sales. Other end-use categories were incorporated in the survey.

[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.

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

[8]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.

TABLE 4

WORLD NATURAL SODA ASH RESERVES AND RESERVE BASE

(Million tons)

	Reserves		Reserve base[1]	
	Short tons	Metric tons	Short tons	Metric tons
North America:				
United States:				
California:				
Owens Lake	50	45	55	50
Searles Lake	850	770	1,345	1,220
Colorado[2 3]	2,600	2,359	4,300	3,900
Wyoming[2]	22,000	19,958	37,000	33,566
Total[4]	25,500	23,130	42,700	38,736
Mexico	200	180	500	454
Total	25,700	23,310	43,200	39,190
Europe:				
Turkey	216	196	260	235
U.S.S.R.	7	6	NA	NA
Total[4]	223	200	260	235
Africa:				
Botswana	400	363	NA	NA
Chad	8	7	NA	NA
Kenya[5]	56	51	NA	NA
Tanzania	72	65	NA	NA
Uganda	18	16	NA	NA
Total[4]	554	500	NA	NA
Asia: China:				
Inner Mongolia	110	100	110	100
Tongbai, Henan	132	120	132	120
Total	242	220	242	220
World total[4]	26,700	24,200	43,700	39,644

NA Not available.

[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]Represents only the quantity recoverable based on an average rate of 60% extraction efficiency from room-and-pillar, longwall, and shortwall methods of underground mining. This extraction rate does not apply to brines or surface evaporite lake beds. Solution mining of trona and nahcolite is estimated to have a 30% extraction efficiency rate.

[3]The sodium carbonate content of nahcolite reserves and reserve base are 0.8 billion short tons and 1.26 billion short tons, respectively. The sodium carbonate content of dawsonite reserves and reserve base are 1.82 billion short tons, and 3.0 billion short tons, respectively.

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

[5]Annual leaching of volcanic rocks replenishes the resources at Lake Magadi.

Note.—There are at least 62 identified natural sodium carbonate deposits in the world, some of which have been quantified. The countries and number of deposits include Australia (1), Bolivia (2), Botswana (1), Brazil (1), Canada (3), Chad (9), China (9), Egypt (1), Ethiopia (1), India (2), Kenya (3), Mexico (1), Namibia (1), Niger (1), Pakistan (1), the Republic of South Africa (1), Tanzania (5), Turkey (1), Uganda (1), the U.S.S.R. (4), the United States (20), and Venezuela (1).

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 metric tons (52 billion short tons) of identified soda ash resources could be obtained from the 56 billion metric tons (62 billion short tons) of bedded trona and the 47 billion metric 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 metric tons (37 billion short tons) of reserve base soda ash could be obtained from the 36 billion metric tons (40 billion short tons) of halite-free trona and the 25 billion metric 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 metric 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 1990 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 metric 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 compose the second largest reserves of sodium carbonate in the United States. Subsurface sodium carbonate-bearing brines and crystalline material compose the resource at Searles Lake, which is almost 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 metric 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 metric tons (32 billion short tons) of nahcolite and 17 billion metric tons (19 billion short tons) of dawsonite, equivalent to 18 billion metric tons and 6 billion metric 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 metric tons (200 million short tons) of available soda ash.

The Rift Valley of eastern Africa has several alkaline lakes resembling those of California. Only Lake Magadi in Kenya is presently in production. The soda ash reserves of these lakes are renewed annually from natural active volcanic sources. Other African countries that may become future suppliers of soda ash are Chad, Ethiopia, Niger, the Republic of South Africa, Tanzania, and Uganda. Botswana is developing its Sua Pan salt and soda ash deposit, and final completion of the project is scheduled for 1991. Elsewhere, deposits of natural soda ash occur in Bolivia, Brazil, Canada, India, Pakistan, the U.S.S.R., and Venezuela. Plans are underway to develop deposits in China at Xilin Gol and in the Wulan Buh desert area. A trona deposit in Turkey near Beypazari is also under consideration for development.

Technology

Soda ash from Wyoming trona is mined, crushed, dried, dissolved, filtered, recrystallized, and 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. 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. Between 1950 and 1990, more than 209 million metric tons (230 million short tons) of trona (equal to about 124 million metric tons or 137 million short tons of soda ash) have been mined. Only about 0.6% of the 36 million metric 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 T.g. Soda Ash Inc. in its shortwall technique. The longwall technique was used by General Chemical Corp. and is now used by FMC. 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 Kerr-McGee Chemical Corp. 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 soda ash refines the product to better than 99% sodium carbonate.

At Owens Lake in California, crude soda ash has been mined and processed by Lake Minerals Corp. by simply digging perimeter channels allowing the interstitial fluids to drain. The surface was tilled to promote evaporation to reduce moisture content, followed by harvesting with front-end loaders.

At Lake Magadi, Kenya, crude trona is dredged from surface crusts, crushed, washed, and calcined to convert the sodium sesquicarbonate to soda ash. At Lake Texcoco in Mexico, underground brines are recovered and sent to a surface spiral concentrator to promote the solar concentration of the sodium carbonate in solution. On the Kola Peninsula in the U.S.S.R., soda ash is recovered from processing nepheline-bearing rocks. Nepheline, a sodium-potassium-aluminum silicate, is calcined in rotary kilns to yield alumina, potash, and soda ash. The alumina content of the rocks is about one-half of bauxite, but the mining and processing produces byproduct soda ash. The Petukhi and Tanatar (Mikhaylovskiy) natural soda ash lakes in Altay Kray of West Siberia provide some source of natural product.

Synthetic soda ash using the Solvay process uses salt and limestone as raw materials. A purified sodium chloride brine is saturated with ammonia and carbon dioxide gas to produce ammonium bicarbonate, which reacts with the salt to form sodium bicarbonate and ammonium chloride. The sodium bicarbonate is calcined at 177° to 218° C (350° to 425° F) to light soda ash, and the gases produced are recycled back to the liquid phase. The liquid containing ammonium chloride is reacted with milk of lime to recover the ammonia and to produce byproduct calcium chloride. Limestone and coke are required to make the milk of lime. Dense soda ash is produced by hydrating light ash to produce larger sodium carbonate monohydrate crystals. The crystals are dehydrated in dryers to change the bulk density. To produce 1.0 ton of synthetic soda ash requires about 2.8 tons of steam, 1.7 tons of salt, 1.4 tons of limestone, 0.6 ton of coal for the boilers, and about 0.2 ton of coal for the dryers. Disposition of effluent streams containing high concentrations of calcium chloride and sodium chloride is a major problem for all Solvay soda ash plants. The Solvay process discharges about 1.7 tons of waste products.

Other chemical processes can produce synthetic soda ash. The Japanese ammonium chloride coproduction process, a variation of the Solvay process, 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 Co. 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 fluegas 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 with 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 necessarily correspond to the posted list prices.

Tariffs.—The United States has a 1.2% ad valorem tariff on imports of soda ash from countries having most favored nation (MFN) status. There is an 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 are the Republic of South Korea, 15%; Taiwan, 12.5%; Thailand, 10%; Indonesia, 5%; Japan, 3.9%; and Malaysia, 2%. Some of these duties will decline over time.

Taxes.—The total effective tax rate on the Wyoming trona industry is about 12.64% and comes from two major taxes. The trona severance tax of 5.5% is a State excise tax on minerals as they are removed from the ground and are applied as a percentage of assessed valuation. The collected taxes are disbursed to the Permanent Wyoming Mineral Trust Fund (2.0%), the General Fund (2.0%), and the Capital Facilities Revenue Account (1.5%). The property, or ad valorem, tax is about 7.14% of the assessed value of trona produced from the mines. The ad valorem taxes on trona are higher than any other Wyoming minerals, including oil, gas, and coal. Other ad valorem taxes are placed on the assessed value of real property (buildings and equipment) and State sales and use taxes on equipment and facilities.

TABLE 5

TIME-VALUE RELATIONSHIPS FOR SODA ASH

Year	Average annual value, dollars per ton			
	Natural soda ash			
	Actual value[1]		Based on constant 1990 dollars[2]	
	Per short ton	Per metric ton	Per short ton	Per metric ton
1970	21.03	23.18	65.84	72.58
1971	21.21	23.38	62.82	69.25
1972	22.28	24.56	63.01	69.46
1973	25.36	27.95	67.37	74.26
1974	33.87	37.34	82.48	90.92
1975	42.20	46.52	93.58	103.15
1976	49.70	54.78	103.57	114.17
1977	54.19	59.73	105.88	116.71
1978	54.51	60.09	99.28	109.44
1979	64.55	71.15	107.99	119.04
1980	89.85	99.04	137.87	151.98
1981	91.19	100.52	127.57	140.62
1982	88.35	97.39	116.18	128.07
1983	76.95	84.82	97.39	107.35
1984	67.00	73.85	81.81	90.18
1985	67.82	74.76	80.42	88.65
1986	65.29	71.97	75.44	83.16
1987	66.78	73.61	74.80	82.45
1988	66.96	73.81	72.59	80.02
1989	77.07	84.96	80.24	88.45
1990	82.85	91.33	82.85	91.33

[1]Values are the combined total revenue of California and Wyoming natural soda ash sold at list prices, spot prices, discount, long-term contracts, and for export, divided by the quantity of soda ash sold on a bulk, f.o.b. basis. The average annual value may not necessarily correspond to posted list prices for soda ash.
[2]From final 1990 implicit price deflators for gross national product, by the Council of Economic Advisors. Based on 1982 = 100.

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 KSLA 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 approximately 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, 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, which has been accumulating since 1950. Some pond water is recirculated into the mines and used as drilling and cutting coolant. Because of changes in environmental legislation in Wyoming, Tenneco Minerals Co. has begun discharging its waste material into abandoned sections of its underground mine, thereby using less surface area on the surface for tailing ponds. The expense of underground discharge is partially offset with the reduction in costs of constructing and maintaining surface tailing ponds.

The alkaline surface ponds, with a pH up to 10.5, have posed some problems for migratory fowl that land on the ponds. The alkaline solutions strip the insulative natural oils from the feathers, thereby increasing the vulnerability of the birds to death from hypothermia. Also, birds have drowned because of the weight of sodium decahydrate that crystallizes on them when the temperature falls below 4° C (40° F). All trona producers have established a rehabilitation program to recover and release contaminated birds and to minimize the mortality and morbidity rate.

Land surrounding trona operations in Wyoming is relatively undeveloped, and the influx of large numbers of workers has caused great strain on the local facilities for housing, schools, shopping, and entertainment. Soda ash companies have provided financial assistance to aid local government in handling any overloads caused by the migration of their employees and families into the community. The companies have given financial aid to employees purchasing homes in the surrounding communities and other fringe benefits such as low-cost transportation to and from work.

Toxicity.—Although soda ash is not considered a highly toxic substance, contact with the eyes may be injurious, and prolonged contact with the skin may cause irritation, especially to those who have allergic reactions to alkaline materials. It has also been found to be corrosive to the stomach lining if ingested. It has an acute oral lethal dose (LD50) of 2.8 grams per kilogram (when tested on a rat) and a primary skin irritation index (PSII) of 2.54 (when tested on a rabbit). Simultaneous exposure to soda ash and lime dusts should be minimized because in the presence of moisture, as from perspiration, the two materials combine to form caustic soda, which is very harmful. Soda ash is not flammable, and the dust is not explosive.

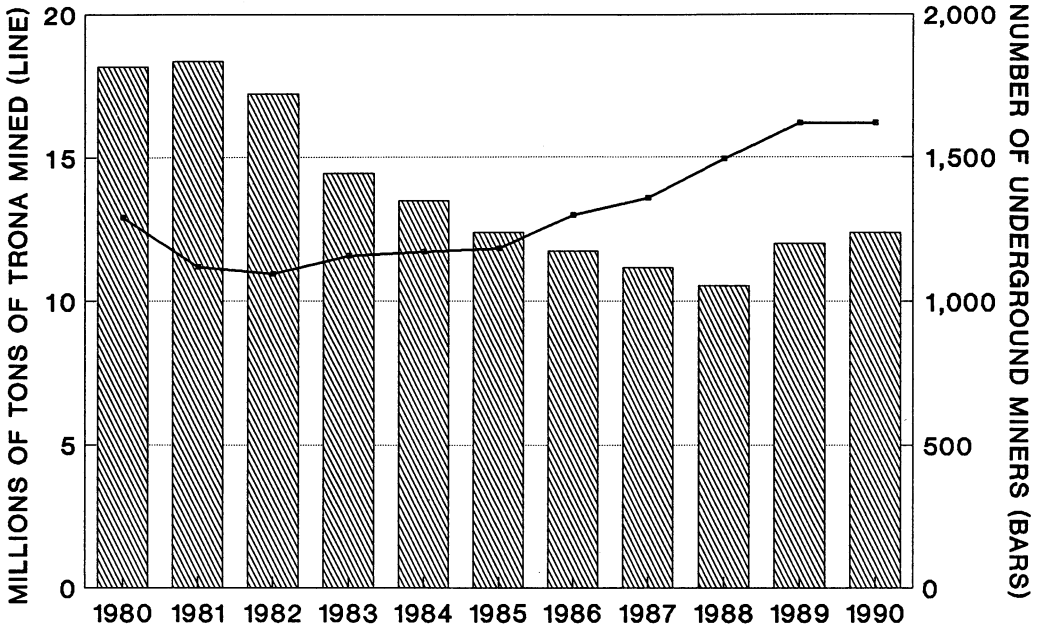
Employment.—According to the Wyoming Office of the State Inspector of Mines, the Wyoming soda ash industry in 1980 employed 3,931 people, of which 1,817 were underground workers, to produce 11.7 million metric tons (12.9 million short tons) of trona. In 1990, 3,047 people were employed, of which 1,237 underground workers produced 14.7 million metric tons (16.2 million short tons) of ore. From 1980 through 1990, the underground work force was reduced about 32%, while the quantity of trona increased 25%. This represented an 84% increase in the amount of ore mined per person per year; 6,439 metric tons in 1980 and 11,884 metric tons in 1990.

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) 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 T.g. and Tenneco and the Argus plant operated by North American Chemical use coal only. As a result of these energy saving measures, the Wyoming soda ash industry lowered its energy requirement to a range of from 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

FIGURE 1

TONS OF WYOMING TRONA MINED VERSUS NUMBER OF UNDERGROUND MINERS



Source: State Inspector of Mines of Wyoming.

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, natural soda ash production requires less energy than the Solvay process or any other synthetic technique.

Transportation.—The western geographic locations of the domestic natural soda ash industry often pose problems because of the great shipping distance to most foreign customers. Even within the United States, the majority of domestic consumption is in the Midwest and east of the Mississippi River. Overland and ocean transportation rates become important factors in the delivered price of soda ash and must be considered seriously in negotiations with foreign consumers who often have alternate supply sources. Bulk freight rates can usually be reduced by shipping in larger volumes, such as in 7,500-ton units.

The railroad is the dominant mode of transportation for the shipment of soda ash. In Wyoming, the Union Pacific Railroad provides the main service to the industry. All bulk soda ash that is railed is carried in covered hopper cars, each handling about 98 tons. Although the railroad companies make their cars available, most soda ash companies have their own sizable fleet.

Beginning in 1985, soda ash was shipped in large quantities by truck. Bonneville Transloaders Inc. trucked soda ash from Green River to the Burlington Northern Railroad's line at Shoshoni, WY. Of the approximately 8.4 million metric tons (9.2 million short tons) of soda ash produced in Wyoming, Bonneville trucks about 770,000 metric 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 metric 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 bulkloading 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 shiploader spout for transfer to bulk cargo ocean vessels. Port Arthur was the third largest port of the 23 ports that shipped soda ash in 1990, most of which was shipped to South America. Longview, WA (out of the Portland, OR, customs district), has a bulkloading terminal, which transferred the most soda ash, 55%, in 1990.

ANNUAL REVIEW

Issues

The major issues in 1990 that affected the U.S. soda ash industry were the global environmental consciousness toward certain chlorine-base chemicals that altered the international chloralkali supply-demand balance; the elimination of the antidumping duties on imports of U.S. soda ash in Europe; and the movement by some domestic soda ash producers to make higher value added downstream products that use soda ash as feedstock.

The world supply and demand balance between chlorine and caustic soda historically has fluctuated. When chlorine demand was low, the availability of coproduct caustic soda was also low, which often resulted in higher prices for caustic when the market for caustic soda was strong. Some consumers temporarily switched to lower priced soda ash that was in abundant supply. This conversion usually was always a short-term cycle because the balance between the chlorine and caustic soda markets ultimately became stabilized. The present cycle of reduced supplies and higher prices, however, has lasted longer than many analysts forecasted based on previous experiences.

Major market sectors that use chlorine in products or in a process have been under pressure to reduce or eliminate chlorine use. Chlorine-base compounds such as those used in chlorofluorocarbons (CFC's) have been asssociated with stratospheric ozone depletion and contributing to global warming. In paper bleaching, discharges of chlorine chemicals from various pulp mills were found to contain trace amounts of carcinogenic dioxin (2,3,7,8-TCDD) and furan (2,3,7,8-TCDF).

The elimination of the antidumping duties on U.S. soda ash entering Europe raised hope for future export sales to that continent. The timing of this action was fortuitous; U.S. exports to China had drastically declined, and the U.S. soda ash industry needed replacement markets. Other important issues confronting the growth of U.S. soda ash are the political events in Eastern Europe and the reunification of the Federal Republic of Germany, both areas that have tremendous potential for increased soda ash consumption. The export opportunities are encouraging, pending a favorable resolution to the political and economic problems.

Historically, the main product produced at each soda ash plant was exclusively soda ash, which usually was sold as a raw material for other companies to make different downstream products. FMC had been producing sodium phosphates, and Rhône Poulenc had been making sodium bicarbonate, but it was apparent that many other sodium-base commodities could be made from the resource. Soda ash values between 1984 and 1988 were virtually flat because of stagnant market conditions and oversupply. In 1990, FMC, Tenneco, and Texasgulf made plans to produce higher value added products derived from soda ash to increase corporate revenue.

Production

U.S. production of natural soda ash from California and Wyoming reached a record 9.156 million tons. About 112,000 tons of soda ash equivalent from soda liquors and mine waters was included in the total and used primarily for neutralizing powerplant process water. The liquors represent a growing market for soda ash producers and provide additional revenue.

In February, Tenneco Minerals Co. and Asahi Glass Co. of Japan formed a joint venture named Tenneco Soda Ash Joint Venture. The new $100 million project will add 544,000 tons (600,000 short tons) of annual soda ash capacity to Tenneco's 1.13-million-ton-per-year (1.25 million short tons) facility by late 1992. Asahi will receive 20% ownership of the combined 1.67-million-ton-per-year (1.85 million short tons) operation or about 335,000 tons (370,000 short tons). This output will be exported to Japan or other areas served by Asahi.[1]

On September 19, 1990, Tenneco announced plans to process an additional 1.36 million tons (1.5 million short tons) of trona into calcined trona, which can be used to produce several other sodium carbonate-base products such as soda ash, sodium sulfite, and caustic soda.[2] Calcining converts trona into an unrefined sodium carbonate product with some residual insoluble impurities. Because Tenneco's ore grade exceeds 93% compared with an industry average of about 89%, its calcinate contains less impurities. Calcined trona can be shipped more economically to greater distances than regular trona because the water content and other volatiles have been removed. At the customers location, the trona could be converted to caustic soda with the addition of lime and the insoluble impurities disposed to landfills.

T.g. and Atochem North America Inc., both subsidiaries of Société Nationalé Elf Aquitaine of France, formed a joint venture in August to make chemical caustic soda at T.g.'s Granger, WY, facility.[3] The plant will have an annual production capacity of 91,000 metric tons (100,000 short tons) with startup scheduled for early 1992. The company will use available sodium carbonate-rich mine water to produce the caustic soda. Atochem has a chloralkali facility in Tacoma, WA, that produces electrolytic caustic soda and coproduct chlorine.

FMC commissioned its 65,000-ton-per-year caustic soda plant at Green River, WY, in March. A major portion of the caustic soda was to be used captively to make sodium cyanide for FMC's precious-metals operations in Nevada. The sodium cyanide plant, which has a capacity of 27 million kilograms (60 million pounds) per year, was operable in November. The company also brought on-stream a 60,000-ton-per-year sodium bicarbonate facility that used sodium sesquicarbonate as the raw material because it required one-third less carbon dioxide for conversion to sodium bicarbonate.[4]

The Kerr-McGee Chemical facility in California was sold November 30 for a reported $210 million to North American Chemical, a company formed by a consortium led by D. George Harris and Associates.[5] Oriental Chemical Industries of the Republic of South Korea, which was one of the investors, owns about 27% of the venture and has a synthetic soda ash plant at Inchon, Korea. In addition to soda ash produced at the Argus plant, North American will continue to produce various boron, potassium, and sodium products from its Trona and Westend facilities on Searles Lake.

Consumption and Uses

U.S. apparent consumption in 1990 increased 5% compared with that of the previous year, whereas reported consumption rose only 1%. The discrepancy between the two was attributed to disagreement between the sources of export data used to derive consumption statistics. The two sources were the Bureau of the Census, which reports exports upon departure from the U.S. port, and the soda ash producers, which consider a shipment as exported when their export association, the American Natural Soda Ash Corp., takes charge at the California or Wyoming plant sites. Transit times between the plant and port and carryover export inventories contribute to the discrepancy between reported and apparent consumption.

Based on reported industry sales, the manufacture of glass represented about 49% of domestic soda ash consumption, with the container sector composing 60% of this end use; flat, 27%; fiber, 7%; and specialty, 6%. The other end uses include

chemicals (primarily sodium bicarbonate, sodium chromates, sodium phosphates, and sodium silicates), 24%; soap and detergents, 13%; distributors, 6%; flue gas desulfurization, 3%; pulp and paper and miscellaneous, 2% each; and water treatment, 1%.

U.S. reported consumption of soda ash increased in the chemical, soap and detergent, and pulp and paper sectors in 1990. The rise in demand was because of greater substitution of high-priced caustic soda for less expensive soda ash by chemical consumers in the pulp and paper, chemical, and alumina industries.

Less soda ash was used in glass because of the increased use of recycled cullet. Sales to the flat glass sector declined, mainly due to the downturn in the national economy that adversely affected the building construction and automobile industries. The industrial building construction industry consumes about 57% of all flat glass made, whereas the automotive glass sector used 25%. The remainder went to specialty flat glass products.

The third largest use of soda ash is in detergents. It is used as a builder to emulsify oil stains, reduce the redeposition of dirt during washing and rinsing, provide alkalinity for cleaning, and soften laundry water. In addition, soda ash is a component of sodium tripolyphosphate (STPP), another major builder in detergent formulations, but soda ash consumption has been decreasing because phosphatic detergents contribute to the environmental problems of eutrophication. Many regions of the Nation have adopted phosphate limitations or bans. These areas represent about 33% of the U.S. population. In response to the environmental issue, detergent manufacturers began reformulating their detergents to make compact and superconcentrated products. These reformulations require sodium silicates and synthetic zeolites, which are made from soda ash. Liquid detergents, which do not contain any soda ash, compete with powdered detergents and command 40% of the household laundry detergent market, up from only 15% in 1978.

TABLE 6

REPORTED CONSUMPTION OF SODA ASH IN THE UNITED STATES, BY END USE

(Metric tons)

SIC code	End use	1987	1988	1989	1990
32	Glass				
3221	Container	2,106,662	2,128,250	1,961,039	1,908,983
3211	Flat	820,976	851,853	907,333	850,687
3296	Fiber	249,358	246,273	240,799	227,770
3229	Other	165,793	163,560	185,083	189,452
	Total	3,342,789	3,389,936	3,294,254	3,176,892
281	Chemicals	1,237,588	1,445,211	1,412,180	1,572,891
284	Soaps and detergents	684,374	717,894	780,634	834,691
26	Pulp and paper	63,001	110,996	113,962	131,973
2899	Water treatment[1]	71,568	109,865	92,268	91,057
	Flue gas desulfurization	182,899	199,630	208,296	207,067
	Distributors	349,042	373,439	380,021	375,804
	Other	169,097	147,456	187,073	136,324
	Imports[2]	136,171	120,609	128,790	145,534
	Total domestic reported consumption[3]	6,100,358	6,494,427	6,468,688	6,526,699
	Export[4]	2,124,240	2,662,472	[5]2,644,618	2,588,478
	Total industry sales[6]	[7]8,224,598	9,156,899	[8]9,113,306	9,115,177
	Total production	8,065,559	8,738,042	8,994,717	9,156,039

[1]Includes soda ash equivalent from soda liquors, purge liquors, and mine water, sold to powerplants for water treatment: 63,469 tons in 1987, 73,365 tons in 1988, 95,027 tons in 1989, and 111,894 tons in 1990.
[2]Data are from the Bureau of the Census and may vary from the quantity reported by the producer/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]In monthly Mineral Industry Surveys reports, "Total Industry Sales" for 1987 were erroneously reported as 8,088,423 metric tons (8,915,951 short tons). The misreported figure deducted imports, which already had been included in specific end uses under "Total domestic reported consumption."
[8]An extra 23,548 metric tons (25,957 short tons) of coproducer sales is included in total, but specific end-use breakout is unknown.

Stocks

Yearend stocks of dense soda ash in plant silos, warehouses, terminals, and on teamtracks amounted to 286,610 tons. Producers indicate that a potential supply problem could exist when inventories fall below 180,000 tons. Most consumers of soda ash do not have storage facilities to accommodate large quantities of soda ash and must rely on suppliers to provide the material on a timely basis.

Markets and Prices

There are essentially two markets for soda ash—domestic and export. 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. Although there were not any increases in the list price during 1990, the soda ash industry was successful in increasing the off-list price of some contracts. The result was that the annual soda ash value increased to $91.33 per metric ton ($82.85 per short ton) for bulk, dense, natural soda ash, f.o.b. Green River, WY, and Searles Valley, CA.

TABLE 7

SODA ASH YEAREND PRICES

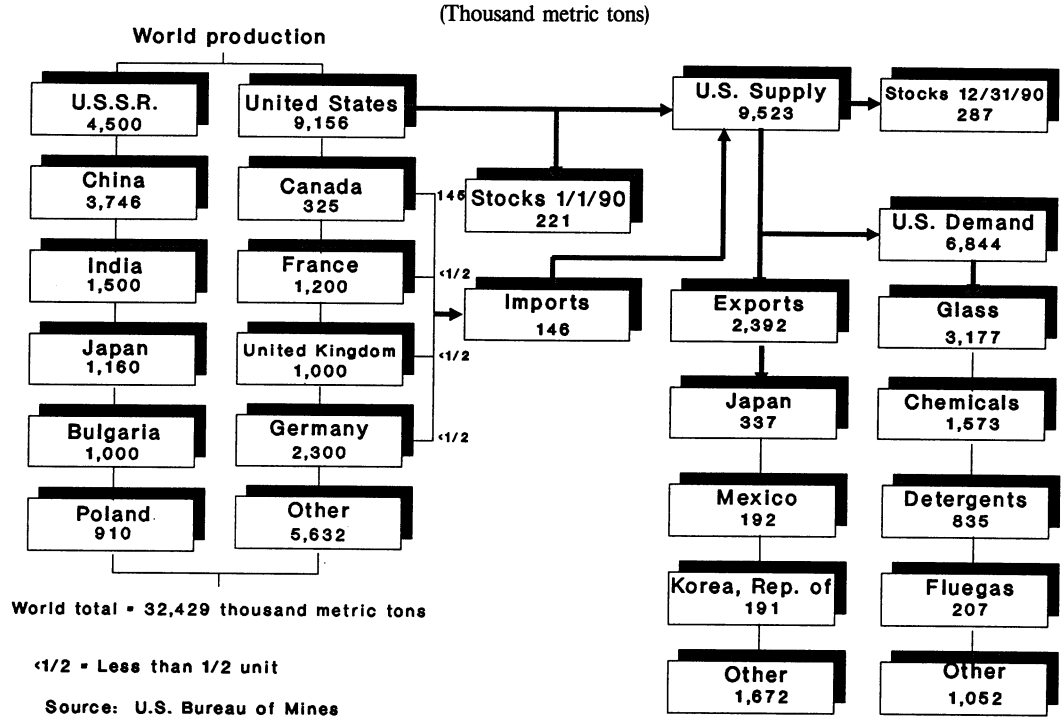
		1989	1990
Sodium carbonate (soda ash):			
Dense, 58%, Na_2O 100-pounds, paper bags, carlot, works, f.o.b.	per short ton	$146.00	$146.00
Bulk, carlot, same basis tons	do.	93.00	98.00
Light 58%, 100-pounds, paper bags, carlot, same basis	do.	150.00	150.00
Bulk, carlot, same basis tons	do.	123.00	123.00

Sources: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials. V. 237, No.1, Jan. 1, 1990, p. 39; and v. 238, No. 27, Dec. 31, 1990, p. 31.

FIGURE 2

SODA ASH SUPPLY-DEMAND RELATIONSHIPS—1990

(Thousand metric tons)



Foreign Trade

Exports of U.S. soda ash have increased every year since 1976, growing more than 325% between 1976 and 1989, when exports reached a record high of 2.65 million tons or about 29% of production. In 1990, however, exports decreased to 2.39 million tons because of the dropoff in export sales to China. China had been the largest consumer of U.S. exports, but its national determination to become self-sufficient in production reduced its import requirements. U.S. exports to 53 countries, on a regional basis, were as follows: Asia, 49%; South America, 16%; North America, 14%; Africa, 7%; Europe, 6%; Oceania, 4%; the Middle East, 2%; and the Caribbean, 1%. Exports to Central America were less than 0.5%.

Section 1205 of the Omnibus Trade and Competitiveness Act of 1988 required the United States to adopt an international nomenclature and metric units for reporting trade information. On January 1, 1989, the Harmonized Commodity Description and Coding System (HS) replaced the Tariff Schedule of the United States, Annotated for import data and Schedule B for exports. The new code numbers for soda ash are listed in the appropriate trade tables in this report.

The antidumping directorate of the European Community Commission (ECC) ruled in October that the six West European synthetic soda ash producers collectively prevented the United States from entering the European market in the early 1980's.[6] The companies were Solvay et Cie of Belgium, Akzo N.V. of the Netherlands, Imperial Chemical Industries PLC (ICI) of England, Rhône-Poulenc S.A. of France, and Chemische Fabrik Kalk and Matthes and Weber G.m.b.H. of the Federal Republic of

TABLE 8

U.S. EXPORTS OF SODA ASH

(Thousand metric tons and thousand dollars)

Year	Disodium carbonate[1]	
	Quantity	Value[2]
1986[3]	1,859	241,238
1987[3]	2,018	253,200
1988[3]	2,238	286,945
1989	2,648	365,469
1990	2,392	346,693

[1]Beginning in 1989, export data were reclassified under the Harmonized Commodity Description and Coding System (HS Code No. 2836200000). Prior years were classified under Schedule B No. 4208400.
[2]F.a.s. value at U.S. ports.
[3]Adjusted by the U.S. Bureau of Mines to account for discrepancies in data.

Source: Bureau of the Census, as adjusted by the U.S. Bureau of Mines.

Germany. The combined output of these producers represented about 20% of world soda ash production. The duty of 67.5 European Currency Units (ECU's), about $67.13 per short ton, was rescinded. ECC investigators also ruled in December that the U.S. export association would not be able to represent the U.S. producers in Europe. European soda ash consumers would prefer to have an alternate source of soda ash, namely the United States. With two Wyoming soda ash plants coowned by French companies and others that have European subsidiaries, the U.S. soda ash industry is hopeful that the investigation will result in reduced or eliminated duties, which could increase U.S. export sales to Europe.

The commission also fined Solvay and ICI a total of $64 million (ECU 47 million) for illegal pricing arrangements and market sharing in the early 1980's. These were the largest fines ever imposed on individual companies found violating ECC competition laws.[7]

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 30% of nameplate capacity.

Eleven countries have the capability to produce more than 1 million tons annually. The major ones include, in

TABLE 9

REGIONAL DISTRIBUTION OF U.S. SODA ASH EXPORTS, BY CUSTOMS DISTRICTS, IN 1990

(Metric tons)

Customs districts	North America	Central America	South America	Caribbean	Europe	Middle East	Africa	Asia	Oceania	Total	Percent of total
Atlantic:											
Baltimore, MD	—	—	—	—	47	—	—	—	—	47	—
Miami, FL	—	17	—	335	—	—	—	—	—	352	—
New York, NY	75	—	77	—	20	—	—	1	—	173	—
Philadelphia, PA	—	—	4	—	—	—	—	—	—	4	—
Tampa, FL	—	—	—	8	—	—	—	—	—	8	—
Gulf:											
Galveston, TX	—	102	9	—	20,028	—	2	197	—	20,338	1
New Orleans, LA	—	78	8	—	—	—	—	9	—	95	—
Port Arthur, TX	1,000	2,000	222,187	14,044	62,607	9,757	38,125	—	—	349,720	15
Pacific:											
Anchorage, AK	4,899	—	—	—	—	—	—	—	—	4,899	—
Los Angeles, CA	—	8,479	74,087	—	21,390	43,248	66,819	139,949	—	353,972	15
San Diego, CA	3,659	—	—	—	—	—	—	—	—	3,659	—
Seattle, WA	2,133	—	—	—	—	—	—	—	—	2,133	—
Portland, OR	—	—	76,228	—	50,947	—	70,083	1,029,401	97,133	1,323,792	55
North Central:											
Cleveland, OH	3	—	—	—	—	—	—	—	—	3	—
Detroit, MI	86,346	—	—	—	87	—	—	—	—	86,433	4
Duluth, MN	20	—	—	—	—	—	—	—	—	20	—
Great Falls, MT	42,318	—	—	—	—	—	—	—	—	42,318	2
Pembina, ND	7,286	—	—	—	—	—	—	—	—	7,286	—
Northeast:											
Buffalo, NY	805	—	—	—	37	—	—	—	—	842	—

See footnote at end of table.

TABLE 9—Continued

REGIONAL DISTRIBUTION OF U.S. SODA ASH EXPORTS, BY CUSTOMS DISTRICTS, IN 1990

(Metric tons)

Customs districts	North America	Central America	South America	Caribbean	Europe	Middle East	Africa	Asia	Oceania	Total	Percent of total
Southwest:											
El Paso, TX	35	—	—	—	—	—	—	—	—	35	—
Laredo, TX	185,472	—	—	—	—	—	—	—	—	185,472	8
Nogales, AZ	2,656	—	—	—	—	—	—	—	—	2,656	—
Other:											
San Juan, P.R.	—	—	—	68	—	—	—	—	—	68	—
Unknown:	7,671	—	—	—	—	—	—	—	—	7,671	—
Total	344,378	10,676	372,600	14,455	155,163	53,005	175,029	1,169,557	97,133	2,391,996	100
Percent of total[1]	14	—	16	1	6	2	7	49	4	100	

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

Source: Bureau of the Census.

TABLE 10

U.S. EXPORTS OF SODA ASH, BY COUNTRY

Country	1980 (metric tons)	Percent of total	1985 (metric tons)	Percent of total	1990 (metric tons)	Percent of total
Algeria	41	—	—	—	4,057	—
Angola	5	—	—	—	1	—
Argentina	12,638	1	41,685	3	74,259	3
Australia	10,203	1	15,000	1	72,737	3
Bahamas	6	—	113	—	5	—
Bahrain	15	—	—	—	—	—
Barbados	—	—	3	—	—	—
Belgium	60	—	—	—	—	—
Belize	36	—	—	—	8	—
Bermuda	—	—	316	—	1,075	—
Bolivia	19	—	2,059	—	554	—
Brazil	124,309	13	58,106	4	101,873	4
Cameroon	9	—	—	—	—	—
Canada	143,759	14	132,768	8	151,480	6
Chile	10,160	1	27,043	2	39,425	2
China	—	—	33,000	—	56,159	2
Colombia	9,940	1	9,977	1	21,910	1
Costa Rica	3,064	—	3	—	8,479	—
Denmark	(1)	—	—	—	—	—
Dominican Republic	5,187	1	4,443	—	2,722	—
Ecuador	9,808	1	5,499	—	10,634	—
El Salvador	598	—	1,032	—	—	—
France	—	—	5	—	11,474	—
French Pacific Islands	2	—	—	—	—	—
Gabon	—	—	—	—	1	—
Germany, Federal Republic of	—	—	—	—	64	—

See footnotes at end of table.

TABLE 10—Continued

U.S. EXPORTS OF SODA ASH, BY COUNTRY

Country	1980 (metric tons)	Percent of total	1985 (metric tons)	Percent of total	1990 (metric tons)	Percent of total
Ghana	24	—	—	—	—	—
Guatemala	8,503	1	11,025	1	—	—
Guyana	19	—	—	—	8	—
Haiti	7	—	55	—	41	—
Honduras	55	—	82	—	7	—
Hong Kong[2]	1,109	—	492,691	31	40,734	2
Hungary	—	—	—	—	9,916	—
India	11,034	1	9,394	1	—	—
Indonesia	2,033	—	53,401	3	173,920	7
Iran	—	—	—	—	43,248	2
Ireland	—	—	3	—	(1)	—
Israel	(1)	—	—	—	9,757	—
Jamaica	6,539	1	3,936	—	6,059	—
Japan	57,513	6	205,713	13	337,207	14
Korea, Republic of	8,064	1	14,002	1	190,521	8
Leeward and Windward Islands	42	—	41	—	—	—
Liberia	5	—	—	—	—	—
Malaysia	—	—	15,499	1	55,844	2
Mexico	177,795	18	85,532	5	191,820	8
Morocco	—	—	—	—	600	—
Netherlands	22,178	2	—	—	20,028	1
Netherlands Antilles	13	—	—	—	—	—
New Zealand	18,678	2	39,502	2	24,397	1
Nicaragua	4	—	—	—	3	—
Pakistan	20	—	—	—	—	—
Panama	3,389	—	1,611	—	2,181	—
Peru	22,429	2	16,306	1	11,181	—
Philippines	26,784	3	42,847	3	86,095	4
Qatar	5	—	3	—	—	—
St. Lucia	—	—	—	—	5	—
Saudi Arabia	98	—	1	—	—	—
Senegal	3	—	—	—	—	—
Seychelles	3	—	—	—	—	—
Singapore[2]	6,869	1	3	—	12,987	1
Somalia	—	—	2	—	—	—
South Africa, Republic of	138,077	14	130,423	8	170,370	7
Sri Lanka	—	—	—	—	9	—
Sudan	1	—	5	—	—	—
Suriname	5	—	9	—	—	—
Sweden	—	—	—	—	20,521	1
Switzerland	—	—	—	—	447	—
Taiwan[2]	11,629	1	13,999	1	112,449	5
Thailand	—	—	21,224	1	103,635	4
Trinidad and Tobago	6,412	1	—	—	5,624	—
Trust Territories	—	—	4	—	—	—

See footnotes at end of table.

TABLE 10—Continued

U.S. EXPORTS OF SODA ASH, BY COUNTRY

Country	1980 (metric tons)	Percent of total	1985 (metric tons)	Percent of total	1990 (metric tons)	Percent of total
Turkey	—	—	—	—	58,530	2
Untied Arab Emirates	37	—	—	—	—	—
United Kingdom	18,652	2	10,049	1	34,179	1
Uruguay	331	—	—	—	2,990	—
Venezuela	114,552	12	86,048	5	109,766	5
Total[3]	992,770	100	1,584,462	100	2,391,996	100

[1]Less than 1/2 unit.
[2]The majority was bagged and transshipped to China.
[3]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 11

U.S. IMPORTS FOR CONSUMPTION OF SODA ASH

Year	Disodium carbonate[1]	
	Quantity (metric tons)	Value[2] (thousands)
1986[3]	96,130	$15,023
1987[3]	136,171	18,334
1988[3]	120,609	15,999
1989	128,790	17,396
1990	145,534	20,495

[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.

descending order, the United States, the U.S.S.R., China, the Federal Republic of Germany, France, Bulgaria, and India. 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.

Capacity.—World soda ash production capacity is about 34.8 million tons divided among 35 countries. Approximately 70% of world capacity is synthetic soda ash, 30% natural. The United States represents 28% of world capacity and 94% of the total natural capacity.

The largest soda ash company in the world, excluding State-owned facilities, is Solvay et Cie of Belgium. It operates nine plants in seven countries and has a combined annual capacity of more than 4 million tons. FMC of the United States is the second largest with 2.59 million metric tons (2.85 million short tons) of capacity.

Botswana.—Soda Ash Botswana, the venture formed by the Botswana Government and African Explosives and Chemical Industries with its partners, the Anglo American Corp. and De Beers Holdings, commenced limited brine production at yearend. A wellfield containing 40 wells covering 200 square kilometers was developed to supply the newly constructed soda ash refinery. The wells are sunk to depths of about 35 meters. Approximately 20,000 tons of refined soda ash was expected to be produced by March 1991.[8]

Jordan.—Arab Potash Co. awarded contracts to Fluor Daniel, MDPA, and Batelle Europe to do feasibility studies of expanding the Dead Sea chemical works. Arab Potash had the intention to produce chlorine, phosphoric acid, potassium sulfate, sodium tripolyphosphate, and soda ash.[9]

Saudi Arabia.—Plans were announced by International Chemical Industries and Trading Co. Ltd. to construct a 250,000-ton-per-year synthetic soda ash plant at Jubail, near the Persian Gulf coast. One-half of the plant's production was slated for domestic consumption and the remainder for export to other Middle Eastern countries. The $240 million facility was scheduled to come on-stream by 1994 using Akzo Salt and Basic Chemicals International BV ammonia-soda technology.[10]

Turkey.—Etibank, the state mining agency, received bids from seven foreign consulting and engineering companies for planning work on a $500 million trona project. The deposit is in Beypazari near Ankara.[11]

OUTLOOK

World soda ash production has grown about 2.5% per year since 1970. Assuming that world production is equal to world demand (worldwide inventories are insignificant compared with output levels), world production would reach 41.1 million tons by the year 2000, based on the growth rate trend between 1970 and 1990 shown in figure 3. The environmental, energy, and economic issues of the 1980's reduced the international growth rate of soda ash to about 1.2% per annum. These issues, which will continue to be of greater importance during the 1990's, affect the overall supply and demand balance of soda ash than those events of the 1970's. Using a growth rate of 1.2% per year, world soda ash production by the year 2000 could reach 36.4 million tons, which is a conservative forecast as noted in figure 4. Developed nations, where soda ash consumption is mature and growth rates are proportional to population changes, are more concerned about environmental quality, energy efficiency, recycling, and

TABLE 12

SODA ASH: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989	1990[e]
Albania[e]	32,000	31,000	30,000	30,000	30,000
Australia[e]	300,000	300,000	300,000	300,000	300,000
Austria[e]	150,000	150,000	145,000	150,000	150,000
Belgium	481,656	447,972	378,960	[e]380,000	380,000
Brazil	201,000	170,000	184,416	[r]196,526	200,000
Bulgaria	1,054,214	1,070,188	[e]1,100,000	[e]1,100,000	1,000,000
Canada[e]	350,000	325,000	325,000	325,000	325,000
China	[r]2,146,000	[r]2,363,000	[r]2,609,000	[r]3,042,000	[2]3,746,000
Colombia	112,920	116,864	114,087	[e]115,000	115,000
Czechoslovakia	113,000	[r]102,659	[r]112,217	[e]110,000	100,000
Denmark[3]	117	[e]120	[r]134	[r]140	140
Egypt[e]	50,000	[r]45,000	[2]47,711	47,000	47,000
France[e]	1,245,000	1,270,000	1,270,000	1,300,000	1,200,000
Germany, Federal Republic of:					
Western states	1,442,000	1,448,000	1,404,000	[r]1,443,000	1,450,000
Eastern states	885,000	893,000	914,000	[e]900,000	850,000
Total	2,327,000	2,341,000	2,318,000	[r]2,343,000	2,300,000
Greece[e]	([4])	([4])	([4])	([4])	—
India	873,600	969,600	[r]1,098,200	[r]1,343,500	1,500,000
Italy[e]	590,000	612,000	612,000	615,000	610,000
Japan	1,020,849	1,098,465	1,083,121	[r]1,105,308	1,160,000
Kenya[5]	237,650	228,650	220,000	240,880	240,000
Korea, Republic of	264,213	288,500	[e]280,000	[e]280,000	280,000
Mexico[6]	[r]405,344	[r]417,329	421,158	456,466	475,000
Netherlands[e]	380,000	380,000	[r]400,000	[r]400,000	400,000
Pakistan	130,894	[r]133,133	134,106	[re]135,000	135,000
Poland	963,000	930,000	[r]956,000	[e]910,000	910,000
Portugal[e]	155,000	160,000	155,000	150,000	150,000
Romania[e]	850,000	860,000	860,000	800,000	800,000
Spain[e]	525,000	550,000	560,000	560,000	550,000
Switzerland[e]	43,000	23,000	—	—	—
Taiwan	133,358	127,332	126,828	[r]115,572	120,000
Turkey[e]	330,000	376,000	379,000	[r]381,000	385,000
U.S.S.R.[7]	5,032,000	5,049,000	5,097,000	[r]4,809,000	4,500,000
United Kingdom[e]	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
United States[8]	7,655,001	[r]8,065,559	8,738,042	8,994,717	[2]9,156,039
Yugoslavia	207,968	201,539	213,891	[r]204,050	165,000
Total	[r]29,359,784	[r]30,202,910	[r]31,268,871	[r]31,939,159	32,429,179

[e]Estimated. [r]Revised.

[1]Table includes data available through Apr. 26, 1991. Synthetic unless otherwise specified.

[2]Reported figure.

[3]Production for sale only; excludes output consumed by producers.

[4]Revised to zero.

[5]Natural only.

[6]Includes natural and synthetic. In 1988 and 1989, Mexico produced an estimated 180,000 metric tons per year of natural soda ash. The new series listed is as reported by Asociacin Nacional de la Industria Qumica, beginning with 1986.

[7]Excludes potash for 1986–87.

[8]Natural and synthetic for 1986, natural only thereafter.

FIGURE 3

U.S. AND WORLD SODA ASH PRODUCTION GROWTH RATES

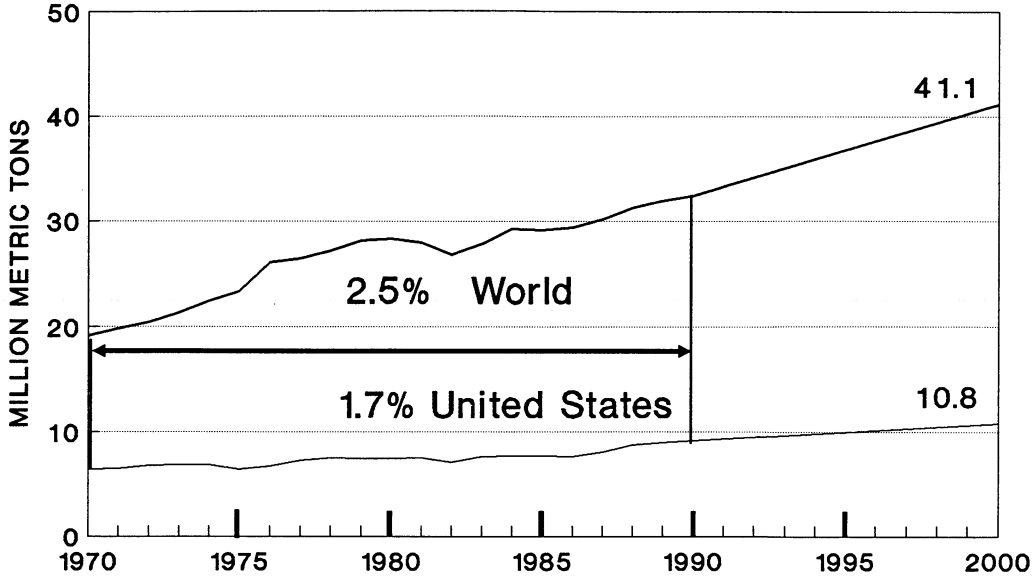
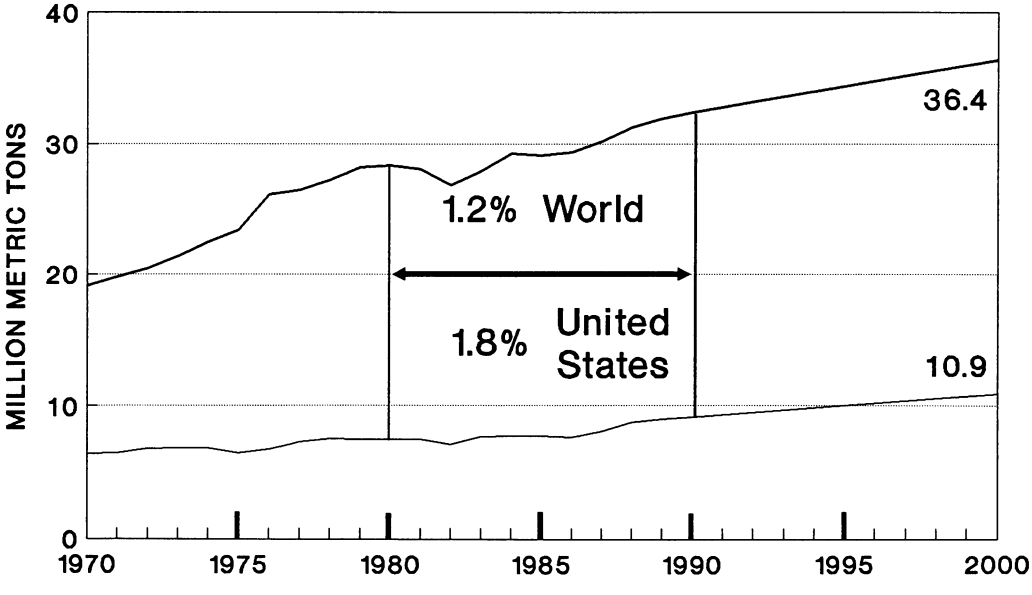


FIGURE 4

U.S. AND WORLD SODA ASH PRODUCTION GROWTH RATES



and consumer preferences—all of which have an adverse affect on soda ash usage. Developing countries still have a greater demand for soda ash but often have less hard currency to purchase all their requirements.

The U.S. annual growth rate for domestic production since 1970 has been about 1.7% per annum. The 1973 energy crisis and subsequent higher fuel costs changed the operating factors between competing natural and synthetic soda ash industries. U.S. production was close to what was forecast for 1990 in the 1985 "Mineral Facts and Problems." The export market grew greater than anticipated, mainly through the efforts of the industry's export association, and raised total industry sales despite periods of stagnant domestic sales.

Domestic production is forecast to grow at 1.8% per year and reach 10.9 million tons by the year 2000, as indicated in figure 4. This growth rate, based

on the trend between 1980 and 1990, is similar to the 21-year pattern from 1970 through 1990.

Exports

The outlook for soda ash is excellent. Export opportunities to the Middle East and Western and Eastern Europe are very favorable. With the removal of the ECC antidumping tariffs on U.S. soda ash, more soda ash will be exported to Western Europe in the near future. The changes in the political situation in the U.S.S.R. and Eastern Europe may also lead to more U.S. exports to meet the growing demand for consumer products in those areas. The limiting factor, however, may be the lack of available hard currency and the internal manufacturing capabilities of the industries that use soda ash.

The future of reestablishing U.S. exports to China is uncertain. China has been debottlenecking several synthetic soda ash plants and constructing new ones, but production has not kept pace with demand. China was forced to reduce its soda ash consumption by limiting imports because of economic problems. Bulgaria had supplied some of China's requirements; future shipments could be curtailed to satisfy Eastern Europe's needs, thereby reducing Bulgaria's level of exports. This could allow the United States the opportunity to continue to supply China, pending the availability of U.S. product. Despite these obstacles, total U.S. exports could grow by at least 400,000 tons in the next several years.

Glass

Although glass is the largest end use of soda ash, domestic consumption in the glass container sector is declining because of (1) the increasing use of cullet (2) the national interest in recycling, and (3) the continuing competition with polyethylene terephthalate (PET) plastic containers.

Glass container shipments were less in 1990 than in previous years. The public's perception that glass is completely recyclable compared with plastics will raise the quantity of cullet now being consumed. Aside from the problems with plastics' recyclability, the public also is concerned about the dioxin emissions from incineration of polyvinyl chloride (PVC) bottles. Flat glass consumption was also down because of adverse economic conditons affecting housing starts and automobile sales. This situation is temporary because interest rates will decline for home mortgage loans.

Municipal landfills are a growing national problem. Glass reportedly accounts for 8.4% of disposable household waste. The U.S. Environmental Protection Agency has a goal of reducing the Nation's waste by 25% by 1992. It is probable that new taxes will be placed on items manufactured at the source of production to encourage greater use of recycled products. Rebates would be given for every ton of recycled material utilized.

Chemicals

The global chloralkali supply and demand imbalance will continue to be an important topic for the next few years. The demand for PVC products will govern chlorine supplies and the availability and price of coproduct caustic soda. Chemical caustic soda produced by the lime-soda process will satisfy part of the projected caustic soda shortages. For foreign shortages, trona deposits outside the United States will be evaluated as potential natural sources to produce chemical caustic soda.

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 the Federal Republic of Germany, consumption of phosphates in detergents dropped from 276,000 tons in 1975 to 80,000 tons in 1987. The quantity of packaging waste discarded to landfills prompted detergent manufacturers to test market compact and superconcentrated products in different regions. Whatever amount of soda ash lost due to reformulation could be partially offset from the use of soda ash in synthetic zeolites and sodium silicates in the new formulations.

Consumer preferences also may determine the preferred detergent and format (i.e., liquid versus powdered, unit dose packets versus bulk). Depending on the choice, the growth of future soda ash sales is optimistic.

Pulp and Paper

Although the U.S. pulp industry is growing at about 2.75% per year, changes are taking place to alter the pulp- 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, Tenneco, and T.g. have made announcements to produce caustic soda from their Wyoming soda ash operations. Although the majority of the output is for captive needs, the opportunity will demonstrate the economic feasibility of producing caustic soda from nonsalt feedstocks. Soda ash consumption in the pulp and paper sector could increase during the next few years depending on the strength of chlorine demand, which is influenced by the strength of PVC 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 1990, approximately one-quarter million tons of soda ash was used for reducing harmful 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. When Western powerplants retrofit older facilities with dry-injection scrubbing equipment to conserve water, demand for soda ash will increase.

Soda Ash Industry

Although the outlook for the U.S. soda ash industry is very good, the structure of the industry continues to change as foreign participation increases. The United States will remain an important supply source of inexpensive natural soda ash for international consumption. However, a growing percentage will be shipped by the foreign partners of the U.S. resource—primarily Australia, France, Japan, and the Republic of Korea. More shares of the U.S. soda ash industry are available for joint venture at the present time. It is unlikely that any new grassroots operation will be constructed in the United States for the remainder of this century.

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[2]Tenneco Minerals News Release. Sept. 19, 1990, 2 pp.

[3]T.g. Soda Ash News. (Press release). Texasgulf and Atochem Chemical Caustic Soda Joint Venture, Aug. 13, 1990.

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[5]The Wall Street Journal. Kerr-McGee Corp. July 19, 1990, p. 4.

[6]Chemical Week. EC Drops U.S. Soda Ash Duties. V. 147, No. 15, p. 6.

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[8]Mining Magazine (London). The Sua Pan Soda Ash Project. V. 163, No. 5, p. 323.

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SODIUM SULFATE

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 12 years of U.S. Bureau of Mines experience, has been the commodity specialist for sodium sulfate since 1979. Domestic survey data were prepared by Carleen Militello, mineral data assistant; and international data tables were prepared by William Zajac, Chief, Section, International Minerals.

Sodium sulfate is produced from natural sources or recovered as a byproduct from various manufacturing processes and has several important and useful applications in various consumer products. In a survey of the top 50 basic organic and inorganic chemicals made in the United States, sodium sulfate ranked 48th in terms of quantity produced.[1]

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. As foreign trade of soda ash increases and foreign participation in U.S. joint mining ventures continues, communicating information with an international standard of measurement becomes more important.

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, also known as byproduct, sodium sulfate data were collected by the U.S. Department of Commerce, Bureau of the Census, from monthly and annual surveys (aggregate data published in Current Industrial Reports, Inorganic Chemicals, M28A and MA28A) of companies engaged in recovering and selling byproduct sodium sulfate. Any revised Census Bureau data have been included using most recent Census Bureau statistics. These data are aggregated with U.S. Bureau of Mines natural sodium sulfate data and included in several tables.

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

TABLE 1

SALIENT SODIUM SULFATE STATISTICS

(Thousand metric tons and thousand dollars)

	1986	1987	1988	1989	1990
United States:					
Production[1]	763	725	r743	r685	665
Value[2]	$72,419	$69,289	r$64,545	r$62,703	$64,244
Exports	101	111	77	62	62
Value	$10,183	$10,554	$8,737	$6,241	$6,704
Imports for consumption	171	125	136	173	162
Value	$13,829	$10,363	$11,962	$13,990	$13,155
Stocks, Dec. 31: Producers'	65	50	54	24	39
Apparent consumption	796	754	r798	r826	750
World: Production	r4,609	r4,800	r4,937	r5,009	e4,998

eEstimated. pPreliminary. rRevised.

[1]Includes natural and synthetic. Total production data for synthetic sodium sulfate, obtained from the Bureau of the Census, was revised in Dec. 1990 M28A Inorganic Chemicals, Current Industrial Report.

[2]The value for synthetic sodium sulfate is based upon the average value for natural sodium sulfate.

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 15 companies operating 16 plants primarily in the Midwest and Mid-Atlantic regions. Total rated production capacity in 1990 was 836,000 tons, and the industry operated at 80% of this capacity.

Geology-Resources

Sodium is the sixth most abundant element in the Earth's crust. Sodium sulfate-bearing mineral deposits are geologically young, mainly of post-glacial age. Sodium sulfate is widespread in occurrence and is a common component of seawater and many saline or alkaline lakes. Economic reserves of natural sodium sulfate are estimated at 3.3 billion tons worldwide. With world production of natural sodium sulfate averaging about 2.6 million tons per year, supplies are sufficient to meet anticipated demand for several centuries. The quantity of synthetic sodium sulfate is dependent on the longevity of the manufacturing firms recovering byproduct sulfate.

Surface depressions or lakes that have no outlets and are fed by spring waters flowing over volcanic rocks containing sulfide minerals often yield soluble sulfide salts that are oxidized by contact with the air to produce sulfates. Some minerals over which the spring water may flow contain the sulfates directly, such as bentonite or gypsum. When an inland lake of this type evaporates and becomes highly concentrated in salts, one of the first salts to precipitate would be mirabilite, also known as Glauber's salt, which has very poor solubility at low temperatures. During seasonal temperature variations, the sulfate will precipitate preferentially to the lake bottom.

Thenardite and mirabilite are the only sodium sulfate minerals that are commercially important. Many economic deposits of sodium sulfate are in the form of crystalline beds of mirabilite such as those found in Canada and the U.S.S.R., which has the world's largest sodium sulfate resource in the Kara-Bogaz-Gol Gulf. Because mirabilite converts to thenardite when exposed to air, its outer surface may develop a thenardite crust. Some buried sedimentary formations contain very large deposits of thenardite and glauberite, such as the deposit in Villarrubia de Santiago in Spain.

Sodium sulfate is also found dissolved in underground brines in California, Texas, and other parts of the world. The sulfate is usually converted to mirabilite when extracted from the brine by mechanical refrigeration techniques.

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

TABLE 2

PRODUCERS OF NATURAL AND SYNTHETIC SODIUM SULFATE IN 1990

Product and company	Plant nameplate capacity (thousand metric tons)	Plant location	Source
Sodium sulfate, natural:			
Great Salt Lake Minerals & Chemicals Corp.	45	Ogden, UT	Salt lake brine.
North American Chemical Co.,[1] Westend plant	218	Trona, CA	Dry lake brine.
Ozark-Mahoning Co.[2]	141	Seagraves, TX	Do.
Total	404		
Sodium sulfate, synthetic:			
BASF	34	Lowland, TN	Rayon manufacture.
North American Rayon Corp.	14	Elizabethton, TN	Do.
Climax Chemical Co.	45	Hobbs, NM	Hydrochloric acid manufacture.
Courtaulds North America Inc.	45	La Moyne, AL	Rayon manufacture.
Cyprus Specialty Metals	16	Kings Mountain, NC	Lithium carbonate.
W. R. Grace & Co. Organic Chemicals Div.	8	Nashua, NH	Chelating agents.
Green Bay Packaging	10	Green Bay, WI	Byproduct.
Hoffman-La Roche Inc.	14	Belvidere, NJ	Ascorbic acid manufacture.
J. M. Huber	32	Etowah, TN	Silica pigment.
Do.	14	Havre de Grace, MD	Do.
Indspec Chemical Corp.	35	Petrolia, PA	Resorcinol manufacture.
Lithium Corp. of America	41	Bessemer City, NC	Lithium carbonate.
Occidental Chemical Corp.	109	Castle Hayne, NC	Sodium dichromate manufacture.
Public Service of New Mexico	6	Waterflow, NM	Fluegas desulfurization.
Teepak Inc.	6	Danville, IL	Cellulose manufacture.
Texaco Chemical Co.	3	Delaware City, DE	Fluegas desulfurization.
Total	432		
Grand total	836		

[1]Purchased Nov. 30, 1990, from Kerr-McGee Chemical Corp.
[2]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.

water in a vacuum crystallizer. After the second separation and drying, the crystals are about 98.2% sodium sulfate. Additional treatment can obtain a 99.3% purity. Major impurities remaining are sodium chloride, sodium carbonate, and boron.

In Texas, after the crystals are processed in rotary drum vacuum filters and washed, they are melted and dehydrated using mechanical vapor recompression evaporators, which are more energy efficient than triple effect evaporators or submerged gas burners. Final classifying, centrifuging, drying in rotary kilns, and screening converts the Glauber's salt to marketable anhydrous sodium sulfate of 99.7% purity.

Purification and dehydration procedures at the facility on the Great Salt Lake are similar to those of other sodium sulfate plants. The final product results in a purity between 99.5% to 99.7%.

Sodium sulfate is also produced as a byproduct of the production of ascorbic acid, boric acid, cellulose, chromium chemicals, lithium carbonate, rayon, resorcinol, and silica pigments. It is also recovered from certain flue gas desulfurization operations. The Mannheim and Hargreaves furnace processes also produce byproduct sodium sulfate. In the Mannheim furnace, salt and sulfuric acid are reacted to form hydrogen chloride (HCl) and sodium sulfate. The Hargreaves furnace produces HCl and sodium sulfate by the reaction of sulfur dioxide, sodium chloride, air, and water. The Mannheim process is the major method used in Europe, but its use in the United States has decreased considerably since less expensive methods to produce HCl became available.

Recycling.—Because of environmental concerns regarding sulfur emissions from pulp and paper mills, many Kraft pulpers were installing pollution abatement equipment to reduce sulfur losses in the pulping process. This will result in more sodium sulfate being recycled and less used in batch makeup solutions.

Byproducts and Coproducts

The brines of Searles Lake in California contain sodium sulfate as well as coproduct borax, potassium chloride, sodium chloride, and soda ash. The Great Salt Lake in Utah is a source of magnesium compounds, potassium sulfate, sodium chloride, as well as sodium sulfate. The brines in Texas do not yield any secondary products.

Some manufacturers of ascorbic acid, boric acid, cellulose, chromium chemicals,

TABLE 3

WORLD NATURAL SODIUM SULFATE RESERVES AND RESERVE BASE

(Million metric tons)

	Reserves	Reserve base[1]
North America:		
Canada	84	272
Mexico	165	227
United States	857	1,361
Total	1,106	1,860
Europe:		
Spain	180	272
U.S.S.R.	1,814	2,268
Total	1,994	2,540
Africa:		
Botswana	188	227
World total	[2]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]Data do not add to total shown because of independent rounding.

NOTE.—Resources of sodium sulfate are known to also exist in Antarctica, Argentina, Chile, India, Iran, Italy, Mongolia, Romania, the Republic of South Africa, and Turkey. Production of synthetic sodium sulfate is dependent on the supply and demand of the primary product.

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

FIGURE 1

PRODUCTION AND PROCESSING OF SODIUM SULFATE

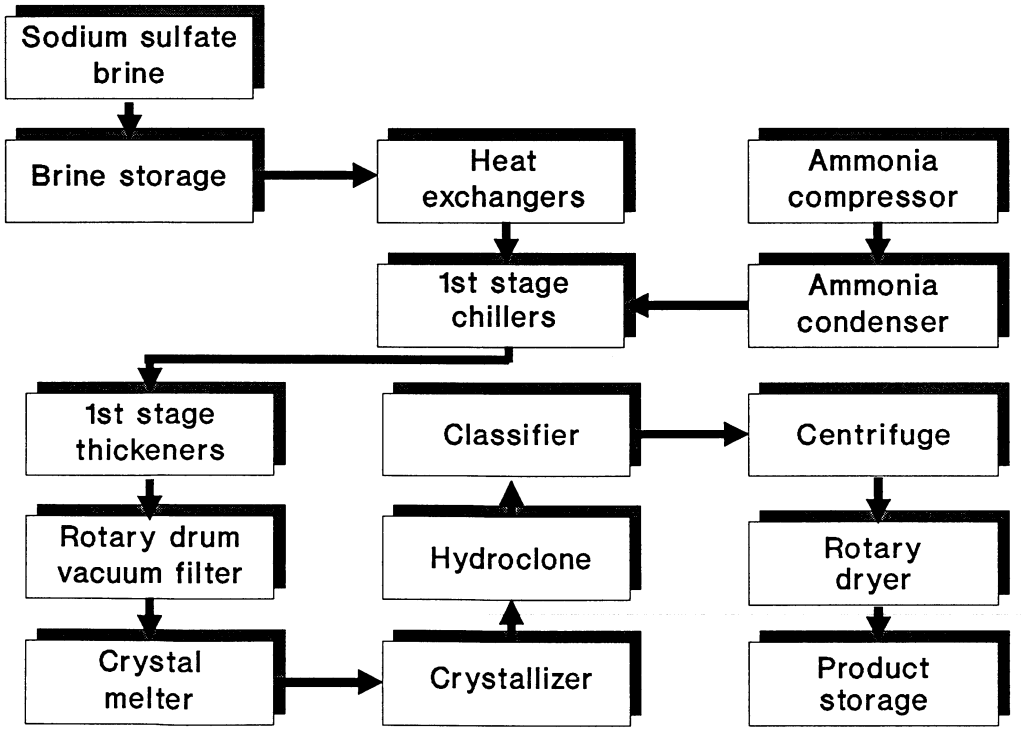


TABLE 4

TIME-VALUE RELATIONSHIPS FOR SODIUM SULFATE

Year	Average annual value,[1] dollars per ton			
	Natural sodium sulfate			
	Actual value		Based on constant 1990 dollars[2]	
	Short ton	Metric ton	Short ton	Metric ton
1970	18.28	20.15	57.23	63.09
1971	16.00	17.64	47.39	52.24
1972	16.26	17.92	45.98	50.68
1973	17.26	19.03	45.85	50.54
1974	23.99	26.44	58.42	64.40
1975	41.48	45.72	91.98	101.39
1976	49.25	54.29	102.64	113.14
1977	46.09	50.81	90.06	99.27
1978	46.06	50.77	83.89	92.47
1979	55.69	61.39	93.17	102.70
1980	62.42	68.81	95.78	105.58
1981	71.03	78.30	99.37	109.54
1982	83.00	91.49	109.15	120.32
1983	93.30	102.85	118.08	130.16
1984	92.16	101.59	112.53	124.04
1985	92.19	101.62	109.31	120.49
1986	86.11	94.92	99.50	109.68
1987	86.72	95.59	97.14	107.08
1988	78.81	86.87	85.44	94.18
1989	83.05	91.55	86.47	95.32
1990	87.66	96.63	87.66	96.63

[1]Based on the average valuation by producers of their annual total production and reported sales. The values incorporate the price differences charged by producers for the same finished product sold in bulk at the plant.
[2]From final 1990 implicit price deflators for gross national product, by the Council of Economic Advisors. Based on 1982 = 100.

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.

Tariffs.—Import tariffs serve to protect the interests of domestic producers for particular products. For sodium sulfate, a 32.5-cent-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 groundwater discharge problem in some areas. Reinjection of spent solutions into underground source strata is expensive but often is the only acceptable method of disposal.

Because sodium sulfate is water-soluble, most releases of sodium sulfate to the environment affect water quality rather than air or land quality. These releases are mainly from Kraft pulp mills, which typically discharge between 5 to 15 million kilograms (11 to 33 million pounds) of sodium sulfate per year per site. The resulting drinking water concentrations have been estimated as high as 38.8 milligrams per liter, which is significantly below the maximum concentration level of 250 milligrams per liter set by the National Secondary Drinking Water Standard.

Problems associated with chemical effluents discharged from manufacturing plants that recover sodium sulfate have also caused environmental concerns not attributed to sodium sulfate. The second largest byproduct sodium sulfate facility in the United States at Front Royal, VA, owned by Avtex Fibers Inc., was closed in late 1989 by Federal and State regulatory agencies because of contaminated water discharges containing carbon disulfide and polychlorinated biphenyls (PCB's). These toxic chemicals were produced from rayon manufacture, not sodium sulfate recovery.

Toxicity.—Sodium sulfate was deleted in early 1989 from the list of toxic chemicals under section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986. The U.S. Environmental Protection Agency determined that there was no evidence that sodium sulfate caused, or could reasonably be anticipated to cause, adverse human health or environmental effects as specified in the act.

Employment.—According to the Bureau of Labor Statistics and industry sources, approximately 300 persons are employed in mining and processing natural sodium sulfate in the United States. 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) were 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

U.S. production of sodium sulfate decreased about 3% in 1990, but overall domestic apparent consumption declined more than 9%. The downturn in production was attributed to depressed economic conditions that affected some of the industries that recover byproduct sodium sulfate and the effects of the shutdown of Avtex Fibers Inc. the previous year. 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 13% in 1990.

Issues

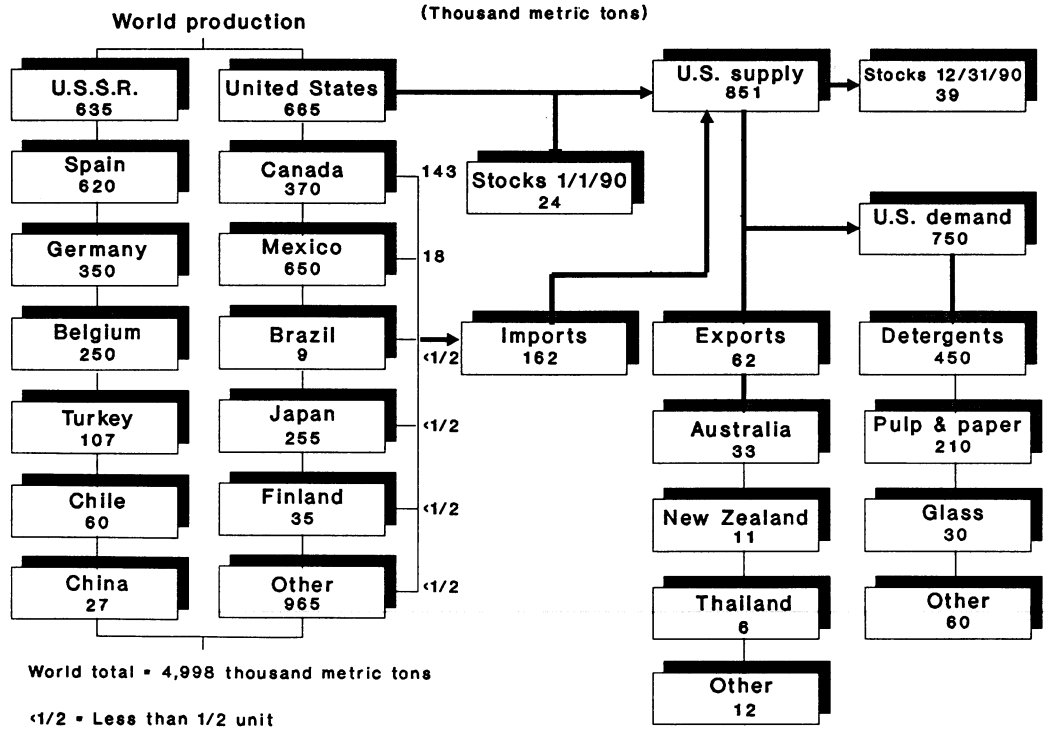
The soap and detergent industry, the largest consumer of sodium sulfate, began reformulating powdered home laundry detergents that substantially reduced the quanity of sodium sulfate used as filler. The growing national environmental awareness regarding the volume of packaging material discarded to landfills prompted certain detergent manufacturers to begin making superconcentrated or compact products that are packaged in smaller containers. This reduction in package size will minimize the amount of landfill waste but will also reduce the quantity of sodium sulfate used in powdered detergents.

The use of superconcentrates also has had a psychological affect on some of the public. Consumers traditionally have believed that adding more than the recommended quantity of powdered detergent to a washload would make clothes more cleaner. Although the technology to make superconcentrated detergents has existed for several years, detergent manufacturers could not counter the consumers' long-standing belief that "more is better." Interest in the environment has made it possible for detergent manufacturers to invoke this change in perception.

Sodium sulfate consumption by the pulp and paper industry remained firm despite all the publicity regarding the

FIGURE 2

SODIUM SULFATE SUPPLY-DEMAND RELATIONSHIPS, 1990



environmental effects of discharged pulp bleaching chemicals.

Production

U.S. production of sodium sulfate decreased about 3% in 1990 primarily because of the closure in 1989 of Avtex Fibers Inc., a rayon manufacturer in Front Royal, VA, that recovered byproduct sodium sulfate. Avtex was the second largest synthetic sodium sulfate producer in the United States with an annual production capacity of 77,000 tons.

North American Chemical Co., a company formed by a group of investors led by D. George Harris and Associates, purchased the Kerr-McGee Chemical Corp. sodium sulfate operation at Searles Lake in Trona, CA, for a reported $210 million in November 1990.[2] Oriental Chemical Industries of the Republic of Korea was one of the investors that acquired about 27% of the operation. In addition to sodium sulfate, the operation produces soda ash, salt, and various boron and potassium compounds. Harris and Associates was affiliated with Great Salt Lake Minerals and Chemicals Corp., which also produced natural sodium sulfate in Utah.

The United States was the largest producer of total sodium sulfate, representing about 13% of the world total, followed by Mexico and the U.S.S.R. with about 13% each; Spain, 12%; and Canada, 7%. These five countries accounted for approximately 58% of the world's output of total sodium sulfate, based on obtainable production data.

Consumption and Uses

Domestic consumption of sodium sulfate decreased about 9% because of environmental considerations, rather than economic conditions, affecting users of sodium sulfate. Imports for consumption of anhydrous sodium sulfate, primarily from Canada and Mexico, also declined.

About 60% 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

TABLE 5

SODIUM SULFATE SUPPLY-DEMAND RELATIONSHIPS[1]

(Thousand metric tons)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
WORLD PRODUCTION											
United States	1,033	1,008	784	776	791	736	763	725	r743	r685	665
Rest of World	3,498	3,693	3,337	3,306	3,611	3,773	r3,846	r4,075	r4,194	r4,324	e4,333
Total	4,531	4,701	4,121	4,082	4,402	4,509	r4,609	r4,800	r4,937	r5,009	e4,998
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic sources	1,033	1,008	784	776	791	736	763	725	r743	r685	665
Imports	209	249	357	311	240	177	171	125	136	173	162
Industry stocks, Jan. 1[2]	26	30	60	27	44	54	28	65	50	54	24
Total U.S. supply	1,268	1,287	1,201	1,114	1,075	967	962	915	r929	r912	851
Distribution of U.S. supply:											
Exports	117	112	101	83	69	108	101	111	77	62	62
Industrial demand	1,121	1,115	1,073	987	952	831	796	754	r798	r826	750
Industry stocks, Dec. 31[2]	30	60	27	44	54	28	65	50	54	24	39
U.S. DEMAND PATTERN[e]											
Glass	67	62	54	50	49	48	48	r45	r48	r33	30
Pulp and paper	538	508	490	464	454	445	r239	r226	r239	r231	210
Soaps and detergents	437	435	426	425	363	318	r414	r392	r415	r495	450
Other[3]	79	110	103	48	86	20	r95	r91	r96	67	60
Total U.S. primary demand	1,121	1,115	1,073	987	952	831	796	754	r798	r826	750
VALUES[4]											
Average annual value per short ton[5]	62.42	71.03	83.30	93.30	92.16	92.19	86.11	86.72	78.81	83.05	87.66
Average annual value per metric ton	68.81	78.30	91.49	102.85	101.59	101.62	94.92	95.59	86.87	91.55	96.63

[e]Estimated using data from "Chemical Profile" issues on sodium sulfate by Chemical Marketing Reporter for 1980, 1983, 1986, and 1989. [r]Revised.

[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]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.

[4]Dollars per ton for natural sodium sulfate, f.o.b. mine or plant.

[5]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)			Natural	
	Lower purity[3] (99% or less)	High purity	Total	Quantity	Value
1986	328	435	763	359	34,102
1987	312	414	[4]725	346	33,086
1988	r312	431	r743	361	31,377
1989	r291	r394	r685	340	31,104
1990	305	360	665	349	33,748

rRevised.
[1]All quantities converted to 100% Na_2SO_4 basis.
[2]Current Industrial Reports, Inorganic Chemicals, Bureau of the Census. Revisions from Dec. 1990 M28A, p. 1.
[3]Includes Glauber's salt.
[4]Data do not add to total shown because of independent rounding.

TABLE 7

SODIUM SULFATE YEAREND PRICES

(Per ton)

	1989	1990
Sodium sulfate (100% Na_2SO_4):		
East, bulk, carlot, works, freight equalized	$113.00–$114.00	$113.00–$114.00
Gulf, bulk, carlot, same basis	90.00– 100.00	105.00
West, bulk, carlot, same basis	117.00	122.00
Salt cake (100% Na_2SO_4):		
East, bulk, f.o.b. works	65.00– 98.00	62.00
West, same basis	90.00– 99.00	—

Sources: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials. v. 237, No. 1, Jan. 1, 1990, p. 39; and v. 238, No. 27, Dec. 31, 1990, p. 31.

33% of the U.S. population. In response to this environmental issue, detergent manufacturers continued reformulating 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 increased in the Kraft pulping industry because of the rise in demand for paper products and the high prices of caustic soda, which is an alternative to sodium sulfate when prices and availability are favorable. Kraft pulping represented about 83% of the domestic pulp market in 1990. 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 28% of the total demand for sodium sulfate.

Stocks

Yearend inventories of natural sodium sulfate stored by the three producers were 39,150 tons, which was a 63% 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

A tightness in supply owing to Avtex Fiber's closure in 1989 caused the prices of available bulk and bagged sodium sulfate to increase. The average value rose from $91.55 per metric ton ($83.05 per short ton) in 1989 to $96.63 per metric ton ($87.66 per short ton) for bulk sodium sulfate, f.o.b. mine or plant. Kerr McGee Chemical Corp. (purchased by North American Chemical Co. later in the year) raised its bulk list price $5 per ton to $122 in April. Ozark Mahoning increased its list price by $5 to $105 per ton also in April.[3] Prior Chemical Corp. and Ashland Chemical Inc., two major chemical distributors, raised the bulk list price of byproduct sodium sulfate by $5 in February and saltcake prices by $10 later in the year.

Foreign Trade

Canada and Mexico represented about 89% and 11%, respectively, of total U.S. imports of sodium sulfate. Although the United States had a net import reliance of about 13%, most imports were less expensive to consumers than products from domestic sources, especially when overland shipping costs are considered.

U.S. exports of 62,000 tons were virtually the same in 1990 when compared with those of the previous year. About 53% of the total quantity was shipped to Australia; New Zealand received 17%; Thailand, 10%; and Colombia, 7%. Most was in the form of low-purity salt cake.

World Review

Industry Structure.—Approximately 52% of the world sodium sulfate production in 1990 was from natural sources; the remainder was represented by synthetic sodium sulfate recovered from various chemical and manufacturing processes. Although the U.S. Bureau of Mines collects or estimates data from 28 sodium sulfate-producing countries, other countries are known or assumed to have produced synthetic sodium sulfate, but production statistics are not reported, and available information is inadequate to make reliable estimates of output.

Capacity.—The data in table 2 are rated capacities for domestic natural operations and byproduct recovering facilities in 1990. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a

TABLE 8

U.S. EXPORTS OF SODIUM SULFATE

(Thousand metric tons and thousand dollars)

Year	Disodium sulfate, salt cake[1]		Disodium sulfate, other[2]		Total[3]	
	Quantity	Value[4]	Quantity	Value[4]	Quantity	Value[4]
1986	97	8,218	5	1,965	101	10,183
1987	96	8,882	15	1,672	111	10,554
1988	62	5,128	15	3,609	77	8,737
1989	60	5,409	2	832	62	6,241
1990	61	6,092	1	612	62	6,704

[1]Prior to 1989, salt cake was Schedule B No. 4214200. In 1989, it was reclassified under the Harmonized Tariff System as HTS No. 2833111000.
[2]Prior to 1989, other sodium sulfate was Schedule B No. 4214500. In 1989, it is listed as HTS No. 2833115000.
[3]Data may not add to totals shown because of independent rounding.
[4]Customs, insurance, and freight (c.i.f.) value at U.S. ports.

Source: Bureau of the Census.

TABLE 9

U.S. EXPORTS 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)
1989:						
Australia	33,483	3,448,712	—	—	33,483	3,448,712
Belgium	—	—	5	1,633	5	1,633
Brazil	—	—	7	22,049	7	22,049
Canada	82	15,700	120	30,559	202	46,259
Cayman	—	—	2	3,522	2	3,522
Chile	—	—	1	3,809	1	3,809
China	—	—	17	23,834	17	23,834
Colombia	4,142	364,505	—	—	4,142	364,505
Costa Rica	—	—	2	3,454	2	3,454
Denmark	—	—	5	11,660	5	11,660
Dominican Republic	—	—	281	69,826	281	69,826
Guyana	—	—	32	3,903	32	3,903
Germany, Federal Republic of	—	—	314	5,123	314	5,123
Haiti	—	—	37	22,820	37	22,820
Hong Kong	72	7,469	13	4,600	85	12,069
Honduras	—	—	35	37,428	35	37,428
Indonesia	5,207	312,429	17	3,800	5,224	316,229
Israel	—	—	1	2,467	1	2,467
Italy	—	—	14	97,800	14	97,800
Jamaica	—	—	(4)	1,502	(4)	1,502
Korea, Republic of	105	13,650	—	—	105	13,650
Mexico	3,079	256,578	395	154,759	3,474	411,337
New Zealand	7,941	543,992	(4)	2,153	7,941	546,145
Panama	—	—	(4)	2,634	(4)	2,634
Philippines	35	8,549	27	20,870	62	29,419

See footnotes at end of table.

TABLE 9—Continued

U.S. EXPORTS 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)
1989—Continued						
Saudi Arabia	—	—	396	124,077	396	124,077
Singapore	—	—	1	2,608	1	2,608
Taiwan	—	—	42	134,987	42	134,987
Thailand	6,254	437,805	5	1,878	6,259	439,683
United Kingdom	—	—	18	13,137	18	13,137
Venezuela	—	—	7	10,902	7	10,902
Zimbabwe	—	—	16	13,935	16	13,935
Total	60,400	5,409,389	1,810	831,729	62,210	6,241,118
1990:						
Australia	32,628	3,468,288	—	—	32,628	3,468,288
Bahrain	—	—	9	19,358	9	19,358
Brazil	—	—	4	15,707	4	15,707
Canada	375	50,141	—	—	375	50,141
China	—	—	17	24,339	17	24,339
Colombia	4,418	246,519	—	—	4,418	246,519
Costa Rica	—	—	18	12,730	18	12,730
Denmark	—	—	5	11,660	5	11,660
Dominican Republic	—	—	138	40,721	138	40,721
France	—	—	4	17,280	4	17,280
Germany, Federal Republic of-	—	—	5	12,325	5	12,325
Hong Kong	—	—	47	61,458	47	61,458
Indonesia	—	—	30	24,000	30	24,000
Italy	—	—	9	63,318	9	63,318
Japan	—	—	15	21,025	15	21,025
Korea, Republic of	5,586	633,418	—	—	5,586	633,418
Mexico	334	35,802	249	84,000	583	119,802
Netherlands	—	—	1	3,759	1	3,759
New Zealand	10,585	946,663	—	—	10,585	946,663
Panama	70	12,125	—	—	70	12,125
Portugal	—	—	103	63,280	103	63,280
Singapore	420	43,560	27	33,016	447	76,576
Spain	—	—	1	3,306	1	3,306
Switzerland	—	—	6	4,222	6	4,222
Taiwan	—	—	181	77,734	181	77,734
Thailand	6,205	639,117	—	—	6,205	639,117
United Kingdom	—	—	16	18,661	16	18,661
Venezuela	160	16,496	—	—	160	16,496
Total	60,781	6,092,129	885	611,899	61,666	6,704,028

[1]Prior to 1989, salt cake was Schedule B No. 42114200. In 1989, it was reclassifed under the Harmonized Tariff System as HTS No. 2833111000.
[2]Prior to 1989, other sodium sulfate was Schedule B No. 4214500. In 1989, it is listed as HTS No. 2833115000.
[3]Free alongside ship (f.a.s.) value at U.S. ports.
[4]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF SODIUM SULFATE

(Thousand metric tons and thousand dollars)

Year	Disodium sulfate, salt cake[1 2]		Disodium sulfate, other[3]		Total[4]	
	Quantity	Value[5]	Quantity	Value[5]	Quantity	Value[5]
1986	29	1,885	142	11,944	171	$13,829
1987	34	2,189	92	8,173	125	10,363
1988	27	1,930	109	10,034	136	11,962
1989	41	3,350	132	10,641	173	13,990
1990	40	3,277	122	9,879	162	13,155

[1]Beginning in 1989, import data were reclassified under the Harmonized Tariff System. Salt cake is HTS No. 2833111000. In prior years, salt cake was under TSUSA No. 4214200.
[2]Includes Glauber's salt as follows: 1986—38 tons ($9,175); 1987—666 tons ($38,318); and 1988—604 tons ($16,963). TSUSA No. was 4214600.
[3]Harmonized Tariff System No. 2833115000 in 1989, changed to No. 2833115010 in 1990; TSUSA No. 4214400 for prior years.
[4]Data may not add to totals shown because of independent rounding.
[5]Customs, insurance, and freight (c.i.f.) value at U.S. ports.

Source: Bureau of the Census.

TABLE 11

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)
1989:						
Brazil	148	20,216	—	—	148	20,216
Canada	33,133	2,593,418	110,336	9,081,486	143,469	11,674,904
Germany, Federal Republic of	—	—	42	20,821	42	20,821
Japan	622	79,383	—	—	622	79,383
Mexico	1,120	104,690	21,313	1,538,228	22,433	1,642,918
Sweden	1	5,754	—	—	1	5,754
United Kingdom	6,003	546,185	—	—	6,003	546,185
Total	41,027	3,349,646	131,691	10,640,535	172,718	13,990,181
1990:						
Brazil	122	21,045	—	—	122	21,045
Canada	40,117	3,220,484	103,164	8,584,982	143,281	11,805,466
Finland	28	9,794	—	—	28	9,794
Germany, Federal Republic of	14	1,426	—	—	14	1,426
Ireland	1	5,447	—	—	1	5,447
Japan	40	18,407	—	—	40	18,407
Mexico	—	—	18,179	1,293,881	18,179	1,293,881
Total	40,322	3,276,603	121,343	9,878,863	161,665	13,155,466

[1]Beginning in 1989, import data were reclassified under the Harmonized Tariff System. Salt cake is HTS No. 2833111000. In prior years, salt cake was under TSUSA No. 4214200.
[2]Harmonized Tariff System No. 2833115000 in 1989, changed to No. 2833115010 in 1990. TSUSA No. 4214400 for prior years.
[3]Customs, insurance, and freight (c.i.f.) value at U.S. ports.

Source: Bureau of the Census.

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

TABLE 12

SODIUM SULFATE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989	1990[e]
Natural:					
Argentina	31,789	27,483	15,341	[r]10,281	11,000
Canada	370,726	342,076	[r]330,971	[r]369,500	370,000
Chile[3]	4,616	12,406	15,879	[r]10,000	10,000
China[e 4]	13,600	18,000	27,000	27,000	27,000
Egypt	18,940	42,484	[e]42,500	[r]45,677	45,000
Iran[e]	[r]123,000	[r]170,000	[r]214,000	[r]200,000	200,000
Mexico[5]	457,704	486,245	502,448	603,551	650,000
Netherlands[e]	18,000	22,000	22,000	22,000	22,000
South Africa, Republic of	466	241	[r]255	[r]15	20
Spain	450,911	475,255	[e]450,000	[e]450,000	460,000
Turkey[6]	[r]58,603	82,628	[r]79,427	[r e]80,000	80,000
U.S.S.R.[e 7]	345,000	365,000	375,000	365,000	365,000
United States	359,260	346,140	361,345	339,761	[8]349,256
Total	[r]2,252,615	[r]2,389,958	[r]2,436,166	[r]2,522,785	2,589,276
Synthetic:					
Austria[e]	55,000	109,000	118,000	120,000	120,000
Belgium[e]	265,000	260,000	255,000	255,000	250,000
Brazil[e]	7,000	7,000	9,000	9,000	9,000
Chile[9]	54,084	48,000	[r]47,000	[r]51,000	50,000
Finland[e]	35,000	35,000	35,000	35,000	35,000
France[e]	110,000	115,000	154,000	155,000	120,000
Germany, Federal Republic of:					
Eastern states	181,000	179,000	180,000	[e]175,000	175,000
Western states	163,000	164,000	[e]168,000	[e]175,000	175,000
Greece[e]	8,000	7,000	7,000	7,000	7,000
Hungary[e]	9,000	9,000	9,000	9,000	9,000
Italy[e]	75,000	80,000	127,000	130,000	130,000
Japan	253,450	255,313	246,541	[r]256,393	255,000
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]	52,000	55,000	54,000	55,000	55,000
Spain[e 10]	150,000	165,000	165,000	165,000	160,000
Sweden[e]	100,000	100,000	100,000	100,000	100,000
Turkey[e]	27,000	27,000	27,000	27,000	27,000
U.S.S.R.[e 7]	260,000	260,000	270,000	270,000	270,000
United Kingdom[e]	90,000	90,000	90,000	90,000	90,000
United States[11]	403,662	391,541	[r]381,517	[r]345,555	[8]315,604
Yugoslavia	42,581	37,556	41,479	[e]40,000	40,000
Total	2,356,777	2,410,410	[r]2,500,537	[r]2,485,948	2,408,604
Grand total	[r]4,609,392	[r]4,800,368	[r]4,936,703	[r]5,008,733	4,997,880

[e]Estimated. [r]Revised.

[1]Table includes data available through Apr. 19, 1991.

[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]Series revised to show output as reported in the Annuario Estadstico de la Industria Quimica Mexicana, 1990 edition.

[6]Reported as concentrate. Run-of-mine production reported as, in metric tons: 1986—160,992; 1987—285,182; 1988—290,579; 1989—290,000 (estimated); and 1990—290,000 (estimated).

[7]Conjectural estimates based on 1968 information on natural sodium sulfate and general economic conditions.

[8]Reported figure.

[9]Byproduct of nitrate industry.

[10]Quantities of synthetic sodium sulfate credited to Spain are reported in official sources in such a way as to indicate that they are in addition to the quantities reported as mined (listed under "Natural" in this table), but some duplication may exist.

[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).

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.—Tonolli Canada Ltd. of Mississauga, Ontario, announced plans to recover sodium sulfate at its battery recycling operation. About 7,000 tons per year of high-purity sodium sulfate would be produced from spent sulfuric acid from the batteries.

Norway.—After the acquisition of Stora Kemi and Rana Kjemi in 1989, Eka Nobel commenced production at its new sodium sulfate facility at Mo i Rana. The plant has an annual production capacity of 25,000 tons. Access to inexpensive electrical energy was one important reason to construct the facility.[4]

OUTLOOK

Sodium sulfate production and consumption declined 36% and 33%, respectively, from those of 1980 to 1990. 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.

Less expensive imports from neighboring countries will continue to serve an important part of the needs of the domestic detergent and pulp and paper industries. Foreign producers dependent on sales to the United States may, however, encounter financial strain as domestic markets shrink. Canada, and possibly Mexico, may be affected by the declining demand for sodium sulfate within the United States. This could allow for more U.S. product to be produced and consumed within the United States.

Detergents

The use of sodium sulfate as a filler appears to have peaked in 1989. In 1990, major detergent manufacturers began reformulating to make superconcentrated detergent products rather than the traditional large boxes filled with bulk detergents containing up to 20% sodium sulfate as filler. This sudden change, initiated by environmental considerations, will further reduce sales of sodium sulfate in the near future unless consumers do not purchase the more-expensive superconcentrate detergents because of the higher cost. In addition, liquid laundry detergents that do not contain any sodium sulfate make up about 40% of the home laundry market.

Pulp and Paper

The economic recession that began in late-1990 had a slight affect on sodium sulfate sales to the pulp and paper sector, resulting in reduced sodium sulfate consumption. Environmental concerns regarding sulfur emissions prompted many Kraft pulpers to install pollution control equipment to reduce sulfur losses in the pulping process. One procedure using bipolar membranes recycles sodium sulfate and converts it to sulfuric acid and caustic soda, which was in short supply and expensive. The technology, developed by Allied-Signal Inc., has application in many pulp mills throughout the world.[5] Widescale use of this process may adversely affect the demand for sodium sulfate in the near future.

The paper industry has responded to the growing international environmental awareness by implementing alternate pulp bleaching technology. The pulp producers have been investigated for discharging carcinogenic wastewater effluents that contain certain dioxins and furans into the environment. Oxygen-based chemicals, such as sodium chlorate and hydrogen peroxide that are environmentally safe, are alternative pulp bleaching chemicals that may lessen the need for additional makeup sodium sulfate because the process generates byproduct sodium sulfate in the pulp liquor. Losses in sodium sulfate consumption may be partially offset by gains in sodium sulfate sales if the prices of caustic soda, which is an alternate pulping chemical, continues to increase, as many industry analysts forecast.

[1]Chemical and Engineering News. Facts and Figures for the Chemical Industry. V. 68, No. 25, p. 37.

[2]Chemical Week. Kerr-McGee Sells Soda Products Business for $210 Million. V. 147, No. 24, p. 17.

[3]Chemical Marketing Reporter. Sodium Sulfate Is Healthy Despite Contracting Market. V. 238, No. 12, p. 32.

[4]European Chemical News. Na_2SO_4 Startup. V. 55, No. 1445, p. 9.

[5]Chemical Marketing Reporter. Allied Sulfate Recycler To Be Marketed by Ahlstrom. V. 237, No. 24, p. 9.

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Sodium Sulfate Deposits, Industrial Minerals and Rocks, Society of Mining Engineers, 5th ed., Vol. 2, 1983, pp. 1207–1223.

CRUSHED STONE

By Valentin V. Tepordei

Mr. Tepordei, a geological engineer with more than 20 years industry experience, has been the crushed stone commodity specialist with the U.S. Bureau of Mines since 1981. Domestic survey data were prepared by the crushed and broken stone survey staff of the Branch of Data Collection and Coordination.

Crushed stone is one of the most accessible natural resources and a major basic raw material used by a wide range of industries from construction to agriculture, chemicals, and complex industrial processes. Despite the relative low-value of its basic products, the crushed stone industry is a major contributor to and an indicator of the economic well-being of the Nation.

A total of 1.2 billion short tons of crushed stone was estimated to have been produced for consumption in the United States in 1990, a slight increase compared with the 1989 total. This tonnage represents the fourth consecutive year of production of more than 1.2 billion tons, indicating a continuation of the strong demand for construction aggregates. 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.

Foreign trade of crushed stone remained relatively minor. Exports increased 30.8% to 5.1 million tons, while value increased 77.3% to $41.4 million. Imports of crushed stone, including calcium carbonate, increased 14.1% to 5 million tons, while the value decreased 4.2% to $35.3 million. Domestic apparent consumption of crushed stone was 1.2 billion tons.

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. The new regulatory requirements being proposed by the Occupational Safety and Health Administration (OSHA) continue to be the other areas of concern for the industry. They include the revised asbestos standards governing occupational exposure to nonasbestiform varieties of actinolite, tremolite, and anthophyllite minerals and the final promulgation of the permissible exposure limit for crystalline silica measured as respirable silica.

DOMESTIC DATA COVERAGE

Domestic production data for crushed stone are developed by the U.S. Bureau of Mines from voluntary surveys of U.S. producers. Full surveys of crushed stone producers are conducted for odd-numbered years only. For even-numbered years, only annual estimates for each State are generated based on information provided by the new quarterly sample survey of crushed stone and sand and gravel producers. This survey provides production estimates by quarters for each State and the nine geographic regions. The sample survey canvasses most of the large companies in each State, accounting for up to 80% of the State's total tonnage. The results of this survey are published each quarter in a separate publication, the Quarterly Mineral Industry Survey.

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. Workers 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 labor 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

TABLE 1

SALIENT U.S. CRUSHED STONE STATISTICS

		1986	1987	1988	1989	1990
Sold or used by producers:						
Quantity[1]	thousand short tons	e1,023,200	1,200,100	e1,247,800	1,213,400	e1,222,000
Quantity	thousand metric tons[2]	928,232	1,088,713	1,131,985	1,100,778	1,108,580
Value[1]	thousand dollars	e$4,255,000	$5,248,600	e$5,558,000	$5,325,800	e$5,591,300
Exports value	do.	$36,957	$26,063	$30,413	$23,345	$32,573
Imports[3] value	do.	$12,451	$14,024	$16,789	$36,870	$75,604

eEstimated.
[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.

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 from Scotland, 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 the American Association of State Highway and Transportation Officials. 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 ⅜- to 2½-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 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 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 trap-rock 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 31 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 1989, the last year when a complete survey of the crushed stone producers was conducted, 1,716 companies produced crushed stone from about 3,416 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 1989, for example, 86 operations each reporting production of more than 2 million tons per year represented only 2.3% of the total number of operations but accounted for 22% of total crushed stone production. The large operations are owned or operated by a small number of companies. In 1989, the combined production of the top 10 producers operating 477 quarries accounted for 27.8% of the total output of crushed stone in the United States. The 10 leading producers were Vulcan Materials Co., Beazer USA Inc., Martin Marietta Aggregates, Tarmac America Inc., Dravo Corp., General Dynamics Corp., The Rogers Group Inc., Lone Star Industries Inc., Genstar Stone Products Inc., and Florida Rock 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 lockup sufficient reserves or

expand into the aggregate business. Some of the recent acquisitions were made by foreign companies or were associated with the influx of foreign capital. Two of the top five crushed stone-producing companies in 1989 are subsidiaries of foreign companies.

The United States is the largest producer of crushed and broken stone among the market economy countries. Other major producing countries are Australia, Canada, France, the Federal Republic of 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 they occur in restricted areas, mostly in the eastern part of the United States, with some formations in the Western States as well.[9] High-purity dolomite deposits are more limited in occurrence than the high-calcium limestone. Of the clastic sedimentary rocks that are produced through mechanical sedimentation, only sandstones, rocks consisting predominantly of cemented sand-size particles, are, to a limited extent, used as crushed stone.

Igneous rocks, rocks that solidify from molten volcanic magma, are classified as intrusive and extrusive rocks. Intrusive or plutonic rocks are those that were formed deep beneath the ground surface, are coarse grained, and include granite, diorite, and gabbro as rock types. Extrusive or volcanic rocks are igneous rocks that were formed from molten volcanic magma at the Earth's surface, are fine grained, and include andesite, rhyolite, and basalt. Plutonic and volcanic rocks are further subdivided on the basis of mineralogy in light-colored igneous rocks with high-silica content that 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 where needed. Reserves, which are measurable amounts of crushed stone that can be produced profitably with current technology under existing economic and political conditions, are controlled mostly by land use and/or environmental constraints. The actual volume of stone available is so vast as to preclude the necessity of measurement on a large scale. The local shortages that occasionally exist are caused less by a lack of stone than by urban encroachment or zoning regulations that force closure of operating quarries or prevent the development of new ones.

Technology

Major technological developments have been instrumental in maintaining adequate production at relatively stable real costs in the crushed stone industry. Equipment manufacturers usually conduct most of the research related to improvements in the mining and processing of crushed stone operations. Larger, more efficient equipment is being developed and improved constantly. The use of computerized control systems in plant operation and quality control has increased significantly in recent years. Automatic controls, along with monitoring by closed-circuit television coordinated with automated counting and recording and radio communications systems, have been installed in many of the larger and newer operations. Automated plants have significantly improved operating efficiency and produce the optimal product mixture to fit market requirements at lower cost.

As part of the national drive to reduce air pollution, significant progress is being made toward the desulfurization of stack gases resulting from coal burning electric generating stations and some industrial installations.[11] Limestone and lime are used as chemically reactive agents in most of the dry- or wet-scrubbing processes as well as in the treatment of acidified waters, specifically lakes and streams.

Exploration.—A large number of geologic formations that have economic potential as a source of crushed stone have been mapped and described in the literature over the years. Consequently, detailed exploration and development work for any new crushed stone operation will most probably be done on one of these formations. However, in the event that a new stone deposit is discovered, more exploration and evaluation work would be required before development. Preliminary examination can establish the extent and nature of the deposit. This is followed by a detailed exploration program aimed at obtaining reasonably accurate information about the quality of the available material, including the kind of stone, its chemical composition and degree of ce-

mentation, 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 (AN-FO) mixtures, 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 load-out bins. In the more efficient plants, the crushed stone is transported from the storage piles on belt conveyors through tunnels installed under the piles, thus facilitating the blending of any desired mixture of sizes from different piles.

Recycling.—As the Nation moves into an age of increased environmental consciousness, recycling of old concrete and asphalt, used mostly in pavements, is increasing. Local scarcity or high cost of construction aggregates in some areas as well as waste disposal problems are making recycling more attractive economically. In some States, limited recycling, especially in road construction, is either encouraged or required by law. The best utilization for recycled cement concrete is as road base material, because the matrix of concrete cannot be converted back to cement, and also because of the lower strength of concrete compared with that of natural aggregates. Sound crushed concrete can make good coarse aggregate, but the fines produced in crushing the concrete have a higher absorption, are more friable, and will require a higher amount of asphalt in asphaltic concrete and a higher amount of mixing water in portland cement.[12]

The amount of asphalt roads recycled is significantly larger than that of concrete roads, mainly because asphalt can be rejuvenated with oil additives and used in pavements, significantly reducing the cost of the finished road. Experience has shown that about 35% of crushed asphalt pavement can be recycled into new asphalt

mixtures. Proper testing under engineering supervision in all construction projects using recycled materials as aggregates should be performed to ensure that the technical specifications are met.

Byproducts and Coproducts

Clay of good quality is sometimes encountered in limestone overburden and is mined as a coproduct. Gypsum is often encountered beneath beds of limestone and is mined as a coproduct. Amphibolite rock often occurs as formations paralleling spodumene-bearing pegmatitic dikes and is mined concurrently with these, notably in North Carolina. This coproduct of lithium mining is marketed primarily as roadstone. Stone is also mined in conjunction with many metallic ores and nonmetallic minerals, but seldom does a market exist for it.

Economic Factors

Crushed stone is a high-volume, low-value commodity. The industry is highly competitive and is characterized by thousands of operations serving local or regional markets, largely because stone is an abundant mineral. Production costs are determined mainly by the cost of labor, equipment, energy, and water, in addition to the costs of compliance with environmental and safety regulations. These costs vary depending on geographic location, the nature of the deposit, and the number and type of products produced. Despite having one of the lowest average per ton values of all mineral commodities, the constant dollar price of crushed stone has changed relatively little over the past 20 years. As a result of rising costs of labor, energy, and mining and processing equipment, the average unit price of crushed stone increased from $1.58 per ton, f.o.b. plant, in 1970 to $4.39 in 1990. However, the unit price in constant 1982 dollars fluctuated between $3.48 and $3.91 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.

TABLE 2

TIME-PRICE RELATIONSHIP FOR CRUSHED STONE

Year	Actual unit price	Unit price in 1982 constant dollars
1971	$1.72	$3.87
1972	$1.72	$3.70
1973	$1.80	$3.64
1974	$2.00	$3.70
1975	$2.24	$3.78
1976	$2.35	$3.72
1977	$2.47	$3.67
1978	$2.64	$3.66
1979	$2.99	$3.80
1980	$3.32	$3.87
1981	$3.58	$3.81
1982[e]	$3.69	$3.69
1983	$3.87	$3.72
1984[e]	$3.93	$3.65
1985	$4.05	$3.65
1986[e]	$4.16	$3.66
1987	$4.37	$3.91
1988[e]	$4.37	$3.60
1989	$4.39	$3.48
1990[e]	$4.58	$3.48

[e]Estimated.

Environmental Requirements.—Many of the environmental problems facing crushed stone producers arise because a great number of stone quarries and processing plants are located 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 pro-

ducers is becoming a necessity that may require sophisticated and expensive processing methods. Significant progress has been made in reducing noise pollution both inside and outside of the quarries, including noise and vibration produced by blasting and movement of heavy trucks. Therefore, the industry must be concerned first about any practices that can affect the community environment. An effective effort must be made to reduce noise, air, and water pollution and to improve the overall appearance of the operating mine, processing plant, and transportation facilities. Second, the industry and community must recognize the time and costs required to protect the environment and the importance of agreeing on fair and realistic environmental standards. Because crushed stone is a local industry, the effect of supply deficiencies and cost of material will affect the local community first. Undue delay and unreasonably high cost can strongly affect the movement of crushed stone into the marketplace. Also, stringent controls by the local governments that prevent permits being issued to operators can have adverse economic effects on the communities around them. These conditions can make it difficult to assess the timing and even the possibility of plants going on-stream and can therefore affect the supply of crushed stone into the marketplace.

Although much progress is being made through premining planning, the crushed stone industry continues to have problems with environmental controls, land use conflicts, and reclamation practices. Many of these problems are acute because extraction areas and plants must be reasonably near to consumers who are largely in metropolitan areas.

Transportation.—Transportation is a major factor in the delivered price of crushed stone. The cost of moving crushed stone from the plant to the market often equals or exceeds the sales price of the product at the plant. Because of the high cost of transportation and the large quantities of bulk material that have to be shipped, crushed stone is usually marketed locally. The high cost of transportation is responsible for the wide dispersion of quarries around the country, usually located 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 fleets 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 7% to 10% 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 them are self-unloading vessels.

ANNUAL REVIEW

In 1990, the crushed stone industry reached the second highest production level ever recorded and the fourth consecutive year of production of more than 1.2 billion tons. This high level of production indicate a continuation of the strong demand for construction aggregates. Production increased significantly in the first quarter of 1990, compared with the same period of 1989, decreased slightly in the second and third quarters, and increased again in the fourth quarter.

Legislation and Government Programs

On November 15, 1990, the U.S. Congress enacted the 1990 Amendments to the Clean Air Act of 1970 (Public Law 101-549). Most of the regulatory programs and air quality standards established by the original Clean Air Act of 1970 were revised and new provisions were promulgated. The new clean air law contains eleven parts covering: National Ambient Air Quality Standards; Mobile Sources; Hazardous Air Pollutants; Acid Rain Control; and Stratospheric Ozone Protection. The new law will be implemented through rules written by the Environmental Protection Agency (EPA) and laws passed by the States. The standard for measuring the amount of solid or liquid "particulate" matter suspended in the atmosphere (PM-10) and the designation of PM-10 noncompliance areas, the new system of operating permits, and the enforcement and review of air pollutant emission factors are areas that will have an impact on the crushed stone industry.

On October 28, 1990, the U.S. Congress approved the Department of Transportation's Appropriation bill that increased funding for the Federal highway and airport programs. The Federal Highway Program increased from a total of $13.5 billion in the fiscal year 1990 to $16 billion in fiscal year 1991. The Airport Improvement Program increased from $1.4 billion in fiscal year 1990 to $1.8 billion in fiscal year 1991. The U.S. Congress also approved the Omnibus Budget Reconciliation Act of 1990, which increased the Federal motor fuels taxes by 5 cents, divided 50-50 between the General Revenue Fund and the Highway Trust Fund.

On February 7, 1990, the EPA and the U.S. Army Corps of Engineers (USACE) signed a revised Memorandum of Agreement (MOA) intended to clarify the policies and procedures to be used by their field personnel in determining compliance with the provisions of the section 404 of the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, dealing with "wetlands." A Wetland Delineation Manual developed by the EPA, the USACE, the U.S. Department of Agriculture, and the U.S. Fish and Wildlife Service was published with the intent to bring consistency to the definition process of wetlands for Federal regulatory purposes.

On February 12, 1990, OSHA issued a notice of proposed supplemental rulemaking on its standards, issued June 17, 1986, governing Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite (AT&A)[13] for industry in general and the construction industry in particular. An administrative stay of enforcement of the standards was extended until November 1990 to provide time to complete this supplemental rulemaking. The former asbestos standard remains in effect for the extent of the stay. Based on available information, OSHA believes that there is insufficient evidence to conclude that exposure to nonasbestiform AT&A mineral fragments presents a risk similar in magnitude or type to fibers of their asbestiform counterparts. Therefore,

OSHA proposed that nonasbestiform AT&A minerals should no longer be regulated in the same way as asbestos, either under the 1972 asbestos standard or under the revised asbestos standard. Public hearings on the proposed supplemental rulemaking were held on May 8, 1990, at the Labor Department, in Washington, DC. After reviewing the notice of proposed rulemaking regarding the Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite, the Department of the Interior informed OSHA that it "recommends that OSHA deal with asbestos and AT&A as separate issues, introduce a mineralogical definition of asbestos into the asbestos regulation, and initiate a separate rulemaking for AT&A because of the potential impact on the mining and minerals industries, the uncertainty in the health risks, and the lack of exposure data and health studies in the consuming industries."[14]

Issues

The implementation of the provisions of the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, Section 404, dealing with "wetlands" and the establishment of a "no net loss of wetlands" policy constitutes one of the major areas of concern to the crushed stone industry. There is a significant amount of uncertainty regarding the process of designating some lands as wetlands, and whether the current exemptions to the Clean Water Act Section 404 permit program will be maintained in the future. The many criticisms of the current wetland regulatory process include the following: it fails to cover activities that are destructive to wetlands; it ignores basic, fundamental rights of private property owners; and covers privately owned lands that provide minimal wetland functions and values. Several bills were introduced in the 102nd Congress to replace the current Section 404 of the Federal Water Pollution Control Act. The new proposed bills plan to provide a concise and structured program for the delineation of wetlands based upon their functions and values, and will balance the need for effective protection of the Nation's important wetlands with the need for essential community growth and the constitutional rights of landowners.

The regulatory requirements being proposed by the Occupational Safety and Health Administration (OSHA) continue to be the other areas of concern for the industry. They include the revised asbestos standards governing occupational exposure to nonasbestiform varieties of actinolite, tremolite, and anthophyllite minerals, and the final promulgation of the permissible exposure limit for crystalline silica measured as respirable silica. The revised OSHA regulations for airborne asbestos standards, if implemented, are expected to have a significant impact on the aggregates and the construction industries that could include increased mining and construction costs and disruption of the supply of aggregates in most areas.

Although progress is being made toward better cooperation between the aggregates industry and the local communities in most parts of the country, problems still exist in other areas. An attempt was made in 1990 in Colorado to amend the State constitution and prohibit surface mining of aggregates in the Front Range mountains within view of six major cities, Colorado Springs, Denver, Manitou Springs, Boulder, Pueblo, and Fort Collins, and in various other parts of the State. The amendment would have allowed local governments to adopt and enforce their own reclamation and bonding requirements for aggregate mines. The proposed amendment was challenged in the State Supreme Court and due to the delay caused by the challenge, backers of the amendment could not gather in time the number of signatures required to place the issue on the November 1990 ballot. Backers of the proposed amendment plan to have it included in the Colorado's 1992 general elections.

Production

A total of 1.2 billion short tons of crushed stone was estimated to have been produced for consumption in the United States in 1990, a 0.7% increase compared with the 1989 total. This tonnage was the second largest production ever recorded in the United States and the fourth consecutive year of production over 1.2 billion tons. 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 1990 the output of crushed stone increased in all geographic regions except New England, Mountain, and the Pacific regions. The South Atlantic region continued to lead the Nation in the production of crushed stone with an estimated 311 million tons or 25.4% of the U.S. total, followed by the East North Central region with 218 million tons or 17.8%, and the Middle Atlantic region with 157 million tons or 12.8%.

A comparison of the reported 1989 and estimated 1990 production for consumption data indicates that the largest increases occurred in the West North Central region, 8.9%; East South Central region, 6.0%; and East North Central region, 3.0%. The largest decreases in the production for consumption occurred in the Pacific region, -17.0%; New England regions, -11.5%; and South Atlantic region, -1.8%. The estimated production for consumption by quarters for 1990 indicates that most of the crushed stone in the United States was produced in the third quarter of 1990, followed by the second quarter and the fourth quarter.

Crushed stone was produced in every State except Delaware. The 10 leading States in the production of crushed stone, in decreasing order of volume, were Pennsylvania, Texas, Florida, Illinois, Virginia, Tennessee, Missouri, Georgia, North Carolina, and Kentucky. Their combined production represented 52.2% of the national total.

Changes in ownership, acquisitions by foreign or domestic companies, and mergers continued in the crushed stone industry. In January 1990, Colonial Sugar Refineries (CSR) Ltd. of Sydney, Australia, completed the acquisition of ARC America Corp. of Newport Beach, CA, and all its subsidiaries. The transaction included American Aggregates Co. of Greenville, OH, Associated Sand and Gravel Co. of Everett, WA, and WMK Co. of Las Vegas, NV, as well as Hydro Conduit, a large producer of concrete pipes with operations in Florida and most of the Western States. The acquisition added 48 aggregates operations located in six States and 40 concrete pipe plants in 20 States to CSR holdings. CSR owns Rinker Materials Corp. of West Palm Beach, FL, since 1988.

In midyear, C. H. Beazer PLC, of Bath, United Kingdom, reorganized its

TABLE 3

CRUSHED STONE SOLD OR USED IN THE UNITED STATES, BY KIND

Kind	1985				1987				1989			
	Number of quarries	Quantity (thousand short tons)	Value (thousands)	Unit value	Number of quarries	Quantity (thousand short tons)	Value (thousands)	Unit value	Number of quarries	Quantity (thousand short tons)	Value (thousands)	Unit value
Limestone[1]	2,316	685,002	$2,618,621	$3.82	2,496	792,448	$3,249,713	$4.10	2,533	806,644	$3,234,317	$4.01
Dolomite	87	31,348	133,271	4.25	119	48,656	206,904	4.25	136	49,304	216,957	4.40
Marble	22	2,437	20,439	8.39	51	5,576	62,335	11.18	63	12,222	137,481	11.25
Calcareous marl	14	3,959	8,083	2.04	16	4,154	7,650	1.84	15	5,118	11,614	2.27
Shell	17	9,106	37,951	4.16	19	8,402	51,028	6.07	18	6,923	34,794	5.03
Granite	580	145,254	669,807	4.61	735	179,972	900,682	5.00	376	168,433	864,962	5.14
Traprock	644	83,548	388,027	4.64	813	103,413	505,187	4.89	446	99,161	524,271	5.29
Sandstone and quartzite	378	23,148	103,483	4.47	523	32,495	157,934	4.86	241	31,842	148,696	4.66
Slate	7	773	3,758	4.86	10	2,330	14,258	6.12	7	2,088	12,926	6.19
Volcanic cinder and scoria	256	2,953	12,504	4.23	359	3,657	14,952	4.09	118	3,630	20,206	5.57
Miscellaneous stone	81	13,269	56,875	4.29	304	19,027	77,954	4.10	110	28,065	119,538	4.26
Total[2]	XX	1,000,800	4,053,000	4.05	XX	1,200,100	5,248,600	4.37	XX	1,213,400	5,325,800	4.39

XX Not applicable.
[1]Includes "Limestone and/or dolomite," reported with no distinction between the two.

TABLE 4

CRUSHED STONE[1] SOLD OR USED IN THE UNITED STATES, BY REGION

(Thousand short tons and thousand dollars)

Region	1989		1990[e]	
	Quantity	Value	Quantity	Value
Northeast:				
New England	30,172	195,607	26,700	178,900
Middle Atlantic	154,421	801,476	156,900	847,300
Midwest:				
East North Central	211,579	787,107	217,900	849,800
West North Central	112,631	407,125	122,700	466,300
South:				
South Atlantic	316,306	1,497,971	310,700	1,584,600
East South Central	134,482	614,623	142,600	656,000
West South Central	125,995	448,560	127,400	471,400
West:				
Mountain	32,166	131,292	31,700	130,000
Pacific	95,679	442,001	81,600	427,500
Total[2]	1,213,400	5,325,800	[3]1,222,000	5,591,300

[e]Estimated.
[1]Includes volcanic cinder and scoria.
[2]Data may not add to totals shown because of independent rounding.
[3]To avoid disclosing company proprietary data, certain State totals do not include estimates for all kinds of stone produced within the State; the amount not shown has been included with U.S. total.

American subsidiaries in two separate companies. All Beazer operations located west of the Mississippi, including Gifford-Hill & Co. operations, became Beazer West Inc. of Dallas, TX, while Beazer Materials and Services of Pittsburgh, PA, and all its operations east of the Mississippi became Beazer East Inc.

The Rogers Group Inc. of Nashville, TN, acquired the assets of Billy Holloway Ag-gregates of Louisville, KY, that included two quarries at Avoca and Fern Creek, TN. In addition, the new Rogers Group affiliate, Billy Holloway Ready Mix of Louisville, KY, and American Builders Supply, of Louisville, KY, an affiliate of Sibo Services Inc. of Louisville, KY, formed a joint venture that will operate under the name of American Builders Supply, a Rogers Group company. Sibo Services Inc. is a holding company with assets in aggregates and concrete in Kentucky and Indiana, a subsidiary of Sibo Gruppe, Dyckerhoff Cement Co., Hans Sievert A.G. & Co., Oppermann Sand and Gravel, and Homann Co., all of Germany.

TABLE 5

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1990, BY QUARTER AND REGION

(Thousand short tons and thousand dollars)

Region	Quantity					Value total	Percent coverage	Number of companies[1]
	1st quarter	2d quarter	3d quarter	4th quarter	Total			
Northeast:								
New England	1,600	7,700	10,200	7,200	26,700	$178,900	54	24
Middle Atlantic	22,600	43,300	49,400	41,600	156,900	847,300	63	38
Midwest:								
East North Central	27,100	60,100	70,100	60,600	217,900	849,800	69	45
West North Central	19,200	33,400	40,000	30,100	122,700	466,300	49	41
South:								
South Atlantic	72,700	88,000	78,200	71,800	310,700	1,584,600	77	45
East South Central	28,600	37,800	43,100	33,100	142,600	656,000	72	21
West South Central	26,800	32,300	34,700	33,600	127,400	471,400	61	35
West:								
Mountain	4,300	7,900	11,300	8,200	31,700	130,000	51	30
Pacific[2]	17,100	17,300	19,700	17,800	71,900	352,300	44	27
Total[3]	219,900	327,700	356,600	304,100	[4]1,222,000	[4]5,591,300	XX	XX

XX Not applicable.

[1]Number of companies reporting for the quarterly survey.

[2]Does not include Alaska and Hawaii.

[3]Data may not add to totals shown because of independent rounding and differences between projected totals by States and by regions.

[4]Includes Alaska, Hawaii, and "Other" totals; these totals represent preliminary estimates and, therefore, do not equal the final totals resulting from the annual survey.

FIGURE 1

PRODUCTION OF CRUSHED STONE IN THE UNITED STATES IN 1990, BY GEOGRAPHIC REGION

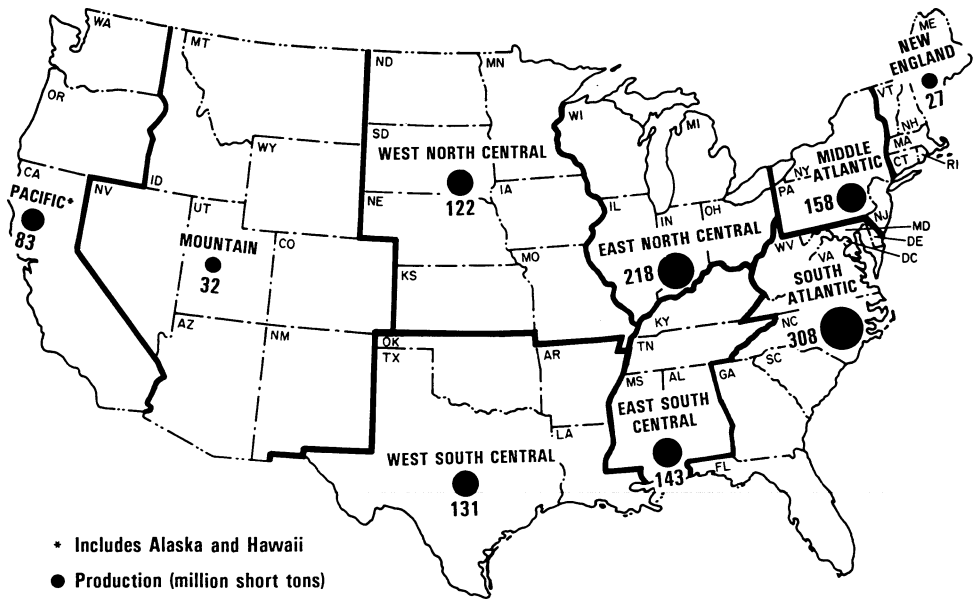

TABLE 6

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

(Thousand short tons and thousand dollars)

State	1989		1990[e]	
	Quantity	Value	Quantity	Value
Alabama	31,737	$167,332	36,100	$202,400
Alaska	2,900	20,300	2,700	19,800
Arizona	6,649	28,552	5,300	13,500
Arkansas	18,791	76,419	17,800	76,900
California	54,887	238,034	42,500	200,600
Colorado	7,261	32,435	7,600	36,100
Connecticut	11,480	78,734	10,200	70,600
Florida	83,995	341,397	74,400	317,400
Georgia	50,417	262,805	53,000	317,300
Hawaii	6,205	46,746	7,000	55,400
Idaho	3,298	12,609	4,300	12,900
Illinois	60,829	256,832	62,700	283,100
Indiana	36,188	136,252	36,700	147,700
Iowa	28,049	111,182	29,000	118,600
Kansas	15,850	56,976	20,800	79,200
Kentucky	48,178	187,849	50,100	182,900
Louisiana	3,206	24,414	2,100	16,800
Maine	1,591	8,801	1,700	8,700
Maryland	30,841	153,375	30,500	163,900
Massachusetts	11,880	67,768	9,200	54,500
Michigan	40,905	123,678	43,100	129,000
Minnesota	8,760	30,218	9,100	31,900
Mississippi	1,069	3,994	1,400	5,500
Missouri	51,754	171,848	53,100	190,900
Montana	2,846	9,718	4,000	15,300
Nebraska	3,978	20,050	4,000	21,200
Nevada	1,560	4,638	1,600	5,000
New Hampshire	771	4,020	600	2,500
New Jersey	20,799	140,998	21,200	131,700
New Mexico	2,784	11,672	2,400	12,800
New York	39,851	201,749	39,900	207,600
North Carolina	51,519	257,976	52,900	276,200
North Dakota	—	—	1,000	4,600
Ohio	46,426	183,190	48,400	190,900
Oklahoma	23,598	81,969	25,300	89,500
Oregon	18,407	81,204	18,000	86,600
Pennsylvania	93,123	455,004	95,800	502,700
Rhode Island	1,208	7,170	1,600	8,800
South Carolina	24,429	111,656	26,200	135,400
South Dakota	3,833	14,303	4,800	16,800
Tennessee	52,917	252,785	54,600	268,600
Texas	76,823	252,982	81,800	285,700
Utah	4,683	19,176	4,600	20,200
Vermont	3,119	28,110	3,700	35,000
Virginia	64,061	328,050	59,400	320,000
Washington	13,259	55,624	12,700	41,900
West Virginia	10,904	42,538	12,000	45,200
Wisconsin	26,520	83,664	26,600	91,000
Wyoming	2,990	12,120	2,200	14,000
Other	6,303	26,845	6,300	26,500
Total[2]	1,213,400	5,325,800	1,222,000	5,591,300

[e]Estimated.

[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 inluded with "Other."

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

Cements Francais of Paris, France, acquired most of the Midwest Portland Cement Co., of Uniontown, PA, operations that included two crushed stone quarries in Ohio, one ready-mix plant in Toledo, OH, and a concrete block plant in Bessemer, OH.

Inspiration Resources Corp. of New York, NY, acquired Rogue Aggregates Inc., and LTM Inc., of Medford, OR. Rogue Aggregates has three crushed stone and sand and gravel operations, while LTM is an aggregates, ready-mix concrete, and asphalt producer. Inspiration Resources is a diversified natural resources company that operates base and precious-metal mines as well as coal mines, and also produces construction materials.

In June, Martin Marietta Aggregates of Bethesda, MD, acquired McKee Quarries, Inc., of Greenwood, MO, and its two limestone quarries located near Kansas City, MO.

Vulcan Materials Co. of Birmingham AL, completed the acquisition of Reed Crushed Stone Co. of Paducah, KY, and two subsidiary companies, Reed Terminal Co. and BRT Transfer Terminal Inc. Reed Crushed Stone quarry is one of the largest quarry in the United States.

Consumption and Uses

Crushed stone production reported to the U.S. Bureau of Mines is material that was either sold or used by producers. Stockpiled production is not reported. Therefore, the "sold or used" tonnage represents the amount of production released for domestic consumption or export in a given year. Because some of the crushed stone producers did not report a breakdown by end use, their total production is reported under "Other unspecified uses, actual." The estimated production of nonrespondents is reported under "Other unspecified uses, estimated." 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 1989, the 1990 estimated average unit price for all crushed stone increased 4.3% to $4.58. Over a 20-year period, the average unit price of crushed stone increased from $1.72 per ton, f.o.b. plant, in 1972, to $4.58 in 1990. However, the unit price in constant 1982 dollars fluctuated between

TABLE 7

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1990, BY QUARTER AND STATE

(Thousand short tons and thousand dollars)

State	Quantity					Value total	Percent coverage	Number of companies[1]
	1st quarter	2d quarter	3d quarter	4th quarter	Total			
Alabama[2]	7,700	9,600	10,000	8,800	36,100	$202,400	79	13
Alaska[3]	—	—	—	—	2,700	19,800	—	—
Arizona	1,300	1,300	1,300	1,400	5,300	13,500	33	4
Arkansas[2]	3,800	4,300	5,100	4,600	17,800	76,900	45	7
California	11,100	9,900	11,400	10,100	42,500	200,600	50	13
Colorado[2]	1,000	1,900	2,900	1,800	7,600	36,100	64	7
Connecticut[2]	700	3,200	3,500	2,800	10,200	70,600	43	6
Delaware	—	—	—	—	—	—	—	—
Florida	20,700	19,500	16,800	17,400	74,400	317,400	61	12
Georgia	12,700	14,900	13,900	11,500	53,000	317,300	91	8
Hawaii[3]	—	—	—	—	7,000	55,400	—	—
Idaho	—	—	—	—	4,300	12,900	36	4
Illinois[2]	8,400	16,600	20,700	17,000	62,700	283,100	66	12
Indiana[2]	6,300	9,400	11,700	9,300	36,700	147,700	78	15
Iowa	4,000	8,300	9,200	7,500	29,000	118,600	41	6
Kansas[2]	3,300	5,700	6,700	5,100	20,800	79,200	61	12
Kentucky[2]	10,600	12,200	16,200	11,100	50,100	182,900	74	9
Louisiana[3]	—	—	—	—	2,100	16,800	—	—
Maine	100	500	600	500	1,700	8,700	35	4
Maryland	6,200	8,500	7,700	8,100	30,500	163,900	94	10
Massachusetts	500	2,700	3,600	2,400	9,200	54,500	55	6
Michigan	2,700	13,500	14,200	12,700	43,100	129,000	78	9
Minnesota	500	2,700	3,700	2,200	9,100	31,900	68	6
Mississippi[3]	—	—	—	—	1,400	5,500	—	—
Missouri	11,100	12,900	16,500	12,600	53,100	190,900	38	15
Montana	400	1,300	1,100	1,200	4,000	15,300	39	4
Nebraska	600	1,200	1,200	1,000	4,000	21,200	116	6
Nevada	400	400	400	400	1,600	5,000	46	3
New Hampshire	40	200	200	200	600	2,500	204	5
New Jersey	2,900	5,100	5,600	7,600	21,200	131,700	92	9
New Mexico	600	500	700	600	2,400	12,800	42	4
New York	4,500	11,000	14,400	10,000	39,900	207,600	62	10
North Carolina	12,300	15,800	12,400	12,400	52,900	276,200	92	10
North Dakota	—	—	—	—	1,000	4,600	—	—
Ohio	7,200	13,200	14,100	13,900	48,400	190,900	68	12
Oklahoma[2]	4,900	6,300	7,200	6,900	25,300	89,500	83	13
Oregon[2]	3,400	4,500	5,400	4,700	18,000	86,600	41	13
Pennsylvania[2]	15,400	27,700	29,900	22,800	95,800	502,700	57	23
Rhode Island[2]	80	400	600	500	1,600	8,800	73	3
South Carolina[2]	6,000	7,300	7,200	5,700	26,200	135,400	70	6
South Dakota	500	1,400	1,700	1,200	4,800	16,800	87	6
Tennessee	9,900	15,600	16,400	12,700	54,600	268,600	66	9
Texas	17,500	21,000	21,900	21,400	81,800	285,700	58	18
Utah[3]	—	—	—	—	4,600	20,200	41	5
Vermont	200	800	1,700	1,000	3,700	35,000	53	3
Virginia	12,700	17,400	16,100	13,200	59,400	320,000	75	17
Washington	2,400	3,400	3,300	3,600	12,700	41,900	23	5
West Virginia[2]	1,900	3,700	3,400	3,000	12,000	45,200	37	4
Wisconsin	2,300	7,200	9,400	7,700	26,600	91,000	47	9
Wyoming	100	800	800	500	2,200	14,000	110	7
Other[3]	—	—	—	—	6,300	26,500	—	—
Total[4]	XX	XX	XX	XX	1,222,000	5,591,300	XX	XX

XX Not applicable.

[1]Number of companies reporting for the quarterly survey.

[2]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."

[3]Due to a low number of reporting companies, no production estimates by quarters were generated.

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

TABLE 8

KIND OF CRUSHED STONE PRODUCED IN THE UNITED STATES IN 1990, BY STATE

State	Lime-stone	Dolo-mite	Marble	Marl	Shell	Granite	Trap-rock	Sand-stone	Quartzite	Slate	Volcanic cinder and scoria	Miscella-neous
Alabama	X	X	X			X						
Alaska	X	X				X	X					X
Arizona	X		X			X			X		X	
Arkansas	X	X				X		X		X		X
California	X	X	X		X	X	X	X	X	X	X	X
Colorado	X					X	X	X			X	X
Connecticut	X					X	X					
Florida	X	X		X	X							X
Georgia	X		X	X		X			X	X		
Hawaii	X						X				X	X
Idaho	X					X	X		X			
Illinois	X	X						X				
Indiana	X	X		X								X
Iowa	X	X						X				
Kansas	X							X	X			
Kentucky	X	X										
Louisiana					X							X
Maine	X			X		X	X		X			
Maryland	X				X	X	X	X	X			X
Massachusetts	X	X				X	X	X				X
Michigan	X	X	X	X			X	X	X			X
Minnesota	X	X				X	X					X
Mississippi	X											
Missouri	X	X				X	X	X				X
Montana	X						X	X	X			X
Nebraska	X											
Nevada	X	X	X			X	X				X	X
New Hampshire	X					X	X					X
New Jersey	X					X	X					
New Mexico	X					X	X		X		X	X
New York	X	X	X			X	X	X		X		X
North Carolina	X	X		X		X	X	X	X	X	X	X
Ohio	X	X						X	X			
Oklahoma	X	X				X	X	X				
Oregon	X	X				X	X	X	X		X	X
Pennsylvania	X	X	X			X	X	X				X
Rhode Island	X					X	X					
South Carolina	X				X	X						
South Dakota	X			X				X	X			X
Tennessee	X	X						X				X
Texas	X	X	X				X	X				X
Utah	X	X		X		X			X		X	
Vermont	X		X			X	X					X
Virginia	X	X	X			X	X	X	X	X		X
Washington	X	X				X	X	X	X		X	X
West Virginia	X					X		X				
Wisconsin	X	X				X	X	X				
Wyoming	X	X	X			X					X	X
Guam	X											
Puerto Rico	X		X			X	X	X				X
Virgin Islands							X					X

TABLE 9

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY MAJOR USES

Use	1985			1987			1989		
	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
Coarse aggregate (+1½ inch)	43,554	$177,902	$4.08	43,905	$189,283	$4.31	42,689	$197,250	$4.62
Coarse aggregate, graded	219,616	1,009,879	4.60	231,082	1,060,965	4.59	231,092	1,088,284	4.71
Fine aggregate (-⅜ inch)	58,566	256,707	4.38	65,099	293,945	4.52	73,167	318,089	4.35
Coarse and fine aggregates	310,173	1,188,080	3.83	325,187	1,276,911	3.93	284,913	1,116,429	3.92
Agricultural	24,887	115,474	4.64	23,040	116,933	5.08	23,035	119,799	5.20
Chemical and metallurgical	127,705	386,612	3.03	115,440	384,115	3.33	122,489	404,668	3.30
Special uses	11,777	99,646	8.46	9,665	128,112	13.26	11,836	187,157	15.81
Other miscellaneous uses	12,998	66,506	5.12	4,742	31,078	6.55	4,047	22,968	5.68
Unspecified:									
Actual	90,015	368,486	4.09	199,360	977,834	4.32	333,085	1,482,690	4.45
Estimated	101,506	383,526	3.78	182,608	789,422	4.37	87,081	388,431	4.46
Total[1]	1,000,800	4,053,000	4.05	1,200,100	5,248,600	4.37	1,213,400	5,325,800	4.39

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

a low $3.48 per ton in 1990 and a high of $3.91 in 1987 (see table 2). 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 of crushed stone increased 30.1% to 5.1 million tons compared with those of 1989, while value increased 39.5% to $32.6 million. About 74% of the exported crushed stone was limestone, Canada being the major destination with over 99% of the total.

Imports.—Imports of crushed stone increased 14.1% to 5 million tons compared with those of 1989, while the value decreased 4.2% to $35.3 million. About 91% of this tonnage was limestone, 35% of which came from Mexico, 34% from Canada, and 20% from the Bahamas.

Imports of natural calcium carbonate fines decreased 17.5% to 3,300 tons, while the value decreased 70% to $864,000. About 59% of processed calcium carbonate was imported from France and 25% from Switzerland.

Shipments of crushed stone from the Bahamas, Canada, and Mexico into the United States continued in 1989. The imported crushed stone, used mostly as construction aggregates or for cement manufacturing, was shipped to Florida, Louisiana, New York, North Carolina, Pennsylvania, South Carolina, and Texas. This trend is expected to continue and the volume of imports to increase.

World Review

Canada.—The 1989 production of stone in Canada was 118 million metric tons, a decrease of 1.7% over the revised 1988 total, valued at $662 million. About 99% of this output was crushed stone. The Province of Ontario continued to be the largest producer of stone, with 58.3 million tons valued at $330 million, followed by Quebec with 42.6 million tons valued at $230 million. The two Provinces accounted for 88% of the total stone production. Preliminary estimates for 1990 stone production indicate a decrease of 5% to 112 million tons valued at $651 million. The Provinces of Ontario and Quebec continued to be the largest producers of stone with about 85% of the total output.

United Kingdom.—The 1989 production of crushed stone in Great Britain (Northern Ireland not included) reached a record-high level of 193 million tons, as reported by the British Aggregate Construction Materials Industries Association (BACMI). Of this total, 170 million tons was used for construction purposes. About 67% of the total output of crushed stone was limestone and dolomite. South West and East Midlands were the largest crushed stone-producing regions, followed by Wales and Scotland. Preliminary estimates made by BACMI indicate that a total of 185 million tons of crushed stone was produced in 1990, a 4% decrease compared with that of 1989.

Current Research

The 5-year Strategic Highway Research Program (SHRP) that will conclude in 1992 passed its midpoint this year. The program made significant progress toward its main goal of improving the Nation's highways through the use of high-performance technology. SHRP's mission is to produce usable research results targeted toward technical areas where there is potential for rapid progress that could yield significant cost savings. SHRP was conceived as a research program with the following distinguished characteristics: an accelerated research activity to be conducted during the short 5-year life of the program; a dollar-driven and performance-oriented program; management-

TABLE 10

U.S. EXPORTS OF CRUSHED STONE IN 1990, BY DESTINATION

(Short tons)

Destination	Limestone	Limestone used for flux, lime, and cement manufacturing	Other	Chalk, crude	Granules, chippings	Total[1]
North America:						
Anguilla	—	—	3,316	—	—	3,316
Antigua	—	—	3,278	—	—	3,278
Bahamas	—	882	3,337	—	433	4,652
Barbados	—	—	2,758	—	—	2,758
Bermuda	—	44	353	—	193	590
British Virgin Islands	—	—	13,541	—	—	13,541
Canada	164,442	3,618,003	808,128	17,057	195,475	4,803,104
Cayman Islands	—	—	1,292	—	175	1,467
Dominica	—	—	3,614	10	—	3,624
Guadalupe	—	—	636	—	—	636
Martinique	—	—	4,273	—	—	4,273
Mexico	18	3,489	124,105	150	5,501	133,262
Netherlands Antilles	—	—	6,834	—	—	6,834
Panama	267	11	337	40	—	655
Trinidad and Tobago	—	107	66	—	—	173
Turks and Caicos Islands	—	—	1,256	—	—	1,256
Other[2]	—	—	75	21	45	141
Total[1]	164,727	3,622,536	977,198	17,278	201,822	4,983,559
South America:						
Colombia	474	—	10	15	6	505
Guyana	246	—	—	—	—	246
Venezuela	—	—	1,443	—	450	1,893
Other[3]	—	8	36	—	41	85
Total[1]	720	8	1,489	15	496	2,728
Europe:						
Belgium	—	—	844	—	28	872
Denmark	—	—	15,247	—	14	15,261
France	—	—	1,322	15	13	1,350
Germany, Federal Republic of	261	—	3,868	25	33,970	38,125
Italy	—	—	386	110	2,396	2,892
Netherlands	—	12	1,106	—	—	1,118
Spain	—	—	1,490	—	—	1,490
Sweden	—	28	128	—	—	155
Switzerland	20	—	99	—	—	119
United Kingdom	13	3,133	1,529	1	2,997	7,673
Other[4]	—	—	38	1	4	43
Total[1]	294	3,172	26,056	153	39,423	69,099
Asia:						
China	—	152	—	—	—	152
Hong Kong	—	—	1,593	—	22	1,615
Japan	20	3,431	25,506	1,424	316	30,698
Korea, Republic of	—	50	1,424	165	18	1,657
Malaysia	—	—	157	1	—	158
Phillippines	—	175	26	—	—	202
Singapore	—	—	6,278	—	—	6,278
Taiwan	—	—	860	43	151	1,054
Thailand	—	—	—	—	263	263

See footnotes at end of table.

TABLE 10—Continued

U.S. EXPORTS OF CRUSHED STONE IN 1990, BY DESTINATION

(Short tons)

Destination	Limestone	Limestone used for flux, lime, and cement manufacturing	Other	Chalk, crude	Granules, chippings	Total[1]
Asia—Continued						
Other[5]	—	—	33	—	94	127
Total[1]	20	3,808	35,877	1,633	865	42,203
Oceania:						
Australia	154	53	294	112	—	614
Other[6]	—	39	9	—	—	48
Total[1]	154	91	303	112	—	661
Middle East:						
Israel	399	—	47	3	—	450
Jordan	—	—	134	—	—	134
Saudi Arabia	—	—	14	—	79	94
Total[1]	399	—	196	3	79	678
Africa:						
South Africa, Republic of	—	—	1,287	—	22	1,309
Other[7]	—	—	11	17	6	34
Total[1]	—	—	1,299	18	28	1,344
Grand total[1]	166,300	3,629,600	1,042,400	19,210	242,700	5,100,300
Total value (thousands)	$813	$14,090	$18,340	$3	$8,155	$41,400

[1]Data may not add to totals shown because of independent rounding.
[2]Includes Aruba, Belize, Dominican Republic, Haiti, and Jamaica.
[3]Includes Argentina, Brazil, Chile, and Ecuador.
[4]Includes Austria, Finland, Iceland, and Yugoslavia.
[5]Includes India and Indonesia.
[6]Includes French Polynesia and Palau.
[7]Includes Ghana and Nigeria.

TABLE 11

U.S. IMPORTS OF CRUSHED STONE AND CALCIUM CARBONATE FINES, BY TYPE

(Thousands short tons and thousand dollars)

Type	1989		1990	
	Gross	Value c.i.f.	Gross	Value c.i.f.
Crushed stone and chips:				
Limestone	1,076	6,955	2,358	12,439
Limestone for flux or cement manufacturing	2,311	19,464	2,176	16,587
Quartzite	14	854	10	845
Other	950	8,359	425	4,571
Total[1]	4,352	35,631	4,969	34,442
Calcium carbonate fines:				
Chalk, crude	(2)	284	(2)	94
Calcium carbonates-chalk, other	4	950	3	770
Total	4	1,234	3	864
Grand total[1]	4,356	36,870	4,972	35,310

[1] Data may not add to totals shown because of independent rounding.
[2] Less than 1/2 unit.

directed activities determined by management imperatives; and a product-oriented program designed to develop better and more useful highway technology for immediate practical application.[15] SHRP's research activities account today for more than one-quarter of all highway research conducted in the United States by the Federal agencies, the States, and the private industry.

SHRP's four areas of research are asphalt, concrete and structures, highway operations, and long-term pavement performance. The broad objective of SHRP's research program in the asphalt area is to improve the long-term durability and cost-effectiveness of the Nation's annual $10 billion-plus investment in asphalt pavements. Preliminary drafts of the performance-based specifications for asphalt

and asphalt binders were released for discussion in 1990. The report indicates that "the chemical and physical properties of the asphalt binder determine, to an important degree, the level of performance achieved by the asphalt pavement."[16] Accordingly, chemical analysis of the asphalt yields a large amount of information on how the asphalt will perform as a binder in pavement. An initial draft of specifications for asphalt-aggregate mixture was also released in an effort to generate input from users and producers. "The specifications address five pavement performance characteristics—aging, fatigue cracking, moisture sensitivity, permanent deformation, and low-temperature cracking. Applying mixture and binder specifications in the design of specific highways will enable designers to account for severe traffic and climatic conditions. The result will be more durable and economical pavements."[17]

The concrete and structure program includes research in the area of improved concrete materials and corrosion of steel in concrete structures. Tables that provide guidance for curing concrete, developed by the Pennsylvania State University, and a new test for selection differences between concrete and the environment in which the concrete will be placed are some of the emerging products from the concrete program. A new test for control of freeze-thaw damage was developed as an alternative to the standard ASTM C-666B test, as well as a fiber-optic air meter, a portable, battery-operated device for measurement on-site of air voids in fresh concrete. All new products and methods will be pilot-tested by State highway agencies around the country in the coming year.

Highway maintenance problems and their high costs are addressed by SHRP's highway operations research program, while SHRP's long-term pavement performance (LTPP) program is measuring pavement performance in different climate, traffic, and subgrade conditions.

A Midcourse Assessment meeting organized by SHRP in Denver, CO, on August 1-3, 1990, was attended by more than 400 representatives of State highway agencies, research organizations, and the industry. SHRP's activities and progress of the research program were examined by the participants, and specific recommendations were made regarding the direction of the program.[18]

The mining industry uses annually very large quantities of explosives to fragment rock.[19] Blasting techniques continue to evolve as new explosives and initiation systems are developed. The U.S. Bureau of Mines, working with Sandia National Laboratory, is developing new computerized blasting designs for better control of rock fragmentation in the mining industry. Mining companies could achieve significant savings in mining costs if blasts can be designed to produce desired size and motion of the blasted material without extensive trial and error. Blasting experiments at one-tenth to full scale were used to examine the effects of various blast parameters on fragment size. From these tests, researchers developed prediction equations that relate design parameters to resulting fragment size distribution. The predictions are accurate to within 16% for massive and relatively unjointed rock. For highly bedded and jointed rock, an additional factor to account for these planar features must be included in the prediction. Because about one-half of the U.S. mineral production is crushed stone, initial tests concentrated on limestone and other rocks with similar properties. Future tests will focus on hard rock such as granite.

The Bureau's Automation in Mining Research Program is pursuing development of systems and technologies required for computer-assisted mining systems.[20] Such systems will enable relocation of workers to a safe work environment that will significantly reduce or eliminate human casualties that result especially from working in underground mines. The Bureau's research program is directed specifically at the automation of present-day underground equipment. Projects under Bureau's Automation in Mining Research Program address: guidance technology for navigation of autonomous mining vehicles; expert systems for reducing mining machines downtime caused by electrical, mechanical, or hydraulic failures; intelligent control systems for autonomous mining; and natural language processing and computer graphics for worker-machine interface.

For a long time, good base design and good drainage under pavements was the accepted rule among pavement designers. The development of "rational" methods of pavement design in the 1950's and 1960's led to the belief that pavements could be built strong enough to resist damage without the benefits of good drainage.[21] That rationale led the designers to increase the thickness and strength of pavements, while reducing drainage capabilities (capacity) of the base and subbase layers. The bases became also denser and stronger in order to be able to carry heavier loads during the construction and especially after the completion of the roads. Over the years, the inadequate drainage of pavement structures was identified as one of the primary cause of pavement distress and failure in today's highways.

Today, a different design approach is emerging. Rather than using impermeable dense-graded materials, several States started to use open-graded permeable bases that allow moisture to rapidly drain through the base and out from beneath the pavement structure. Permeable bases usually consist of open-graded crushed aggregate with very limited amount of fines and a longitudinal edge-drain system that collects the water from the permeable base. The permeable bases are used mostly under portland cement concrete pavements, but their use under asphaltic concrete pavement is increasing. There are two kind of permeable bases in use: the untreated or unbound permeable bases that are dense-graded aggregate material with reduced amount of fines, and the treated or bound with either asphaltic concrete or portland concrete bases. A good number of States are using the permeable base design method for some time, with California, Michigan, New Jersey, and Pennsylvania being the most advanced States. Performance data indicate that properly designed and constructed permeable bases virtually eliminate pumping, faulting, and cracking of pavements. Studies of pavements constructed on permeable bases in California suggest a minimum service life increase of 33% and 50%, respectively, for asphalt concrete and portland cement concrete pavements constructed on permeable bases.[22]

For the existing roads built on dense-graded bases, a patented process for installing transverse drains under the joints of concrete pavements is being tested in Wisconsin.[23] The drains effectively remove free water from dense-graded bases under the pavement joints, reducing or eliminating the pumping of fines and faulting of joints under heavy traffic. Drainage Technologies Inc., of Oconomowoc, WI, is the patent holder for the new drainage system.

Following the suggestion of the National Pavement Association (NAPA), and in cooperation with AASHTO, and the Federal Highway Administration (FHWA), a 14-day study tour of six Eu-

ropean countries was organized in September 1990. Representatives of AASHTO, FHWA, NAPA, Strategic Highway Research Program, The Asphalt Institute, and the Transportation Research Board visited Denmark, France, the Federal Republic of Germany, Italy, Sweden, and the United Kingdom. The objective of the tour was to exchange ideas and experiences with European highway agencies and construction industry representatives regarding the design, production, and maintenance of asphalt pavements. The group members concluded that there was "a lot to learn from Europe about asphalt pavements and about pavement philosophy in general. European pavements are better than ours. The Europeans invest more in research, development, and deployment of new pavement technology. They build their pavement foundations better. They use innovative surfaces, such as Stone Mastic Asphalt, and mix in additives to a greater extent and with better results. And, the Europeans maintain their pavements to get the maximum life out of them."[24] A report summarizing the findings of the study group that also provided a plan for applying these finding in the United States was published by AASHTO.

Technology

A steep-incline, high-capacity conveyor capable of operating uphill or downhill at angles of up to 70° on short or very long lifts was produced by Huwood, a United Kingdom conveyor manufacturer.[25] A troughed conveyor belt runs in parallel with a chain conveyor system. Attached to the chain are paddles shaped to the profile of the belt trough that propel the material and the belt up or down the incline. A single drive is used on the chain conveyor that allows the troughed belt to be manufactured from flexible, abrasion resistant, low-tensile material. The rated operation capacity of the conveyor is 10,000 tons per hour. The conveyor will accommodate irregular-sized material, large lumps of fines, and abrasive as well as sticky or frozen materials. The conveyor is said to offer substantial cost benefits for bulk material transportation, especially in surface mine operations and stockyards.

Significant changes are taking place in the design and the use of conveyor systems and their accessories. Stationary or self-propelled conveyors are replacing in quarry and pit haul trucks because they provide increased productivity by moving large volumes of materials at a faster speed and lower cost. A new computerized designing method for belt conveyor systems was developed by Don Suverkrup and John Cloes, mechanical engineering consultants of Bakersfield, CA.[26] Their computer program provides an improved method for producing the proper design of belt conveyors and accessories at a low cost. A review of the latest developments in conveyor systems and their accessories as well as their use was published by Rock Products.[27]

As the supply of aggregates from land-based resources becomes more restricted, European sand and gravel producers are placing more emphasis on offshore dredging of sand and gravel. To satisfy increased requirements for greater consistency of the products supplied, more sophisticated mining and processing methods are being used. For years, a common practice for offshore dredging was to do some on-board vessel screening of the dredged material. Recently, based on increased environmental concerns, some United Kingdom licenses started to prohibit on-board screening of dredged aggregates. To overcome this restriction, new excavating methods are being tested that will be more selective regarding the material being dredged. The USP RoxAnn seabed classification system is a device that improves the efficiency of trailer-suction dredges.[28] The device works through reflected hydroacoustic signals that are able to determine the type of aggregate present in the seabed before the material is excavated. The dredging is therefore adjusted according with the information provided by the device.

Self-unloading vessels were created first and continue to thrive in the Great Lakes area. However, a new market for ocean-going self-unloaders transporting aggregates, cement, and other free-flowing, dry-bulk commodities is developing. The main advantages provided by such vessels for transporting low-value/high-volume commodities are reduced handling costs, improved turnaround time, and capability to supply ports that are not equipped with high capacity unloaders. These kinds of vessels are most cost effective if they perform short hauls and operate often and therefore make full use of the installed equipment, but some are being used for long ocean hauls. Some new developments in the use of self-unloaders as well as reviews of some operations were published by Bulk International Journal.[29]

OUTLOOK

The demand for crushed stone in 1991 is expected to be about 1.1 billion tons, a 10% decrease compared with the estimated total for 1990. The slowdown of the economy that affected the construction industry in the second half of 1990 is expected to have an impact on the demand for crushed stone in the first half of 1991. Gradual increases in demand for construction aggregates are anticipated after 1991, based on an increased volume of work on the infrastructure expected to occur following the passage of the Surface Transportation Assistance Act of 1991. 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.

The release of the Department of Transportation comprehensive report on national transportation policy entitled "Moving America, New Directions, New Opportunities"[30] indicates that a significant increase in the volume of work on the infrastructure should be expected in the next 5 to 10 years. The value of public construction work as part of the gross national product has declined constantly from about 3% in the 1950's and 1960's to less than 2% in the 1980's. If this trend begins to reverse in the 1990's, a significant increase in spending for public construction work is expected that will dramatically alter above forecasts.

Crushed stone f.o.b. prices are not expected to increase significantly, even if the demand for construction aggregates will rise over 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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DIMENSION STONE

By Harold A. Taylor, Jr.

Mr. Taylor, a physical scientist with 25 years of industry, Federal Government, and U.S. Bureau of Mines experience, has been the commodity specialist for dimension stone since 1981. Domestic survey data were prepared by Chris Lindsay, mineral data assistant.

Production of dimension stone increased slightly to 1.19 million short tons valued at $210 million. More than one-half of the dimension stone produced was granite. Limestone, marble, sandstone, and slate were also produced.

Exports of dimension stone increased 23% in value to $43 million. The value of dimension stone imports for consumption decreased slightly to $524 million, equivalent to 250% of the value of domestic production.

TABLE 1

SALIENT U.S. DIMENSION STONE STATISTICS

(Thousand short tons and thousand dollars)

	1986	1987	1988	1989	1990
Sold or used by producers	1,060	r1,179	re1,159	r1,238	e1,186
Value	$167,429	r$190,117	re$207,489	re$210,878	e$209,601
Exports (value)	$14,623	$20,470	r$42,668	$34,610	$42,668
Imports for consumption (value)	$379,724	$439,278	$517,835	$525,052	$523,891

eEstimated. rRevised.

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 1990. A sample survey based on the first 9 months of data was used to generate State annual preliminary estimates. Of the 368 dimension stone operations surveyed for 1989 and 1988, including those that were idle, 317, or 72%, responded, representing 96% of the estimated value shown in table 1. The final 1988 data are based on data from the 1989 survey, and updated 1988 preliminary data for nonrespondents were estimated using preliminary production reports, adjusted prior years production levels, and employment data.

BACKGROUND

Definitions, Grades, and Specifications

Dimension stone is a natural rock material that has been selected, trimmed, or cut to specified or indicated shapes or sizes, with or without one or more mechanically dressed surfaces. This includes rough stone, rubble, ashlar, blocks, panel, and curvilinear shapes. Finished surface requirements may vary from a controlled fractured surface to ground and polished. The most prominent required qualities of dimension stone are strength, toughness, hardness, and resistance to environmental damage. Color and grain structure contribute largely to price and marketability. The principal types of dimension stone used in construction are granite, marble, limestone, sandstone, and slate.

Stone classification by type in the dimension stone industry is somewhat ambiguous and does not correspond in some respects with the same terms used in mineralogical rock descriptions. The U.S Bureau of Mines generally accepts the classification reported by producers. Granite includes all feldspathic crystalline rocks of predominantly interlocking texture 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 marble-like veinlets of lighter materials, chiefly calcite or dolomite, and because of their ability to take a high polish.

Commercial sandstone is a sedimentary rock consisting mostly of quartz, sometimes with feldspar, or rock fragments of clastic texture bonded by silica, clay, calcite, or iron oxide. Bluestone is a dense, hard, fine-grained feldspatic 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 sand-

stone or a slate that splits into large, thin slabs.

Quartzite is a metamorphic equivalent of sandstone that has been firmly cemented by secondary silica or by recrystallization so that it is essentially homogeneous and fractures through rather than around the original sand grains.

Slate is a fine-grained metamorphic rock derived from shale, siltstone, or claystone. It has prominent cleavage that is oriented independently from the original sedimentary bedding. Mineral constituents are quartz, mica, sericite, or chlorite with assorted minor accessories. Shale is composed mostly of original clay minerals, and cleavage is parallel to the bedding.

Traprock is a commercial term for all dark, igneous rocks too fine in grain size to be called black granite. In addition to extrusive flow rocks such as basalt, andesite, or dacite, traprock includes intrusive igneous rocks such as diabase, diorites, gabbros, pyroxenites, amphibolites, and peridotites.

Miscellaneous stones used for dimension purposes include schist, scoria, soapstone, wollastonite, argillite, and many others.

Geology-Resources

Domestic resources of most types of dimension stone used in construction are practically unlimited. There is considerable interstate transportation of certain types of stone such as Indiana limestone, Georgia marble and granite, and Vermont granite, marble, and slate. A lack of deposits of certain specific varieties of dimension stone especially noted for their aesthetic qualities in architecture and artifact manufacture is an important cause of importation of these varieties; for example, brightly colored marbles from Italy.

Technology

Mining.—Present mining methods range from antiquated and very inefficient 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.

Economic Factors

The current import duties (tariffs) are shown in table 2.

The depletion allowance for dimension stone is 14%. Dimension stone quarries are generally in mountainous or hilly areas remote from areas of dense population. Because land use for other purposes is limited, the cost of land is reasonable.

Transportation costs for dimension stone are high because of its weight and because special handling methods are required to prevent damage to the finished stone. A single stone panel broken in transit not only results in the loss of the many employee-hours of skilled labor required to produce it, but also can cause construction delays that are even more costly. Nevertheless, dimension stone is routinely shipped long distances by motor and rail freight, and special domestic varieties are shipped by ocean freight to foreign countries.

Operating Factors

Environmental requirements vary from State to State and are often a cause of conflict between State or local governments and the quarry operators.

Stone primary and waste products are not toxic, nor are the supplies utilized in their production. However, sufficient exposure to silica-rich stone dust can cause silicosis.

The approximate number of employees in the dimension stone industry by stone kind are granite, 9,600; limestone, 1,100; marble, 1,500; slate, 950; and sandstone and other dimension stone, 850. Of the total 14,000, about 3,100 are employed in quarrying and approximately 10,900 in finishing operations. Major States for employment were Georgia with 2,100 employees, Vermont with 1,700, Minnesota with 1,250, North Carolina with 850, Texas with 700, and Indiana with 650.

Fuel is used to power quarrying equipment, and electricity is used for sawing and finishing. Water is used in some quarries to cool equipment such as chain saws and in sawing and finishing plants to cool the equipment; water consumption is relatively minimal in all instances.

ANNUAL REVIEW

Production

Dimension stone was produced by 176 companies at 288 quarries in 34 States. Leading States, in order of tonnage, were Indiana, Georgia, and Vermont, producing together 37% of the Nation's total. Of the total production, 53% was granite, 27% was limestone, 11% was sandstone, 3% was slate, 2% was marble, and the remaining 4% was miscellaneous stone. Miscellaneous stone included argillite, schist, soapstone, and traprock (basalt). Leading producing companies in terms of tonnage were Cold Spring Granite Co., principally in California, Minnesota, South Dakota, and Texas; Rock of Ages Corp. in New Hampshire and Vermont; and Fletcher Granite Co. Inc. in Massachusetts and New Hampshire (1988-89).

Granite.—Dimension granite includes all coarse-grained igneous rocks. Production decreased 4% to 634,000 tons and decreased slightly in value to $116.2 million. Granite was produced by 62 companies at 114 quarries in 22 States. Georgia continued to be the leading State, producing 21% of the U.S. total, followed by Vermont and Massachusetts. These three States together produced about 46% of the U.S. total. Cold Spring Granite, Rock of Ages, and Fletcher Granite Co. were the leading producers and accounted for 44% of U.S. production.

Orex Corp. is beginning to quarry a true black granite at a site north of Whitehall, NY. The stone has the coloring and appearance of a good South African or Indian black granite. The United States has imported large quantities of this expensive premium dimension stone for many years. If a large quarry can be opened, a significant shift to domestic

sourcing would result. The quarry is on the site of an old graphite mine. Sample rough blocks are being sent to Vermont for finishing.

The Rock of Ages Corp. of Barre, VT, in partnership with Dakota Granite Co., has acquired two mahogany granite quarries in South Dakota. The purchased quarries, along with equipment and inventories, used to belong to Field Enterprises. Ownership of the new firm, titled Whetstone Granite Co., will be split even-

TABLE 2

U.S. IMPORT DUTIES ON DIMENSION STONE

Tariff item	HTS No.	Most favored nation (MFN) January 1, 1991	Non-MFN January 1, 1991
Slate: Rough blocks or slabs	2514.00	3.7% ad valorem	25% ad valorem.
Rough blocks or slabs of marble, travertine, and other calcareous monumental or building stone:	2515		
Marble and travertine:			
Crude or roughly trimmed	2515.11	$3.46 per cubic meter	$22.95 per cubic meter.
Marble, merely cut	2515.12 2515.12.10	2.1% ad valorem	13% ad valorem.
Travertine, merely cut	2515.12.20	6% ad valorem	50% ad valorem.
Other calcareous stone, alabaster	2515.20.00	6% ad valorem	50% ad valorem.
Rough blocks or slabs of granite, porphyry, basalt, sandstone, and other monumental or building stone	2516		
Granite:			
Crude or roughly trimmed	2516.11.00	Free	$8.83 per cubic meter.
Merely cut	2516.12.00	4.2% ad valorem	60% ad valorem.
Sandstone:			
Crude or roughly trimmed	2516.21.00	Free	$5.30 per cubic meter.
Merely cut	2516.22.00	6% ad valorem	50% ad valorem.
Other monumental or building stone	2516.90.00	6% ad valorem	50% ad valorem.
Setts, curbstones, and flagstones	6801.00.00	4.2% ad valorem	60% ad valorem.
Worked monumental or building stone	6802		
Tiles and cubes under 7 cm square, granules	6802.10.00	6.9% ad valorem	40% ad valorem.
Other stone and articles with a flat or even surface:			
Marble, travertine and alabaster:	6802.21		
Travertine	6802.21.10	6% ad valorem	50% ad valorem.
Other	6802.21.50	2.1% ad valorem	13% ad valorem.
Other calcareous stone	6802.22.00	6% ad valorem	50% ad valorem.
Granite	6802.23.00	4.2% ad valorem	60% ad valorem.
Other stone	6802.29.00	7.5% ad valorem	30% ad valorem.
Other:			
Marble, travertine, and alabaster:	6802.91		
Marble:			
Slabs	6802.91.05	2.8% ad valorem	15% ad valorem.
Other	6802.91.15	6% ad valorem	50% ad valorem.
Travertine:			
Articles of subheading 6802.21.10 that have been dressed or polished, but not further worked	6802.91.20	6% ad valorem	50% ad valorem.
Other	6802.91.25	5.3% ad valorem	40% ad valorem.
Alabaster	6802.91.30	5.3% ad valorem	50% ad valorem.
Other calcareous stone	6802.92.00	6% ad valorem	50% ad valorem.
Granite	6802.93.00	4.2% ad valorem	60% ad valorem.
Other stone	6802.99.00	6.5% ad valorem	40% ad valorem.
Worked slate and articles:	6803.00		
Roofing slate	6803.00.10	6.6% ad valorem	25% ad valorem.
Other	6803.00.50	3.7% ad valorem	25% ad valorem.

TABLE 3

DIMENSION STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1988[r e]		1989		1990[e]	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
California	20,624	$5,397	28,829	$5,564	30,077	$5,213
Colorado	3,456	225	5,310	398	8,490	1,394
Connecticut	19,340	1,962	W	W	W	W
Georgia[1]	[r]157,866	[r]12,384	[r]153,440	[r]12,564	147,068	12,483
Indiana[1]	[r]197,894	[r]29,192	198,531	27,213	194,728	29,504
Iowa	11,769	471	15,151	613	W	W
Maine	W	W	W	W	W	W
Maryland	15,092	1,164	27,529	2,072	24,102	1,751
Massachusetts	54,064	11,878	67,533	10,302	56,254	10,992
Minnesota	40,575	14,940	44,605	16,031	60,195	20,836
New Hampshire	107,411	15,914	55,305	8,769	45,073	6,029
New York	23,454	3,561	23,756	3,575	23,437	3,589
North Carolina	58,695	9,855	62,665	10,477	66,531	11,551
Ohio	W	W	59,923	3,455	61,783	3,468
Oklahoma	5,866	720	[r]8,663	[r]1,418	8,138	684
Pennsylvania	46,143	9,038	44,267	10,032	43,952	9,898
South Dakota	52,560	16,747	[r]56,963	[r]17,765	50,688	12,871
Tennessee	2,768	189	4,888	437	10,108	2,051
Texas	53,183	8,760	81,268	12,447	84,500	12,600
Vermont	98,085	25,640	[r]100,677	31,413	99,243	28,950
Virginia	10,709	3,463	W	W	W	W
Wisconsin	40,872	31,996	[r]43,526	[r]4,794	31,316	3,811
Other[2]	141,684	31,993	[r]155,000	[r]31,629	140,533	32,016
Total[3]	1,162,400	207,489	[r]1,237,829	210,968	1,186,216	209,691

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data, included with "Other."
[1]Totals only includes Georgia granite and Indiana limestone; other stone included with "Other."
[2]Includes data for Alabama, Arizona, Arkansas (1989, 1990), Idaho, Illinois, Kansas, Michigan, Missouri, Montana, New Mexico, South Carolina, and Washington, and data that is withheld.
[3]Data may not add to totals shown because of independent rounding.

TABLE 4

DIMENSION GRANITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1988[r e]		1989		1990[e]	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Georgia	157,866	$12,384	[r]153,440	[r]$12,564	147,068	$12,483
Maine	W	W	W	W	W	W
Massachusetts	54,064	11,878	67,333	10,212	64,532	10,147
New Hampshire	107,411	15,914	55,305	8,769	52,995	8,717
North Carolina	53,057	9,078	W	W	W	W
Oklahoma	5,116	701	5,460	1,355	5,261	1,348
Pennsylvania	11,349	2,900	11,652	3,107	11,157	3,092
South Dakota	52,560	16,747	[r]56,963	[r]17,765	54,580	17,656
Vermont	85,895	16,216	83,073	15,522	79,620	15,424
Wisconsin	2,896	2,192	W	W	W	W
Other[1]	123,742	30,856	[r]228,238	[r]47,645	218,701	47,365
Total	653,956	118,866	[r]661,939	[r]116,939	633,914	116,232

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data, included with "Other."
[1]Includes California, Connecticut, Colorado, Maryland, Minnesota, Missouri, New York, Rhode Island, South Carolina, Texas, Virginia, Washington, and data indicated by symbol W.

ly. Dakota Granite Co. will oversee the operations because it is nearby.

Limestone.—Dimension limestone includes bituminous, dolomitic, and siliceous limestones. Indiana, the leading State, produced 195,000 tons in 1990 compared with 198,531 tons in 1989 and 197,894 tons in 1988. Wisconsin, usually the second or third largest producer, totaled 37,636 tons valued at $1,642,700 in 1989 and 37,976 tons valued at $1,804,000 in 1988.

Marble.—The Colorado Yule Marble Co. reopened the old Yule white marble quarry in mid-1990. The company began by producing rough block to sell to other firms with finishing facilities. Colorado Marble from this quarry, closed for 50 years, was used in the Lincoln Memorial and the Tomb of the Unknown Soldier, as well as in the Colorado State capitol. The quarry was leased from Vermont Marble Co. The firm was thinking of building a finishing plant, but probably at some distance from the quarry.

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 increased slightly to 1.19 million tons valued at $209.7 million in 1990 compared with 1.24 million tons valued at $211.0 million (revised) in 1989 and 1.16 million tons valued at $207.8 million in 1988.

Consumption of domestic granite increased to 614,000 tons valued at $109.5 million in 1990 compared with 661,500 tons valued at $116.9 million in 1989 and 654,000 tons valued at $118.9 million in 1988.

Domestic limestone consumption was 326,000 tons valued at $45.0 million in 1990 compared with 334,200 tons valued at $42.5 million (revised) in 1989 and 320,500 tons valued at $42.3 million in 1988.

Domestic marble consumption, including travertine, totaled 23,000 tons valued at $20.0 million in 1990 compared with 24,280 tons valued at $21.4 million in 1989 and 20,080 tons valued at $21.8 million in 1988.

The Carrara marble used as a cladding on the Amoco Building in Chicago is being removed because of weather-related deterioration and will be recycled. The thin-cut stone lost much of its strength after weather-induced warping. This deterioration is expected to continue, so some other use had to be sought. The warping eliminates most possible uses. As a result, 1,000 tons of the 6,000-ton total will be crushed and used as decorative landscaping gravel at Governors State University. An additional 500 tons will be given to an agency for the handicapped to be carved into souvenir items such as bookends, and the balance will be stored until Amoco needs landscaping gravel for its own purposes.

The marble cladding had bowed enough from freeze-thaw to become noticeable a few years ago. Many panels bowed outward more than one-half inch. Some of the panels cracked, and some even fell to the ground, posing a danger to passers-by.

TABLE 5

DIMENSION STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1988[r e]		1989	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Rough stone:				
Rough blocks for building and construction	245,222	$20,461	r277,918	r$22,574
Irregular-shaped stone[1]	103,912	4,831	r110,096	r6,034
Monumental	226,251	31,074	r224,875	r31,185
Other[2]	20,742	2,436	r32,281	r3,453
Dressed stone:				
Ashlars and partially squared pieces	187,628	42,224	r225,281	r44,356
Slabs and blocks for building and construction	90,340	28,157	r93,276	r27,499
Monumental	38,510	26,459	r37,598	r25,812
Curbing	164,336	31,167	141,083	r23,972
Flagging	36,942	3,077	r38,831	r4,649
Flagging (slate)	7,845	1,179	7,578	1,299
Roofing slate	12,674	7,926	11,408	9,132
Structural and sanitary	5,413	2,884	4,470	3,709
Flooring slate	3,284	1,973	3,197	2,198
Other[3]	16,011	3,641	r29,936	r5,095
Total[4]	1,159,110	207,489	r1,237,829	r210,968

[e]Estimated. [r]Revised.

[1]Includes rubble.

[2]Includes flagging and unspecified uses.

[3]Includes a minor amount of slate used for billiard tabletops, miscellaneous, and unspecified uses.

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

This resulted in a decision to replace the marble cladding with Mount Airy Granite from North Carolina at a cost of $60 to $80 million. This white granite will be almost indistinguishable from the marble at a distance.

Consumption of domestic slate totaled 34,600 tons valued at $16.7 million in 1990 compared with 33,600 tons valued at $17.7 million in 1989 and 33,750 tons valued at $14.5 million in 1988.

TABLE 6

DIMENSION GRANITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1988[r e]		1989	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Rough stone:				
Rough blocks for building and construction	94,001	$9,194	[r]97,718	[r]$9,985
Irregular-shaped stone[1]	20,913	1,199	19,719	1,621
Monumental	226,235	31,064	[r]223,106	[r]31,108
Other[2]	3,891	340	[r]7,989	[r]733
Dressed stone:				
Ashlars and partially squared pieces	90,412	23,570	[r]120,639	[r]24,733
Slabs and blocks for building and construction	26,713	4,623	[r]25,858	[r]4,117
Flagging	4,116	582	3,908	1,741
Monumental	28,706	16,625	28,232	[r]18,472
Curbing	155,881	30,984	129,064	23,707
Other[3]	3,088	684	5,228	723
Total[4]	653,956	118,866	[r]661,464	[r]116,939

[e]Estimated. [r]Revised.
[1]Includes rubble.
[2]Includes rough stone used for flagging and unspecified uses.
[3]Includes uses not specified.
[4]Data may not add to totals shown because of independent rounding.

TABLE 7

DIMENSION LIMESTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1988[r e]		1989	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Rough stone:				
Rough blocks for building and construction	124,885	$10,054	137,479	$10,367
Irregular-shaped stone[1]	41,181	1,120	[r]46,135	[r]1,159
Other[2]	11,211	1,761	18,897	2,341
Dressed stone:				
Ashlars and partially squared pieces	91,224	13,171	[r]69,113	[r]11,435
Slabs and blocks for building and construction	34,865	14,989	[r]46,150	[r]15,998
Flagging	13,802	468	[r]11,469	[r]455
Other[3]	3,309	700	4,945	739
Total[4]	320,477	42,263	[r]334,188	[r]42,495

[e]Estimated. [r]Revised.
[1]Includes rubble.
[2]Includes monumental and unspecified uses.
[3]Includes curbing, monumental, and unspecified uses.
[4]Data do not add to total shown because of independent rounding.

TABLE 8

DIMENSION MARBLE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1988[r e]		1989[r]	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Rough stone:				
Other[1]	2,937	$367	4,952	$1,220
Dressed stone:				
Slabs and blocks for building and construction	5,665	8,015	7,307	6,607
Monumental[2]	11,482	13,331	12,017	13,583
Total[3]	20,084	21,713	24,276	21,409

[e]Estimated. [r]Revised.
[1]Includes rubble, rough blocks for building and construction, irregular shaped stone, and monumental.
[2]Includes stone used in dressed ashlars and partially squared pieces and a small amount used in flagging, and unspecified uses.
[3]Data may not add to totals shown because of independent rounding.

TABLE 9

DIMENSION SANDSTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1988[r e]		1989	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Rough stone:				
Rough blocks for building and construction	24,543	$887	29,524	$956
Irregular-shaped stone[1]	30,261	1,767	28,914	1,812
Other[2]	230	18	204	17
Dressed stone:				
Ashlars and partially squared pieces	12,746	1,313	25,204	1,248
Slabs and blocks for building and construction	9,516	533	11,579	577
Flagging	9,662	1,244	9,768	1,396
Other[3]	17,963	2,432	26,814	2,709
Total	104,921	[4]8,195	132,007	[4]8,714

[e]Estimated. [r]Revised.
[1]Includes rubble.
[2]Includes uses not specified.
[3]Includes curbing and unspecified uses.
[4]Data do not add to total shown because of independent rounding.

TABLE 10

DIMENSION SLATE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use	1988[r e]		1989	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Flagging (slate)	7,845	$1,179	7,578	$1,299
Roofing (slate)	12,674	7,926	11,408	9,132
Structural and sanitary	5,413	2,884	4,470	3,709
Flooring slate	3,284	1,973	3,197	2,198
Other[1]	1,239	253	6,955	1,378
Total	30,455	14,215	33,608	17,716

[e]Estimated. [r]Revised.
[1]Includes a minor amount of slate used for billiard tabletops, blackboards, and unspecified uses.

Prices

The average price for dimension stone increased to $165 per ton, up slightly from $170 in 1989.

Foreign Trade

Exports.—Exports of dimension stone, about 40% of which was granite, increased 23% in value.

Imports.—Imports for consumption of dimension stone decreased slightly in value to $524 million, mostly because of decreases in imports of several major categories of dimension stone, particularly marble slabs. Imports of dressed marble slabs, mostly from Italy, decreased 21% to $147 million. Imports of dressed granite increased 10%. On a value basis, marble accounted for 45% of imports, followed by granite, 37%.

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.

China.—The U.S. Bureau of Mines dimension stone specialist authored a pithy article on recent developments in the Chinese dimension granite industry. According to published numbers of Chinese origin, Chinese production is three times U.S. production or 30% to 40% more than Italian production. Chinese firms have imported more than 200 stone-finishing production lines from Europe in recent years. The decisionmakers for dimension stone exports are the autonomous offices of two Government-owned firms in each Province. Although the Chinese have problems with quality control, they usually offset this by selling at one-half the market price. Chinese exports of dimension stone are rapidly growing, especially to major markets in Japan and the United States.[1]

Germany, Federal Republic of.—The major dimension stone operations in what was formerly East Germany, now owned by four firms, were described in a recent review. Vereingte Thringische Schiefergruben GmbH produces a dark slate that is heavily used locally. The firm exported about 40% of its dimension slate product output in 1989, mainly to the western part of Germany. Elbe Naturstein GmbH and its recent offshoot, Schsische Sandsteinwerke GmbH, have 23 quarries that produce a variety of stone. Elbe Naturstein is going to concentrate on its tavertine and limestone quarries in Thuringia, its marble and schist quarries near Plauen, and its Meissen granite quarries in Saxony. The firm exports a small proportion of its output to Western Europe. Schsische Sandsteinwerke GmbH is going to concentrate on its five sandstone quarries near Dresden. Lausitzer Granit GmbH operates three granite quarries and two dolerite quarries north of Dresden and is likely to be broken up, some of it being returned to the original owners and some being sold off.[2]

The prospects of most of these firms are fairly decent, particularly if a hoped-for building boom occurs. The slate producer probably has the best prospects because it is used to selling in Western markets and because it is the least behind technically.

Ireland.—Prospects for the Irish dimension marble and slate industries were recently described. The famous Connemara marble is no longer quarried, and the tourist trade items still being made are drawing on stockpiled material. A trade association is trying to encourage the industry. Connemara Marble Industries Ltd. is trying to resume production but is involved in a dispute with the national Government over the mining lease.

TABLE 11

U.S. EXPORTS OF DIMENSION STONE, BY TYPE

(Thousand short tons and thousand dollars)

Type	1989		1990		Major destination in 1990, (percent[1])
	Quantity	Value	Quantity	Value	
Marble, travertine, alabaster worked	9	1,733	34	4,905	Canada, 25%.
Marble, travertine, crude or roughly trimmed	NA	343	25	671	Canada, 42%.
Marble, travertine, merely cut, by sawing or otherwise	23	1,156	3	1,650	Mexico, 20%.
Granite, crude or roughly trimmed	74	12,159	NA	10,195	Japan, 44%.
Granite, merely cut, by sawing or otherwise	58	9,107	NA	10,734	Japan, 28%.
Sandstone, crude or roughly trimmed	NA	390	7	334	Canada, 94%.
Sandstone, merely cut, by sawing or otherwise	6	771	12	2,280	Canada, 75%.
Slate, worked and articles of slate	NA	6,228	NA	8,732	Cayman, 22%.
Slate, whether or not roughly trimmed or merely cut	NA	1,038	NA	636	Canada, 81%.
Other calcareous monumental or building stone; alabaster	24	618	5	698	Canada, 80%.
Other monumental or building stone	7	1,067	13	1,833	Canada, 77%.
Total	NA	34,610	NA	42,668	

NA Not available.

[1]By value.

Source: Bureau of the Census.

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF DIMENSION GRANITE, BY COUNTRY

(Thousand cubic feet and thousand dollars)

Country	Rough granite[r e 1]		Dressed granite[r e]					
			Stone and articles		Worked		Total	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1987:								
Canada	595	4,219	—	—	—	—	260	13,130
Italy	37	587	—	—	—	—	4,860	94,260
Other	1,967	4,929	—	—	—	—	1,230	26,280
Total	2,599	9,735	—	—	—	—	6,350	133,670
1988:								
Canada	654	5,790	—	—	—	—	245	16,600
Italy	23	253	—	—	—	—	4,220	109,000
Portugal	246	881	—	—	—	—	80	940
South Africa, Republic of	91	2,495	—	—	—	—	—	—
Spain	26	60	—	—	—	—	505	14,700
Other	60	821	—	—	—	—	1,340	23,760
Total	1,100	10,300	—	—	—	—	6,390	165,000
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
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

[e]Estimated. [r]Revised.

[1]Includes crude or roughly trimmed, and merely cut by sawing or otherwise.

[2]Less than 1/2 unit.

Source: Bureau of the Census as modified by the U.S. Bureau of Mines.

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF MAJOR CATEGORIES OF DIMENSION MARBLE, BY COUNTRY

Country	Dressed marble slabs		Dressed marble, other		Rough marble[1]	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
1987:						
China	19,800	$9,155	2,250	$1,042	159	$6
Italy	296,320	120,692	72,890	29,686	2,350	511
Spain	88,470	20,161	12,560	2,868	125	15
Other	76,770	29,022	51,300	19,513	6,020	308
Total	481,360	179,030	139,000	53,109	8,654	840
1988:						
China	24,310	14,591	2,450	1,369	21	7
Italy	221,850	125,285	58,920	33,274	2,488	267
Spain	66,150	24,863	7,940	2,952	79	50
Other	82,690	36,576	40,100	23,110	11,272	743
Total	395,000	201,315	109,410	60,705	13,860	1,067
1989:						
China	6,033	2,951	606	430	417	245
Greece	15,777	18,620	1,808	2,049	6,466	1,084
Italy	126,862	109,082	34,977	32,541	14,894	8,760
Portugal	7,728	6,701	1,786	1,634	664	496
Spain	31,774	23,735	5,275	5,143	1,893	874
Other	29,208	25,911	20,966	16,392	5,660	3,541
Total	217,382	187,000	65,418	58,189	29,994	15,000
1990:						
China	3,968	3,181	778	168	132	$245
Greece	15,711	17,604	3,116	2,946	555	1,084
Italy	78,104	88,564	42,544	4,071	3,025	8,760
Portugal	5,028	5,001	1,297	47	43	496
Spain	15,482	14,164	5,897	239	235	874
Other	19,253	18,568	17,595	2,057	2,007	3,541
Total	137,546	147,082	71,227	9,528	5,997	15,000

[1]Marble, merely cut by sawing or otherwise.

Source: U.S. Bureau of the Census as modified by U.S. Bureau of Mines.

A new joint venture is trying to reopen a slate quarry in Company Tipperary. This will be a reappearance of the Killaloe slate of the 1800's. One of the partners is the Welsh slate-producing Penrhyn Quarries subsidiary of Alfred McAlpine PLC. The blue-gray slate will be made into roofing and other slate products mostly for the domestic market, but also to be exported to other English-speaking countries, particularly Scotland. The plant and infrastructure will have to be built from scratch, and the total investment may reach $2 millon. Good progress was being made by yearend.[3]

Sweden.—Sweden is one of the major European quarries of granite. About 80% to 90% of the granite gets exported in the form of rough block to the Federal Republic of Germany and Italy also to other destinations of lesser importance. However, Swedish exporters are having some difficulty providing the large, rough blocks that are easier to process in present state-of-the-art equipment. They are encountering increasing competition not only from Finland and Norway but also from Brazil, Canada, China, and Saudi Arabia. An unusually high proportion of the rough block is lost as waste in processing the rough blocks.

The largest dimension stone producer, Emmaboda Granit AB, operates 10 quarries and has a production capacity of about 50,000 tons per year. The firm has been 49% owned by Deutche Steinindustri AG since 1988. The Barap gneiss is the most important product, accounting for about one-half of the firm's production capacity. Domestic markets are served by a finishing plant at the town of Emmaboda.

The second largest producer is the Nilsten firm in Vastervik. AB Broderna Wallins Granitindustrier operates three quarries, two of which produce red granites, including the one that produces Red Vanga. About 80% of this firm's granite is exported to Italy and 10% to Germany. It has plans to open a new quarry for a yellowish granite.[4]

TABLE 14

U.S. IMPORTS FOR CONSUMPTION OF OTHER DIMENSION STONE, BY TYPE

(Thousand short tons and thousand dollars)

Type		1989		1990		Major source in 1990, (percent[1])
		Quantity	Value	Quantity	Value	
Calcareous stone-other	short tons	22,660	10,465	15,807	2,188	Mexico, 48%.
Marble, travertine and alabaster and other	do.	10,860	8,932	8,591	7,976	Italy, 61%.
Sandstone, merely cut, by sawing or otherwise	do.	4,926	569	475	168	India, 50%.
Slate, roofing	million square feet	10.3	4,474	9.8	4,909	Spain, 39%.
Slate, whether or not roughly trimmed or merely cut		NA	3,008	NA	1,816	Italy, 61%.
Slate, worked slate, articles of slate, and other		NA	12,319	NA	14,346	Italy, 65%.
Stone, worked monumental or building stone-other	short tons	19,642	8,625	28,119	33,098	Italy, 41%.
Travertine, worked monumental and/or building stone and articles thereof	do.	3,416	3,000	5,109	3,015	Italy, 94%.
Travertine, worked monumental or building stone	do.	25,173	11,114	34,014	11,930	Italy, 97%.
Other monumental or building stone	do.	34,767	3,764	11,973	1,599	Italy, 27%.
Other, stone-monumental or building stone-articles thereof	do.	8,008	1,721	2,876	1,515	Mexico, 81%.

NA Not available.
[1]By value.
Source: U.S. Bureau of the Census as modified by U.S. Bureau of Mines.

OUTLOOK

Projected demand for dimension granite totaled 1.7 million tons for 1995 and 2.5 million tons for the year 2000. Demand for dimension marble totaled 750,000 tons for 1995 and 1.1 million tons for the year 2000. Demand for dimension limestone totaled 350,000 tons for 1995 and 390,000 tons for the year 2000, while demand for slate ought to be 55,000 tons in 1995 and 57,000 tons in the year 2000. This relatively slow rate reflects a major drop in the market for building stone in 1989-91 and a welcome major recovery later in the 1990's. Certain segments will continue to grow rapidly, such as the uses in kitchens and bathrooms. The supply will be adequate and is likely to shift in favor of domestic producers.

[1]Taylor, H. China—World's Largest Granite Producer. Stone World, v. 7, No. 7, July 1990, pp. 57-58.
[2]Falk, L., and D. Hausser. The Eastern German Industrial Minerals Contribution. Ind. Miner. (London), No. 279, Dec. 1990, pp. 24-47.
[3]McMichael, B. Industrial Minerals of Eire. Ind. Miner. (London), No. 274, July 1990, pp. 44-47.
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STRONTIUM

By Joyce A. Ober

Mrs. Ober, a physical scientist with 13 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 Maureen Nash Riley, mineral data assistant; and the international production table was prepared by Virginia A. Woodson, international data coordinator.

The largest consumption of strontium compounds domestically and internationally was in the production of color television picture tube faceplate glass. Strontium carbonate, produced by processing the mineral celestite, was the most important strontium compound produced. Chemical Products Corp. (CPC) of Cartersville, GA, was the only U.S. producer of strontium compounds from celestite. CPC produced compounds from imported material because there were no active celestite mines in the United States.

Strontium occurs commonly in nature, averaging 0.034% of all igneous rock; however, only two minerals, celestite and strontianite, contain strontium in sufficient quantities to make its recovery practical. Of the two, only celestite has been found to occur in deposits of sufficient size to make development of mining facilities currently attractive. Celestite, the most common strontium mineral, consists primarily of strontium sulfate. Strontianite, the second most common mineral, consists primarily of strontium carbonate. Strontianite would be the more useful of the two common minerals because strontium is used most commonly in the carbonate form, but few deposits have been discovered that are suitable for development.

TABLE 1

SALIENT STRONTIUM STATISTICS

(Metric tons of contained strontium unless otherwise noted[1])

	1986	1987	1988	1989	1990
United States:					
Production, strontium minerals	—	—	—	—	—
Imports for consumption:					
Strontium minerals	13,200	16,900	18,100	12,000	21,500
Strontium compounds	4,300	5,000	7,800	11,300	11,800
Exports[2] (compounds)	680	1,600	3,000	3,200	1,300
Shipments from Government stockpile excesses	—	—	—	—	—
Price, average value of mineral imports at port of exportation, dollars per ton	$1[illegible]	$95	$85	$76	$86
World production[3] (celestite)	r153,000	r202,000	r236,000	r234,000	e235,000

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 U.S.S.R.

DOMESTIC DATA COVERAGE

The sole U.S. strontium carbonate producer voluntarily provided domestic production data to the U.S. Bureau of Mines. Production and stock data, however, were withheld from publication to avoid disclosing company proprietary data.

The Bureau also estimated the distribution of strontium compounds by end use. Of the 10 operations to which a survey request was sent, 8 responded. The information collected from this survey represents about 100% of the end-use data shown in table 2. Consumption for the nonrespondents was estimated using reported prior-year consumption levels.

ANNUAL REVIEW

Issues

The Government of Mexico requested a waiver of the competitive need limit for strontium carbonate. Under the General System of Preferences, Mexican strontium carbonate entered the U.S. duty free. A tariff was assessed against imports of strontium carbonate from Mexico when those imports represented more than 50% of total strontium carbonate imports. The duty free status was revoked in July 1990. The waiver was expected to be approved because there was no opposition from the domestic strontium carbonate producer, and the consumers favored the proposal.

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 occurred in California and Texas. U.S. celestite mines had at that time been inactive since World War I, and all demand for strontium minerals was met from foreign sources.

Strontium carbonate, the most important strontium compound by far, was produced in 1990 by one company in the United States. CPC was the only company

that produced strontium chemicals from celestite. The majority of the celestite CPC used was imported from Mexico. CPC utilizes the black ash method of strontium carbonate production at its facility. The black ash method and the soda ash method are the two most common recovery techniques. The black ash method, known alternatively as the calcining method, produces chemical-grade strontium carbonate, which contains at least 98% strontium carbonate. The soda ash or direct conversion method produces technical-grade strontium carbonate, containing at least 97% strontium carbonate.

The black ash method received its name because the first step in the procedure involves mixing the crushed and screened celestite with powdered coal, making a black mixture. The mixture is then heated to about 1,100° C, expelling oxygen in the form of carbon dioxide from the insoluble strontium sulfate to form water-soluble strontium sulfide.

Strontium sulfide is dissolved in water, and the resulting solution filtered. Carbon dioxide then passes through the solution or soda ash is added. Either compound provides the necessary carbon and oxygen for strontium carbonate to form and precipitate from the solution. The precipitated strontium carbonate is then removed from the solution by filtering and is dried, ground, and packaged. The sulfur released in the process is either recovered as elemental sulfur or in other byproduct sulfur compounds.

In the soda ash method, ground celestite is washed and most of the water removed. The thickened mixture is then mixed with soda ash and treated with steam for 1 to 3 hours. During this time, celestite and soda ash react to form strontium carbonate and sodium sulfate. Sodium sulfate is water soluble, making it possible to separate the insoluble strontium carbonate by centrifuging. Although the soda ash method is a simpler process, the lower grade of the product causes it to be the less preferred method of recovery. The black ash method is the most common method of strontium carbonate production, and new production facilities usually use black ash technology.

CPC purchased the strontium nitrate production facilities from FMC Corp. in Modesto, CA, when that company discontinued production of carbonate and nitrate in 1984. The company moved the equipment to Cartersville and now is also the sole U.S. producer of strontium nitrate.

There are several U.S. companies that produced strontium compounds from strontium carbonate. Mallinkrodt Inc. of St. Louis, MO, produced strontium chloride, and Mineral Pigments Corp. of Beltsville, MD, produced strontium chromate. A few other companies produced downstream strontium compounds, but on a very small scale.

Domestic strontium deposits were operated in 1944 near Blanket, in Brown County, TX; in Nolan County, TX; in the Fish Mountains in Imperial County, CA; and near Ludlow, CA.[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 the World War II, this demand disappeared, 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. In the past 20 years, color television production has become the major consumer of strontium. Because of unique properties that strontium compounds possess, technologies have developed that take advantage of those properties for specific applications. All color televisions and other devices containing color cathode-ray tubes sold in the United States were required by law to contain strontium in the faceplate glass of the picture tube. Strontium blocks X-rays better than barium, which was previously used, and although lead is a better X-ray barrier than strontium, it causes a browning of the glass, which makes its use undesirable. Major manufacturers of television picture tube glass incorporate about 8%, by weight, strontium oxide in their glass faceplate material. The strontium is added to the glass melt in the form of strontium carbonate, and during processing, it is converted to strontium oxide. In addition to blocking X-rays, the strontium improves the appearance of the glass, increasing the brilliance and improving the quality of the picture.

Trends in television production show a shift to larger, flatter tubes that require thicker glass, and therefore, more strontium. Although the television industry in the United States is considered mature, there is a continuing demand for replacement televisions as well as additional sets in large numbers of households. The trend to personal computers and sophisticated, computerized instrumentation increased the demand for strontium in color monitors for these devices.

Permanent ceramic magnets were another large end use for strontium compounds in the form of strontium ferrite. When these magnets were first developed, they were used primarily as magnetic closures for refrigerator doors. Applications have expanded to include extensive use in small direct current (dc) motors, especially for automotive applications such as windshield-wiper motors, as well as loudspeakers, other electronic equipment, toys, and magnetically attached decorative items.

Strontium ferrites are used in permanent ceramic magnets because they have high coercive force, high thermal and electrical resistivity, and are chemically inert. They retain their magnetism well, are not adversely affected by electrical currents or high temperatures, and do not react with most chemical solvents. Other properties that make the strontium magnets more attractive for specific applications are their resistance to demagnetization and lower density, making them more desirable in applications where weight is a factor.

Barium or lead can replace the strontium in ferrite magnets, but strontium ferrites have been found to possess the best combination of properties necessary for superior magnets.

One of the most consistent and continuing applications for strontium has been in pyrotechnic devices. Strontium burns with a brilliant red flame, and no other material has been found to be better in this application.

The strontium compound used most frequently in pyrotechnic devices was strontium nitrate. Some strontium compounds

are slightly hygroscopic, but strontium nitrate takes on very little water and imparts the desired brilliant red. Strontium carbonate, strontium oxalate, strontium sulfate, and strontium chlorate can be used in pyrotechnic applications, but strontium nitrate was used in significantly larger quantities than any of these.

Pyrotechnic devices were used in military and nonmilitary applications. Military pyrotechnic applications that contained strontium included tracer ammunition, military flares, and marine distress signals. Nonmilitary applications included warning devices and fireworks.

Strontium was used to remove lead impurities during the electrolytic production of zinc. Zinc used in diecasting alloys is required to contain less than 0.003% lead. Addition of strontium carbonate in sulfuric acid to the electrolyte reduced the lead content of the electrolyte and of the zinc that is deposited on the cathode.

The addition of strontium chromate to paint creates a coating that is resistant to corrosion. It is an effective coating for aluminum, most notably on aircraft fuselages and ships. These paints are used to some degree on aluminum packaging to prevent package corrosion. The nitrate and chloride contents of strontium chromate paint pigment are very strictly controlled to prevent corrosion.

Consumption of metallic strontium was still a very limited factor in total strontium consumption. Small amounts of strontium are added to molten aluminum to improve the castability of the metal, making it much more suitable for casting items that have been traditionally made from steel. The addition of strontium to the melt improves the machinability of the casting. The use of cast aluminum parts is currently gaining popularity in the automotive industry. Aluminum parts were impractical before modification techniques were developed. The reduction in the weight of the automobile by using cast aluminum parts instead of steel helps to improve energy efficiency of the cars incorporating these parts.

At the present time, other strontium 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 eliminates 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.

Prices

The average customs value for celestite imported from Mexico was about $80 per ton ($73 per short ton). Mexico was the source of 89% of all celestite imports in 1990. Another 10%, valued at $190 per ton ($172 per short ton), was imported from Spain. Average value for total strontium imports was about $85 per ton ($77 per short ton). This value was slightly higher than the average customs value reported for 1989. Values of imported strontium compounds varied according to the type of compound and the country of origin.

Foreign Trade

According to the Port Import/Export Reporting Service of The Journal of Commerce, U.S. exports of strontium compounds were about 2,200 tons, a 58% decrease from the exports reported from the same source in 1989. Of these exports, 98% was strontium carbonate that went to Taiwan. Other reported strontium exports were chloride, chromate, ferrite, nitrate, and peroxide, all in relatively small quantities.

The Bureau of the Census began using the Harmonized Tariff Schedule in 1989 to identify material passing through U.S. customs. This system makes classification codes for imports and exports consistent internationally. With the adoption of the new codes, imports and export codes for strontium changed, and some formerly listed details are no longer available. Trade information for strontium metal was grouped with barium under a classification of other alkaline earth metals, making specific information concerning strontium unavailable. Strontium chromate data were eliminated. Other strontium compounds experienced changes in classification numbers, and the grouping of compounds differed.

According to reports from the Bureau of the Census, imports of celestite increased 90% from the levels reported in 1989. Nearly all of it was from Mexico and a small amount from Spain.

Mexico continued to grow in importance as a source for imported strontium compounds; the Federal Republic of Germany was second. Imports of strontium carbonate were virtually the same as in 1989; with imports from Mexico becoming a larger percentage of total imports. Strontium carbonate from the Republic of Germany continued to decrease as Mexico took over more of that market. Imports of strontium nitrate nearly tripled for the second consecutive year.

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

TABLE 2

U.S. ESTIMATED DISTRIBUTION OF PRIMARY STRONTIUM COMPOUNDS, BY END USE

(Percent)

End use	1988	1989	1990
Electrolytic production of zinc	4	4	3
Ferrite ceramic magnets	11	10	9
Pigments and fillers	4	3	4
Pyrotechnics and signals	10	10	11
Television picture tubes	68	70	70
Other	3	3	3
Total	100	100	100

TABLE 3

U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM MINERALS,[1] BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Mexico	25,640	1,956	46,484	3,727
Spain	—	—	2,234	425
Other	—	—	6	37
Total	25,640	1,956	48,724	4,189

[1]Celestite (strontium sulfate).
[2]Customs value.

Source: Bureau of the Census.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM COMPOUNDS AND METAL, BY COUNTRY

Country	1989		1990	
	Kilograms	Value[1]	Kilograms	Value[1]
Strontium carbonate:				
Canada	18,000	11,256	17,781	2,978
China	—	—	75,000	45,558
France	216,000	131,602	—	—
Germany, Federal Republic of	4,427,276	2,992,291	2,806,028	2,018,791
Italy	3,648	3,520	—	—
Japan	934,883	635,860	6,300	33,899
Netherlands	—	—	15,506,833	9,210,192
Mexico	12,872,502	6,669,611	36,000	24,760
United Kingdom	6,137	11,012	16	12,670
Total	18,478,446	10,455,152	18,447,958	11,348,848
Strontium nitrate:				
Germany, Federal Republic of	600	8,536	—	—
Italy	43,003	40,725	17,000	16,016
Mexico	571,849	546,291	1,661,385	1,586,517
Spain	18,000	17,100	36,000	30,618
Total	633,452	612,652	1,714,385	1,633,151

[1]Customs value.

Source: Bureau of the Census.

occurs with barium and calcium, two elements with properties very similar to strontium, thus making separation difficult. Because removing many impurities from celestite is difficult and energy intensive, current strontium chemical producers require material to contain at least 90% strontium sulfate. Most of the currently operating celestite facilities can produce sufficient supplies with only minimal processing necessary to achieve acceptable specifications. Hand sorting and some washing are all that are necessary at many strontium mines; only a few operations use froth flotation or gravity separation to beneficiate their ore.

Detailed information on most world resources is not readily available. Many of the large deposits are in remote, sparsely inhabited areas, and very little formal exploration has been done. Other deposits may be well identified but are in countries from which specific mineral information is not easily obtained.

Capacity.— The data in table 5 are annual rated capacity for chemical processing plants as of December 31, 1990. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Two types of strontium capacity exist, ore production capacity and compound production capacity. Strontium compound capacity was deemed the more important for several reasons. Essentially, all strontium is consumed in compound form, primarily as the carbonate and to a lesser extent as the nitrate. Strontium carbonate is also the intermediate product in production of downstream compounds. At least 12 countries mined celestite in 1989. Virtually all of the celestite mined annually is consumed in the production of strontium carbonate and other strontium compounds. Very little strontium was consumed directly in the mineral form.

Listing both ore and compound production capacity could be misleading, possibly resulting in double-counting of strontium capacity. Because most ore is produced for market by means of very simple sorting and beneficiation techniques, capacity can easily be raised to meet increased demand. Strontium carbonate production capacity is the limiting factor in strontium production, requiring complicated and sophisticated processing facilities. Therefore, strontium carbonate production capacity, reported in terms of contained strontium, was selected for tabulation. Construction to expand strontium carbonate capacity has increased because of the continued growth in international sales of color television sets. Capacity information was compiled from published reports.

Algeria.—Celestite was mined in Algeria from a surface deposit near Beni Mansour. Estimated reserves were more

TABLE 5

WORLD STRONTIUM CARBONATE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990

(Metric tons)

Country	Rated capacity[1]
North America:	
Mexico	65,000
United States[2 3]	22,000
Total	87,000
Europe:	
Germany, Federal Republic of[2]	15,000
Spain	8,000
U.S.S.R	(4)
United Kingdom	(4)
Total	23,000
Asia:	
China	1,800
Japan[2]	31,000
Korea, Republic of	40,000
Total	72,800
World total	182,800

[1]Includes capacity at operating plants as well as plants on a stand-by basis.
[2]Production was entirely from imported celestite.
[3]Includes strontium nitrate production capacity.
[4]Strontium carbonate production capacity existed in these countries, but specific data were not available.

than 1 million short tons. The deposit was mined by Enterprise des Produits Nonferreux et des Substances Utiles (ENOF) and was controlled by L'Enterprise Nationale de Developpement Minière (Edemines), a division of Société Nationale de Recherches et d'Exploitations Minières (SONAREM). No strontium has been exported in recent years, but in the past, up to 3,600 tons per year has been exported to nations in Eastern Europe and the Federal Republic of Germany. Although the celestite was relatively low grade, only about 70% strontium sulfate, it contained low concentrations of barite, silicate, gypsum, and iron, making it possible to concentrate the ore to acceptable levels using only gravity separation. The deposit has not been fully exploited, but there is interest in further development.[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, Cerro Partido, and Llao Llao Mines in the Province of Neuquen. It is unlikely that any production was carried out on a regular basis at these mines. Most Argentine production was exported to Brazil.[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 at Enon, Cape Breton County, Nova Scotia. Mineral rights were acquired by Timminco Metals, a division of Timminco Ltd. of Toronto. 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 and the only producer of strontium metal in North America. The company operated a processing facility in Westmeath, Ontario. The strontium production facilities in Westmeath and facilities in Haley, Ontario, produce strontium metal by the aluminothermic reduction of strontium oxide.

China.—Celestite was mined in China almost exclusively for domestic consumption. An ore-dressing facility at the Nanjing Mine in Jiang Su Province has a capacity of 10,000 tons per year. The Nanjing deposit is reported to be high grade and close enough to the surface for open pit mining.[6] Past import data indicated that strontium chemical plants must exist, but no specific details were available. Reports indicated that Japan imports strontium carbonate from China and that strontium carbonate from China has also been reported in the United States.

Cyprus.—Celestite mining began in Cyprus in 1985 at Vassliko, near Limassol, in southern Cyprus. The mine was operated by Hellenic Mining Co. Ltd. The ore averaged about 54% strontium sulfate and, therefore, required concentration to make it marketable. The ore was beneficiated through a flotation process to reach 94% strontium sulfate. The reserves have been determined to be 200,000 tons of celestite.[7] No mining has occurred for the past 3 years.

Germany, Federal Republic of.—Kali-Chemie AG of Hannover produced strontium carbonate from imported celestite at its plant at Bad Hoenningen. The major western European producer used the black ash method in the production facilities. Plant capacity is estimated to be 15,000 tons per year. Kali-Chemie imported most of its celestite from Spain and Turkey; it exported 80% to 90% of the production, most of which goes to the United States and the Republic of Korea. Kali-Chemie also produced strontium hydroxide and strontium nitrate. The nitrate was produced by its Italian subsidiary, Societa Bario e Derivati SpA, in Massa.[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 Sanati Va Maadani Irani (Simiran). Average strontium sulfate values for the deposit were reported at more than 91%, but there were unfavorably high levels of barium sulfate and calcium sulfate. Proven reserves total 1.8 million tons of celestite, 430,000 tons of which has no overburden.[9] Most of the celestite produced from this deposit is believed to go to the U.S.S.R.

Italy.—Mining has been done by Minera Chimica Farnesiana SpA in Tarquinia, near Rome. Most production of this 75% strontium sulfate and 5% barium sulfate product was sold domestically. Annual production capacity at the mine was 7,300 tons per year, but production ceased in 1988. Some of the processed ore has been exported to the U.S.S.R. in the past. Other deposits are known to exist in the interior of Sicily, although none are presently being mined. Societa Bario e Derivati, a subsidiary of Kali-Chemie AG of the Federal Republic of Germany, produced strontium nitrate at Massa. Production and capacity figures were not available, but it was known that most of the production is exported to the United States.[10]

Japan.—No celestite was mined in Japan, but that country was the largest consumer of strontium carbonate in the

TABLE 6

STRONTIUM MINERALS: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1986	1987	1988	1989	1990[e]
Algeria[e]	5,400	5,400	5,400	5,400	5,400
Argentina	1,133	1,349	r2,241	r1,193	1,200
Cyprus (celestite)	7,365	6,300	—	—	—
Iran (celestite)[3]	r20,066	r39,194	r56,849	re55,000	55,000
Italy	4,667	177	—	—	—
Mexico (celestite)	24,042	47,739	r51,626	r51,755	52,000
Pakistan	997	r1,114	488	r956	1,000
Spain	34,500	r28,867	e40,000	e40,000	40,000
Turkey	r40,000	r49,000	54,000	e59,000	60,000
United Kingdom	14,739	22,655	25,553	r20,885	20,000
Total	r152,909	r201,795	r236,157	r234,189	234,600

[e]Estimated. [r]Revised.
[1]Table includes data available through May 24, 1991.
[2]In addition to the countries listed, China, Poland, and the U.S.S.R. produce strontium minerals, but output is not reported quantitatively, and available information is inadequate to make reliable estimates of output levels.
[3]Data are for year beginning Mar. 21 of that stated.

world, mostly due to its large television and electronics industry. Four companies produce strontium carbonate from imported celestite. Honjo Chemical Corp. operated a production facility for 18,000 tons per year of carbonate at Neyagawa in Osaka using celestite from Spain and China. Sakai Chemical Industries Co. also produced strontium carbonate, by the black ash method, in Osaka at a 12,000-ton-per-year plant using Chinese, Mexican, and Spanish celestite. Japan Special Chemicals (Nihon Tokushu Kasei) and 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.[11]

Korea, Republic of.—Although celestite deposits have not been identified in Korea, its growing electronics and television industry prompted a European company to form a joint venture with a Korean firm. Kali-Chemie and Samsung Corning Ltd., Korea, formed Daehan Specialty Chemicals Co. Ltd. to build a strontium carbonate and barium carbonate plant. The plant began operation in 1990 with a production capacity of 40,000 tons per year of strontium carbonate and barium carbonate, combined. The production will be targeted to the growing television industry in that country. The black ash method will be used.[12]

Mexico.—Two companies announced plans to build production facilities in the North. CPC planned to build a strontium carbonate plant in Reinosa, Tamaulipas, close to the U.S. border. Capacity should be about 22,000 tons per year.[13] Quimica Dinámica SA de CV, a Monterrey company that currently produces 8,000 tons of strontium carbonate, formed a joint venture with an unnamed Japanese company to create Cistron Mexicana SA de CV. The new company is expected to build a strontium carbonate plant initially designed to produce 30,000 tons per year, with a possible doubling of capacity in a second phase of construction.[14]

Strontium carbonate production has been a recent development in Mexico. This is a very attractive location for additional production facilities because of the huge celestite resources in the country. After a major U.S. strontium carbonate and strontium nitrate producer (FMC Corp.) closed its plant in 1984, Cia. Minera La Valenciana SA (CMV) bought the strontium carbonate processing equipment from the FMC plant in California. The plant, which utilized the soda ash method of carbonate production and was converted to the black ash method, was relocated to Torreón in Coahuila State, near a company-operated mine. The plant capacity is 50,000 tons per year. Shipments from the plant, targeted for the television and electronics industry in the Far East, commenced in May 1987. Sales y Oxidos (SYOSA), 49% owned by Kali-Chemie, built a new strontium carbonate plant near Monterrey with the capacity of 15,000 tons per year. The company's old strontium carbonate operation will be converted to produce barium carbonate. SYOSA, which produced carbonate by the black ash method from celestite it mines nearby, marketed its production in the United States.[15]

Mexico was one of the world's largest producers of celestite in 1990. The most recent Directory of Mexican Non-Metallic Minerals Trust lists 11 companies currently mining celestite. CMV mined celestite from the San Agustín deposit near Torreón, and Compañía Minera Ocampo SA mined a deposit near Saltillo in Nuevo Leon State, as well as some small production in Hidalgo, Aguascalientes, and Chihuahua States. Reserves of the San Augustín Mine alone have been estimated at more than 725,000 tons. SYOSA mines west of Monterrey. Other small operations occur in Coahuila, Aguascalientes, Chihuahua, and Nuevo Leon. Mexican celestite is primarily high grade, and only hand sorting is required to achieve at least 92% strontium sulfate with low barium content. Abandoned mines and easily identified deposits that have not yet been developed are common throughout a large area in northern Mexico. Reserves are believed to be vast, but these deposits have not been extensively explored.[16]

Pakistan.—All 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.[17] 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.[18] Other deposits, with 500,000 tons of reported reserves, have been identified in the Punjab Province.[19]

Spain.—Spain was another 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 Spanish production is exported to Japan, some remains in Spain, and the rest is exported to the Federal Republic of Germany.[20] Promotora de Industria del Sur (Proinsur SA) produced strontium carbonate and strontium nitrate at a combined facility near Granada. The plant has a theoretical design capacity of 8,000 tons per year of carbonate, but has never reached this capacity. Strontium carbonate was produced by the soda ash method. The plant also has a production capacity of about 3,000 tons per year of nitrate, which has not yet been fully utilized.[21]

Turkey.—Turkey competes with Mexico, Spain, and Iran in claiming the world's largest strontium reserves. Barit Maden Turk AS produced celestite from a mine near Sivas. Run-of-mine ore was gravity separated to produce a concentrate with a minimum of 95% strontium sulfate. Because of the harsh climate in the region, the mine can only be operated on a seasonal basis, from May to October. Another mine near Sivas was formerly operated by Bilfer Madencilik AS, which reestablished concessions for future celestite mining. Identified reserves have been placed at 550,000 tons, and further reserve potential is estimated to be greater than 2 million tons. Turkish celestite was primarily exported to the Federal Republic of Germany.[22]

U.S.S.R.—Very little is known about Soviet production of strontium minerals. 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.[23] No details are available concerning the production of strontium carbonate in the U.S.S.R. except that there is production, probably from domestic celestite as well as from imports from Iran and Turkey.

United Kingdom.—Celestite deposits, which occur in the Bristol area, were mined by Bristol Minerals Co. Ltd. The ore is crushed, washed, and graded to achieve a product with 95% strontium sulfate. Reserve estimates vary from 100,000 to 500,000 tons. The British deposits continue to be encroached upon by large-scale housing developments, limiting possible exploitation of the minerals to the near future. This was one of the few sites where celestite deposits are not in remote locations.[24]

Current Research

Strontium-90, a radioactive isotope of strontium, is a component of nuclear waste from reactors and nuclear fallout. It presents special problems for waste disposal and storage because it generates a significant amount of heat as it decays. When released into the atmosphere through nuclear testing or accidents, it easily enters the food supply in milk and vegetables because it is so similar chemically to calcium. Scientists at Argonne National Laboratory have developed a process for removing strontium-90 from liquid nuclear waste.

The method known as SREX dissolves more than 99.999% of the strontium-90 from the waste stream in a special solvent. Pure strontium-90 is then removed from the solvent with water or dilute acid. The recovered strontium-90 could be used in radio-isotopic thermal generators that are used in devices such as harbor markers, which require long-lasting, unattended power supplies.[25]

OUTLOOK

The future continues to look bright for the strontium industry for the near term, although if both planned operations in Mexico are actually accomplished, a serious oversupply situation could occur. 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 likewise. 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. Although a high-quality, large, flat screen is not yet available, small models are, and research continues to perfect 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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SULFUR

By David E. Morse

Mr. Morse, a physical scientist with 14 years U.S. Bureau of Mines experience, has been the commodity specialist for sulfur since 1981. Domestic survey data were prepared by Jessie G. Austin, mineral data assistant; and the international data table was prepared by Harold D. Willis, international data coordinator.

Sulfur, through its major derivative sulfuric acid, ranks as one of the more important elements utilized by humanity as an industrial raw material. It is of prime importance to every sector of the world's industrial and fertilizer complexes. Sulfuric acid consumption has been regarded as one of the best indexes of a nation's industrial development.

The United States retained its position as the world's foremost producer and consumer of sulfur and sulfuric acid in 1990. Production from U.S. Frasch mines decreased slightly to about 3.7 million metric tons. Erection began on the structures to develop a major salt dome discovery on Federal lease block Main Pass 299 in the Gulf of Mexico, which had been 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.

Production of recovered elemental sulfur, a nondiscretionary byproduct of petroleum refining and natural gas processing, continued to increase and set a record-high production standard. Recovered elemental sulfur shipments to domestic consumers were greater than Frasch shipments. Recovered sulfur exports, primarily from California where sulfur supplies exceeded local demands, were higher than Frasch sulfur exports.

Byproduct sulfuric acid from the Nation's nonferrous smelters and roasters, essentially mandated by laws concerning sulfur dioxide (SO_2) emissions, supplied a significant quantity of sulfuric acid to the domestic merchant acid market. Marketing sulfuric acid continued to be difficult for some producers because smelters were near western copper mines and far from major sulfuric acid markets.

Total world production of sulfur in all forms decreased slightly compared with that of 1989; Frasch sulfur output decreased because of a United Nation's trade embargo against Iraq that affected Iraqi output and reduced output in the United States and the U.S.S.R. Recovered elemental production increased in Asia and North America, decreased slightly in Western Europe because of declining production from gas plants, and held at a reduced level in Eastern Europe because of continuing technical problems at gas processing facilities in the U.S.S.R. Nearly five-eighths of the world's elemental sulfur production came from recovered sources; the quantity of sulfur supplied from these sources was dependent on the world demand for fuels and petroleum products, not on the demand for sulfur.

World consumption decreased slightly despite an increase in fertilizer manufacture use, especially in the fertilizer-producing countries of North Africa. 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 increased by an estimated 1 million metric tons, but was about 1.8 million tons less than the quantity traded in 1988. Although individual country sulfur inventories showed important variations from yearend 1989, total world producers' stocks of elemental sulfur were reduced by about 1 million tons, a return to the annual decreases that had been characteristic of the 1980's.

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 173 operations to which a survey request was sent, 172 responded, representing 99.99% of the total production shown in tables 1 and 2. The production of the nonrespondent was estimated using prior production histories adjusted to reflect trends in output of its primary products.

BACKGROUND

Sulfur, known as brimstone, "the stone that burns," was used in small quantities for thousands of years. Ancients 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 employed the burning of 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

TABLE 1

SALIENT SULFUR STATISTICS

(Thousand metric tons, sulfur content, and thousand dollars unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Production:					
Frasch	4,043	3,202	3,174	3,888	3,726
Recovered[1]	5,816	6,161	6,444	6,510	6,536
Other forms	1,228	1,176	1,128	1,194	1,298
Total	11,087	10,539	10,746	11,592	11,560
Shipments:					
Frasch	4,108	3,610	4,341	3,780	3,676
Recovered[1]	5,798	6,180	6,470	6,475	6,483
Other forms	1,228	1,176	1,128	1,194	1,298
Total	11,134	10,966	11,939	11,449	11,457
Exports, elemental[2]	1,895	1,242	1,223	1,024	972
Imports, elemental	1,347	1,599	1,996	2,260	2,571
Consumption, all forms	10,586	11,323	12,712	12,685	13,056
Stocks, Dec. 31: Producer, Frasch and recovered	2,748	2,316	1,112	1,301	1,423
Value:					
Shipments, f.o.b. mine or plant:					
Frasch	$508,512	$386,834	$430,814	$378,712	$335,189
Recovered[1]	$533,752	$492,136	$498,368	$509,582	$479,011
Other forms	$105,639	$90,707	$88,181	$104,304	$117,139
Total	$1,147,903	$969,677	$1,017,363	$992,598	$931,339
Exports, elemental[3]	$251,664	$139,431	$131,863	$107,126	$109,327
Imports, elemental[4]	$142,220	$152,096	$185,864	$209,465	$206,450
Price, elemental, dollars per metric ton, f.o.b. mine or plant	$105.22	$89.78	$85.95	$86.62	$80.14
World: Production, all forms (including pyrites)	r53,736	r56,582	58,528	58,717	e57,668

e Estimated. r Revised.
[1] Includes Puerto Rico and the Virgin Islands.
[2] Includes exports from the Virgin Islands to foreign countries.
[3] Includes value of exports from the Virgin Islands to foreign countries.
[4] Declared customs valuation.

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 the most common acid in the chemical industry.

Sulfur is one of the few elements that occurs in the native, or elemental, state. It also occurs combined with iron and base metals as sulfide minerals and with the alkali metals and alkali earths as sulfate minerals. In petroleum, sulfur is found in a variety of complex organic compounds and in natural gas as hydrogen sulfide (H_2S) gas. In coal, sulfur occurs in complex organic compounds and as "coal brasses" (pyrites-marcasite). Commercial production of sulfur in the United States is accomplished by a variety of methods dictated by the source of sulfur.

Definitions, Grades, and Specifications

Native Sulfur.—Sulfur occurring in nature in the elemental form.

Pyrites.—Iron sulfide minerals that include pyrite, marcasite, and pyrrhotite.

Sulfur Ore.—Unprocessed ore containing native sulfur.

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.

Recovered Sulfur.—Elemental sulfur produced from combined sulfur sources by whatever method.

Crude Sulfur.—Commercial nomenclature for elemental sulfur.

Brimstone.—Synonymous with crude sulfur.

Broken Sulfur.—Solid crude sulfur crushed to minus 8-inch size.

Slated Sulfur.—Solid crude sulfur in the form of slatelike lumps produced by allowing molten sulfur to solidify on water-cooled, moving belt.

Prilled Sulfur.—Solid crude sulfur in the form of pellets produced by cooling molten sulfur with air or water.

Bright Sulfur.—Crude sulfur free of discoloring impurities and bright yellow in color.

Dark Sulfur.—Crude sulfur discolored by minor quantities of hydrocarbons ranging up to 0.3% carbon content.

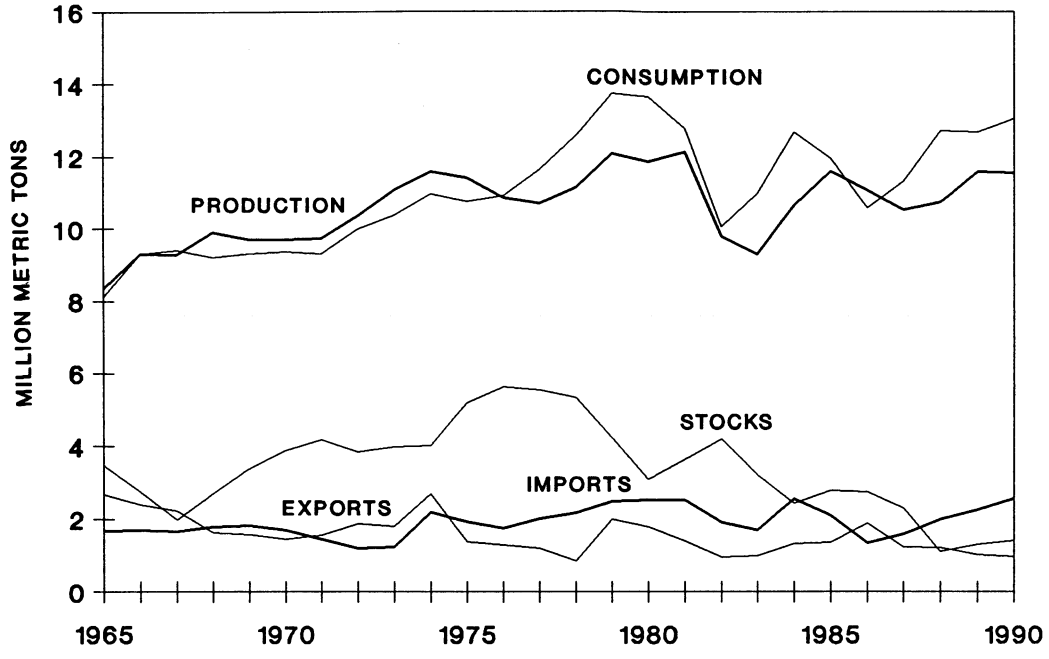
Sulfuric Acid.—Sulfuric acid of commerce produced from all sources of sulfur, generally reported in terms of 100% H_2SO_4 with a 32.69% sulfur content.

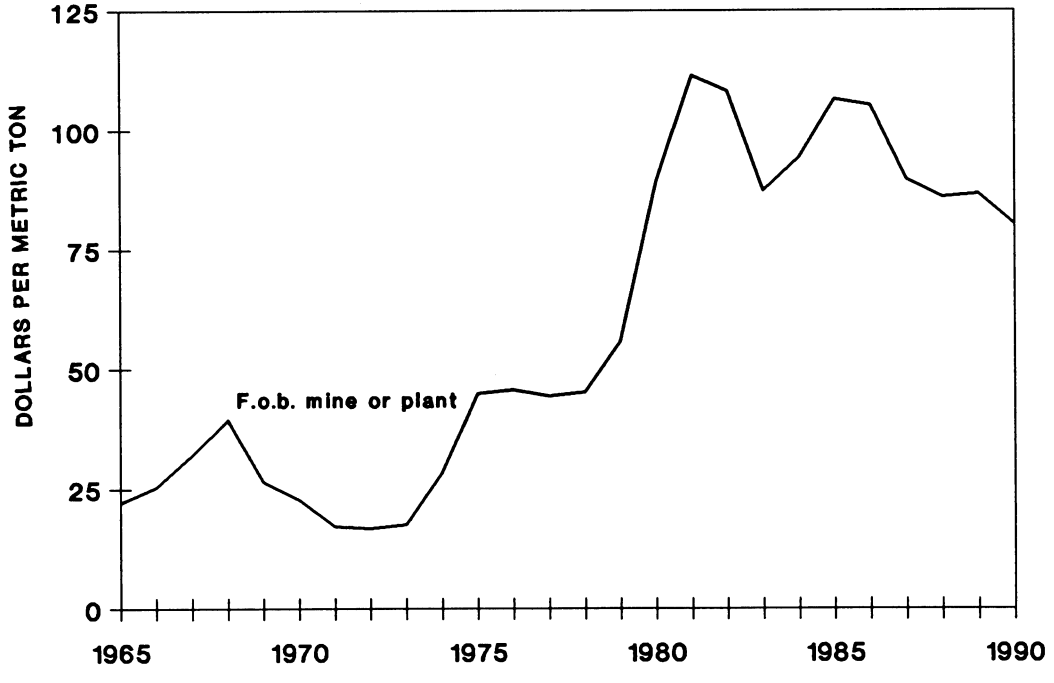
Products for Trade and Industry

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 99.55%. 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

FIGURE 1

TRENDS IN THE SULFUR INDUSTRY IN THE UNITED STATES





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, which led to exorbitant sulfur prices, caused 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 from 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 1990, world sulfur production and consumption amounted to 57.7 and 58.9 million tons, respectively. The United States and the U.S.S.R. were the world's largest producers; both nations, however, were net importers of sulfur. Canada and Poland, respectively, the third and fourth largest world producers, ranked first and second among the world's exporting nations. China, the world's fifth 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 the elemental form; it also occurs combined with other elements as sulfides, sulfates, or organic compounds in sedimentary, metamorphic, and igneous rocks, as well as in all fossil fuels. By type, sulfur deposits are classified as follows:

Native (Elemental) Sulfur Deposits.—These include deposits (1) in anhydrite-limestone cap-rock on the top and flanks of salt domes, (2) in bedded anhydrite-gypsum evaporite basin formations, and (3) in unconsolidated volcanic deposits. In salt dome cap-rock and evaporite beds, the sulfur is believed to have been formed by hydrocarbon reduction of anhydrite, assisted by bacterial action. Volcanic sulfur was produced by the reaction between escaping hydrogen sulfide and sulfur dioxide.

Large deposits over salt domes are mined in the gulf coast regions of the United States and Mexico. Extensive deposits in evaporites are mined in west Texas, Iraq, Poland, and the U.S.S.R. Together, these deposits are by far the principle source of mined elemental sulfur, generally extracted by the Frasch hotwater 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 resource. 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 world sulfur supply. Major deposits of sour natural gas occur in western Canada, the Near East, and the U.S.S.R.; substantial deposits occur in the mountain and gulf coast regions of the United States, in Mexico, France, the Federal Republic of Germany, 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. Because of environmental concerns, the portion of contained sulfur removed continues to increase annually. The vast petroleum reserves of the Near East contain high percentages of sulfur, as do many of the recent discoveries in Mexico and off the U.S. west coast. Additionally, Canadian tar sands constitute a major sulfur resource.

Coal and Oil Shale.—Sulfur occurs as pyrites or complex organosulfur compounds in varying concentrations

in both coal and oil shales. Although little sulfur is produced from these vast resources at present, the potential for large-scale output exists in the United States and in the rest of the world.

Economic Factors

During the past 20 years, world sulfur price leadership has shifted from dominance by the U.S. Frasch producers to the Canadian exporters. The transfer was aided in the 1980's by Canada's ability to export most of its production from the Port of Vancouver and by its willingness to ship large volumes of sulfur from vatted stocks. The maturation of Sultran Ltd., dealing almost exclusively with sulfur destined for the offshore market, into a well-organized and skilled transportation arm of the Canadian sulfur industry aided immeasurably in Canada's ascension to world price leadership.

In the United States, the quoted liquid Frasch sulfur price, f.o.b. terminal Tampa, FL, is the bench-mark price. Recovered sulfur producers, in many cases, consider the economic desirability of producing sulfur subordinate to the necessity of producing it. As a result, domestic recovered elemental sulfur producers normally offer sulfur at a price $5 to $15 per ton below the Tampa quote to ensure prompt sale and reduce storage costs. This marketing strategy has resulted in restricting Frasch sulfur sales from many market areas that they formerly served.

During the 1980's, the sulfur price showed a significant degree of volatility compared with its prior history (see figure 1). The worldwide recession of 1982 and the U.S. Department of Agriculture Payment In Kind program in 1983 reduced world sulfur production and demand. Tampa prices fell from $147.50 per long ton to $122.50 from mid-1982 to yearend 1983. Vancouver, British Columbia, export prices were down from $127.50 in mid-1981 to $85.50 in December 1983. Prices escalated rapidly in 1984 because of a tremendous increase in demand in the United States and worldwide. The quoted Frasch price at Tampa, FL, increased $25 per long ton during the year, and the spot price from Vancouver, British Columbia, jumped $60 per ton. A downward spiral began in mid-1986 because of a slight softening in demand and increased competition for world markets. The Tampa price decreased $20 from August 1986 to September 1987, and Vancouver prices were off about $37 during the same time period. Tampa prices were stable for about 1 year and then increased $12.50 per long ton during the latter part of 1988. Vancouver prices declined another $2 to $3 per ton in late 1987 and held steady until the latter part of 1988 when they rose about $10 per ton. In 1989, the posted price for liquid sulfur, exterminal Tampa, FL, began the year at $142, decreased to $138 per long ton in June, fell to $130 in July, and dropped an additional $12.50 per long ton in September to $117.50. Spot prices and contract prices for sulfur, f.o.b. Vancouver, British Columbia, Canada, were $100 to $108 per metric ton during the first half of the year; Vancouver spot prices decreased to $90 per ton in July, fell further to about $80 per ton well before the end of the third-quarter, and remained at that level through the fourth-quarter.

Domestic and international sulfur price quotations increased steadily and substantially during 1990. The posted liquid Frasch price at Tampa, FL, was raised on three occasions, ending the year at $140 per long ton. Vancouver, British Columbia, solid sulfur spot price indications at the end of 1990 were in the mid-$90 per metric ton range.

TABLE 2

TIME-PRICE RELATIONSHIPS FOR SULFUR[1]

Year	Actual prices	Based on constant 1990 dollars
1971	17.19	50.91
1972	16.76	47.40
1973	17.56	46.65
1974	28.42	69.21
1975	44.91	99.59
1976	45.72	95.28
1977	44.38	86.72
1978	45.17	82.27
1979	55.75	93.27
1980	89.06	136.66
1981	111.48	155.95
1982	108.27	142.38
1983	87.24	110.41
1984	94.31	115.15
1985	106.46	126.24
1986	105.22	121.59
1987	89.78	100.56
1988	85.95	93.18
1989	86.62	90.19
1990	80.14	80.14

[1] Based on the average reported prices for elemental sulfur (Frasch and recovered), f.o.b. mine and/or plant, these prices reflect essentially 90% of the shipments of sulfur in all forms during 1971–90.

ANNUAL REVIEW

Production

Frasch.—Native sulfur associated with the cap-rock of salt domes and in sedimentary deposits is mined by the Frasch hotwater method, in which the native sulfur is melted underground and brought to the surface by compressed air. In January 1990, the United States had five Frasch mines operating in Texas and Louisiana. Mines in Louisiana were Freeport Sulphur Co. at Garden Island Bay on the Mississippi River Delta and Grand Isle and Caminada Pass, 7 miles and 9 miles, respectively, offshore in the Gulf of Mexico. Mines in Texas were Pennzoil Sulphur Co. at Culberson and Texasgulf Inc. (TG) at Boling Dome in Wharton County. At yearend, the Frasch mining industry was operating at about 90% of rated capacity.

In December 1988, Freeport McMoRan Resource Partners, operator for a consortium that included the IMC Fertilizer Group Inc. and Felmont Oil Co., reported a geologic reserve of 50 million long tons of sulfur on its Federal lease block, Main Pass 299, which is offshore in the Gulf of Mexico 17 miles from the mouth of the Mississippi River. The announcement was based on the results of five exploratory holes. Additional drilling in 1989 that delineated the size of the salt dome deposit brought the total reserve to 67 million long tons, which made Main Pass 299 the second largest domestic sulfur deposit yet discovered. Freeport McMoRan began erecting the offshore platform for the mine in 1990. The company planned to ready Main Pass 299 for production by late 1991 or early 1992, which would require an investment of more than $550 million. Pennzoil performed exploratory drilling operations on offshore Federal leases that it had acquired in 1988.

Frasch sulfur output decreased

160,000 tons from the quantity produced in 1989. Total shipments to domestic and overseas consumers decreased by more than 100,000 tons. Frasch sulfur accounted for 32% of domestic production in 1990. Approximately 91% of Frasch sulfur shipments was for domestic consumption and 9% for export. The total value of Frasch sulfur shipments decreased by more than $40 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 57% of the total domestic output of sulfur in all forms compared with 56% in 1989. Production and shipments reached alltime high levels owing to record production from the Nation's petroleum refineries. Production and shipments from natural gas processing plants declined primarily because of lengthy maintenance periods at two of the largest facilities. 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 15 reporting an annual production exceeding 100,000 tons. By source, 64% was produced at 84 refineries or satellite plants treating refinery gases and 3 coking plants. The remainder was produced by 27 companies at 64 natural gas treatment plants. The five largest recovered-sulfur producers in 1990 were Chevron U.S.A. Inc., Exxon Co. U.S.A., Shell Oil Co., Standard Oil Co. (Indiana), and Star Enterprise. The 51 plants owned by these companies accounted for 57% of recovered elemental sulfur output during the year.

Byproduct Sulfuric Acid.—Byproduct sulfuric acid at copper, lead, molybdenum, and zinc roasters and smelters amounted to 11% of the total domestic production of sulfur in all forms. Seven 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 accounted for 73% of the output, and production in

TABLE 3

PRODUCTION OF SULFUR AND SULFUR-CONTAINING RAW MATERIALS IN THE UNITED STATES

(Thousand metric tons)

	1989		1990	
	Gross weight	Sulfur content	Gross weight	Sulfur content
Frasch sulfur	3,888	3,888	3,726	3,726
Recovered sulfur[1]	6,510	6,510	6,536	6,536
Byproduct sulfuric acid (100% basis) produced at copper, lead, molybdenum, and zinc plants	3,641	1,190	3,959	1,294
Other forms[2]	8	4	8	4
Total	XX	11,592	XX	11,560

XX Not applicable.
[1] Includes Puerto Rico and the Virgin Islands.
[2] Includes hydrogen sulfide, liquid sulfur dioxide, and pyrites.

TABLE 4

SULFUR PRODUCED AND SHIPPED FROM FRASCH MINES IN THE UNITED STATES

(Thousand metric tons and thousand dollars)

Year	Production			Shipments	
	Texas	Louisiana	Total[1]	Quantity	Value[2]
1986	2,463	1,579	4,043	4,108	508,512
1987	1,833	1,369	3,202	3,610	386,834
1988	1,991	1,183	3,174	4,341	430,814
1989	2,380	1,508	3,888	3,780	378,712
1990	2,303	1,424	3,726	3,676	335,189

[1] Data may not add to totals shown because of independent rounding.
[2] F.o.b. mine.

TABLE 5

RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES[1]

(Thousand metric tons and thousand dollars)

Year	Production			Shipments	
	Natural gas plants	Petroleum refineries[2]	Total	Quantity	Value[3]
1986	2,246	3,570	5,816	5,798	533,752
1987	2,536	3,624	[4]6,161	6,180	492,136
1988	2,501	3,943	6,444	6,470	498,368
1989	2,537	3,973	6,510	6,475	509,582
1990	2,336	4,200	6,536	6,483	479,011

[1] Includes Puerto Rico and the Virgin Islands.
[2] Includes a small quantity from coking operations.
[3] F.o.b. plant.
[4] Data do not add to total shown because of independent rounding.

TABLE 6

RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1989			1990		
	Production	Shipments		Production	Shipments	
		Quantity	Value		Quantity	Value
Alabama	410	411	40,443	375	375	33,056
California	680	677	39,881	697	700	38,705
Florida	67	67	W	55	55	W
Illinois	252	252	21,852	260	260	20,894
Louisiana	613	616	59,217	669	665	61,434
Michigan and Minnesota	172	172	14,463	185	185	14,369
Mississippi	703	710	64,839	727	715	48,606
New Mexico	45	45	3,001	48	48	2,989
North Dakota	98	99	6,460	109	110	6,368
Ohio	48	48	3,968	46	47	4,245
Pennsylvania	67	68	6,001	70	70	3,711
Texas	1,603	1,602	141,818	1,653	1,645	142,100
Wyoming	1,104	1,110	51,709	944	938	44,568
Other[1]	647	599	55,932	700	671	57,968
Total[2]	6,510	6,475	509,582	6,536	6,483	479,011

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 Virgin Islands, and data indicated by symbol W.
[2]Data may not add to totals shown because of independent rounding.

five States was 89% of the total. The five largest producers of byproduct sulfuric acid were ASARCO Incorporated, Cyprus Miami Mining Corp., Kennecott, Magma Copper Co., and Phelps Dodge Corp. Their eight plants produced 87% of the 1990 total.

Pyrites, Hydrogen Sulfide, and Sulfur Dioxide.—The total sulfur contained in these products did not constitute a significant portion of total domestic sulfur production.

Consumptiom and Uses

Domestic consumption of sulfur in all forms continued the strong performance exhibited in 1988 and 1989. In 1990, 80% of the sulfur consumed was obtained from domestic sources compared with 82% in 1989 and 84% in 1988. The sources of supply were domestic recovered elemental sulfur, 45%; domestic Frasch sulfur, 25%; and combined domestic byproduct sulfuric acid, pyrites, hydrogen sulfide, and sulfur dioxide, 10%. The remaining 20% 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

TABLE 7

RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY PETROLEUM ADMINISTRATION FOR DEFENSE (PAD) DISTRICT

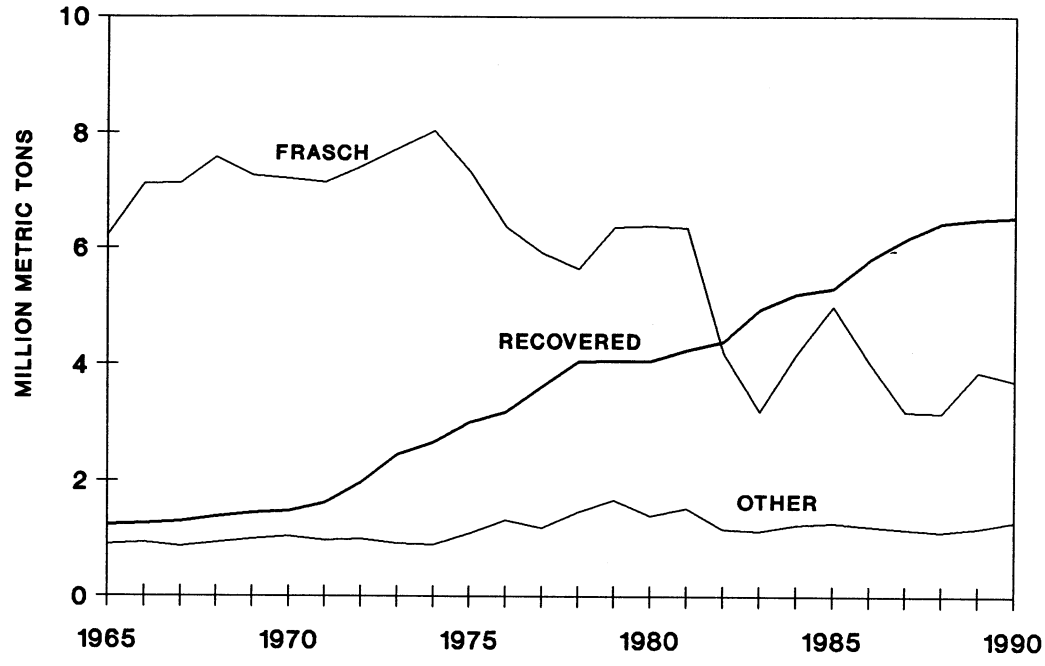
(Thousand metric tons)

District and source	1989		1990	
	Production	Shipments	Production	Shipments
PAD 1:				
Petroleum and coke	305	302	306	305
Natural gas	66	66	55	55
Total[1]	371	369	362	361
PAD 2:				
Petroleum and coke	630	629	674	675
Natural gas	98	99	110	110
Total[1]	729	728	784	786
PAD 3:[2]				
Petroleum	2,182	2,153	2,329	2,287
Natural gas	1,281	1,284	1,241	1,234
Total[1]	3,464	3,437	3,571	3,521
PAD 4 and 5:				
Petroleum	854	842	890	892
Natural gas	1,090	1,096	929	924
Total	1,944	1,938	1,820	1,816
Grand total[1]	6,510	6,475	6,536	6,483

[1]Data may not add to totals shown because of independent rounding.
[2]Includes Puerto Rico and the Virgin Islands.

FIGURE 2

TRENDS IN THE PRODUCTION OF SULFUR IN THE UNITED STATES



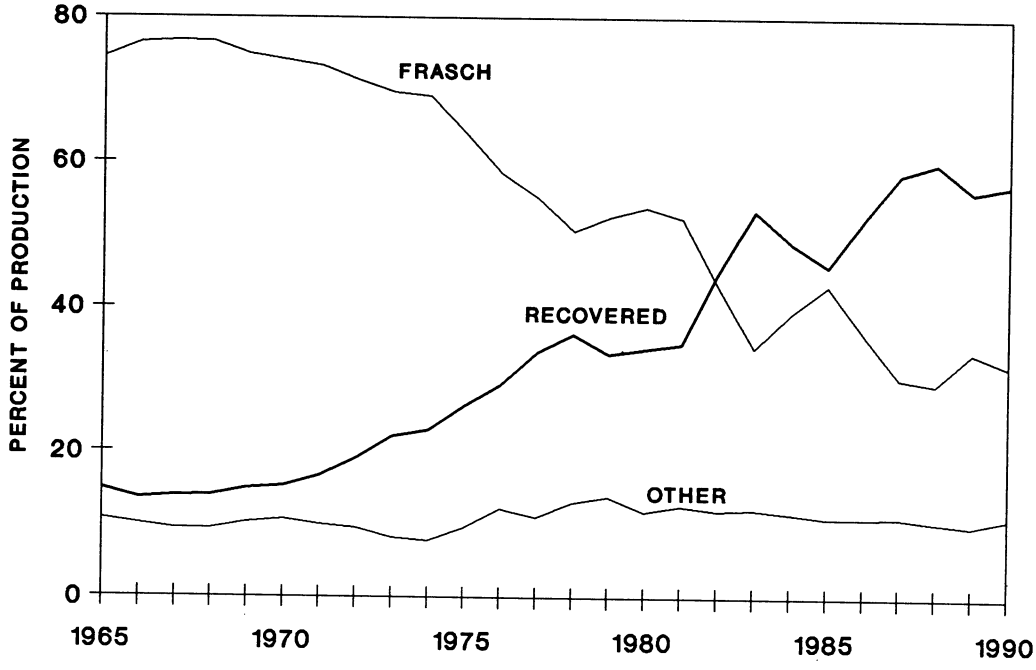


TABLE 8

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 molybdenum plants[3]	Total	Value
1986	755	124	40	919	54,164
1987	831	134	38	1,003	61,996
1988	946	136	43	1,125	87,820
1989	1,005	134	51	1,190	103,526
1990	1,105	135	54	1,294	116,356

[1] Includes acid from foreign materials.
[2] Excludes acid made from pyrites concentrates.
[3] Excludes acid made from native sulfur.

TABLE 9

PYRITES, HYDROGEN SULFIDE, AND SULFUR DIOXIDE SOLD OR USED IN THE UNITED STATES

(Thousand metric tons, sulfur content, and thousand dollars)

Year	Pyrites	Hydrogen sulfide	Sulfur dioxide	Total	Value
1986	W	W	W	309	51,475
1987	W	W	W	173	28,711
1988	W	W	W	3	361
1989	W	W	—	4	778
1990	W	W	—	4	783

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

Classification of industrial activities. Shipments by end use of elemental sulfur were reported by 60 companies, and shipments of sulfuric acid were reported by 53 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 shipments for domestic consumption.

Some identified sulfur end uses were tabulated in the "Unidentified" category because these data were proprietary. Data collected from companies that did not identify shipment by end use were also tabulated as "Unidentified." Although there is no supporting data, it could be reasonably assumed that a significant portion of the sulfur in the "Unidentified" category was shipped to sulfuric acid producers or was exported. The difference between exports reported in the canvass and exports of 0.97 million tons reported by the Bureau of the Census may have been caused by differences in accounting between company records and compilations by the Census Bureau or by sales to other parties that exported sulfur and were not included in the U.S. Bureau of Mines canvass.

Sulfuric acid, because of its desirable properties, retained its position, both domestically and worldwide, as the most universally used mineral acid and the largest volume inorganic chemical in terms of the quantity produced and consumed. U.S. shipments of sulfuric acid (100% basis) increased by more than 100,000 tons in 1990 because of continued high demand for the production of phosphoric acid, the largest single end use. Sulfuric acid demand for copper ore leaching, the second largest end use, increased 158,000 tons to about 2 million tons because solvent extraction-electrowinning (SX-EW) operations could produce high-purity copper at a significantly lower cost than by conventional smelting methods. Reported shipments of sulfuric acid for petroleum refining and other petroleum and coal products decreased significantly from those of 1990.

According to the 1990 canvass reports, company receipt of spent or contaminated sulfuric acid for reclaiming totaled 2.6 million tons. The largest source of this spent acid continued to be the petroleum refining industry, which accounted for 55% of the total returned. About 1.0 million tons of spent acid was reclaimed from plastic and synthetic materials producers. The remaining reclaimed acid was from manufacturers of soaps and detergents, steel, industrial organic chemicals, inorganic chemicals, other chemical products, storage batteries, explosives, agricultural chemicals, and some unidentified sources.

The largest use of sulfur in all forms, for agricultural purposes, increased slightly from 9.1 million tons in 1989 to about 9.2 million tons. The quantity of sulfur needed to manufacture exported agricultural chemicals decreased by more than 150,000 tons to 4.5 million tons, indicating that consumption for domestic purposes, especially for phosphatic fertilizers, increased by more than 250,000 tons.

Stocks

Yearend inventories held by Frasch and recovered elemental sulfur producers increased 9% from those of 1989, but remained well below historical levels. Combined yearend stocks amounted to approximately a 50-day supply compared with a 45-day supply in 1989, a 38-day supply in 1988, and an 82-day supply in 1987, based on domestic and export demands for Frasch and recovered sulfur.

Markets and Prices

The posted price for liquid sulfur, exterminal Tampa, FL, began the year at $123 and increased to $128 per long ton in May because of the continued strong showing of the Florida phosphate industry. Canadian sulfur exporters, encouraged by first half 1990 sales, expected to recoup part of their 1989

TABLE 10

CONSUMPTION OF SULFUR[1] IN THE UNITED STATES

(Thousand metric tons)

	1986	1987	1988	1989	1990
Frasch:					
Shipments	4,108	3,610	4,341	3,780	3,676
Exports	1,250	465	464	330	348
Imports	726	793	1,079	1,086	1,129
Total	3,584	3,938	4,956	4,536	4,457
Recovered:					
Shipments[2]	5,798	6,180	6,470	6,475	6,483
Exports	645	777	759	694	624
Imports	621	806	917	1,174	1,442
Total	5,774	6,209	6,628	6,955	7,301
Total elemental	9,358	10,147	11,584	11,491	11,758
Pyrites, shipments	W	W	W	W	W
Byproduct sulfuric acid, shipments	919	1,003	1,125	1,190	1,294
Other forms, shipments[3]	309	173	3	4	4
Total, all forms	10,586	11,323	12,712	12,685	13,056

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 Virgin Islands.
[3] Includes consumption of hydrogen sulfide, liquid sulfur dioxide, and data indicated by symbol W.

TABLE 11

ELEMENTAL SULFUR SOLD OR USED IN THE UNITED STATES, BY END USE

(Thousand metric tons)

SIC	End use	1989	1990
20	Food and kindred products	W	W
26, 261	Pulp and paper products	8	30
282, 2822	Synthetic rubber and other plastic products	W	W
287	Agricultural chemicals	277	324
28, 286	Other chemical products and industrial organic chemicals	122	187
284	Soaps and detergents	W	W
29, 291	Petroleum refining and petroleum and coal products	142	104
281	Other industrial inorganic chemicals	188	126
	Sulfuric acid:		
	Domestic sulfur	8,241	7,870
	Imported sulfur	2,245	2,528
	Total	10,486	10,398
	Unidentified	372	538
	Total domestic uses	11,595	11,707
	Exports	923	952
	Grand total	12,518	12,659

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

price concessions in the second half of the year. While international buyers of sulfur were resisting Canadian price ideas, Iraq invaded Kuwait in early August. The United Nations Security Council called for all member nations to embargo trade with Iraq, which essentially removed the annual 1.5- to 1.7-million-ton Iraq-Kuwait sulfur exports from international commerce. Sulfur consumers, who had been resisting Canadian pricing, settled shortly after the Iraqi takeover of Kuwait. The posted price, Tampa, FL, was increased $6 per long ton in September and an additional $6 per long ton in December, ending the year at $140 per long ton.

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 $100.18 to $91.17 per ton. The average value, f.o.b. plant, for shipments of recovered elemental sulfur varied widely by geographic region: lowest in the Rocky Mountain States, higher on the west coast, somewhat higher in the midcontinent, and near the values for Frasch sulfur in the East and South. The disproportionately low average value for Wyoming distorted the average calculation for all recovered elemental sulfur shipments.

Foreign Trade

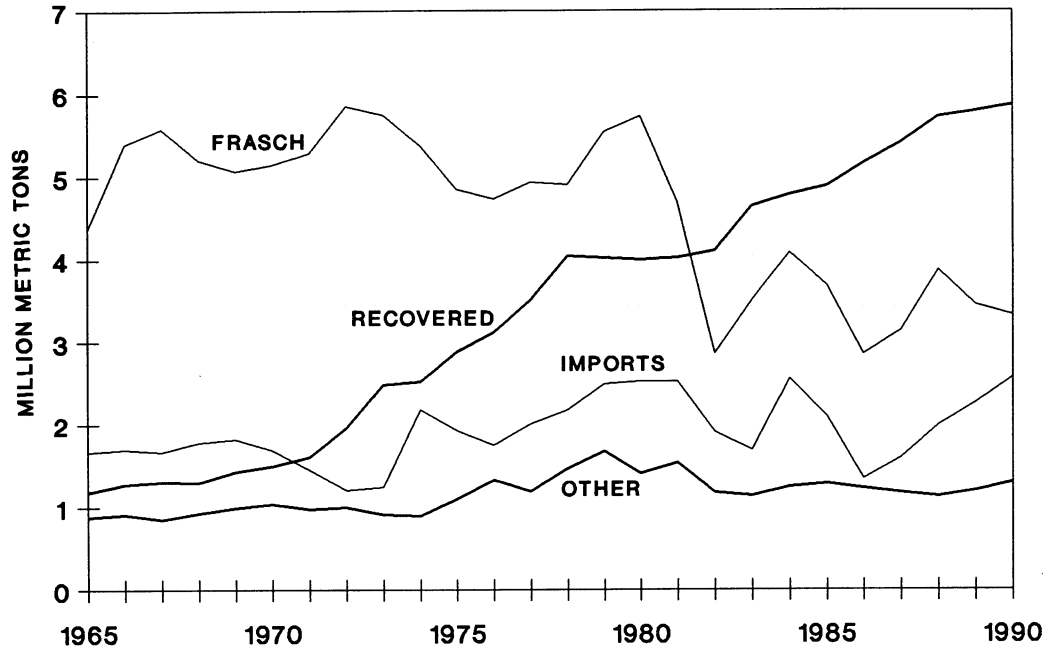
Exports of elemental sulfur from the United States, including the U.S. Virgin Islands, decreased 5% in quantity, but increased slightly in value. According to the Bureau of the Census, exports from the west coast were 550,000 tons or 57% of total U.S. exports.

The United States continued to be a net importer of sulfur; imports exceeded exports by more than 1.6 million tons in 1989. Frasch sulfur from Mexico and recovered elemental sulfur from Canada, both delivered to U.S. terminals and consumers in the liquid phase, continued to furnish nearly all U.S. sulfur import requirements. Total elemental sulfur imports increased 14% in quantity; imports by rail from Canada increased 24%, while waterborne shipments from Mexico were slightly higher than those in 1989.

The United States also had significant trade in sulfuric acid. Sulfuric acid exports increased slightly from those of 1989. Imports, which were significantly

FIGURE 3

TRENDS IN THE CONSUMPTION OF SULFUR IN THE UNITED STATES



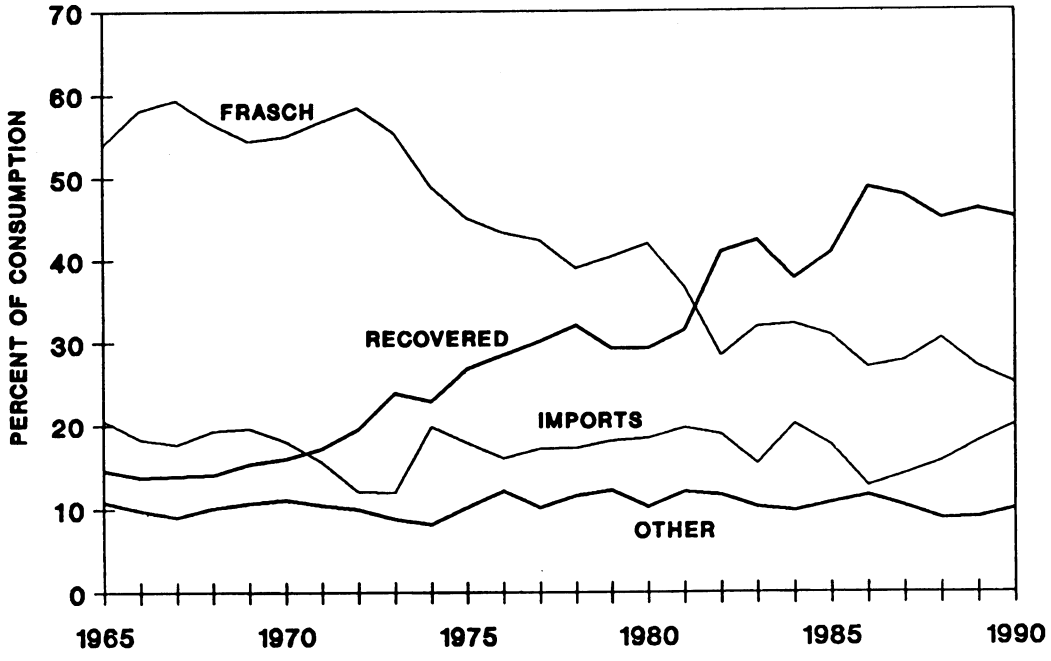
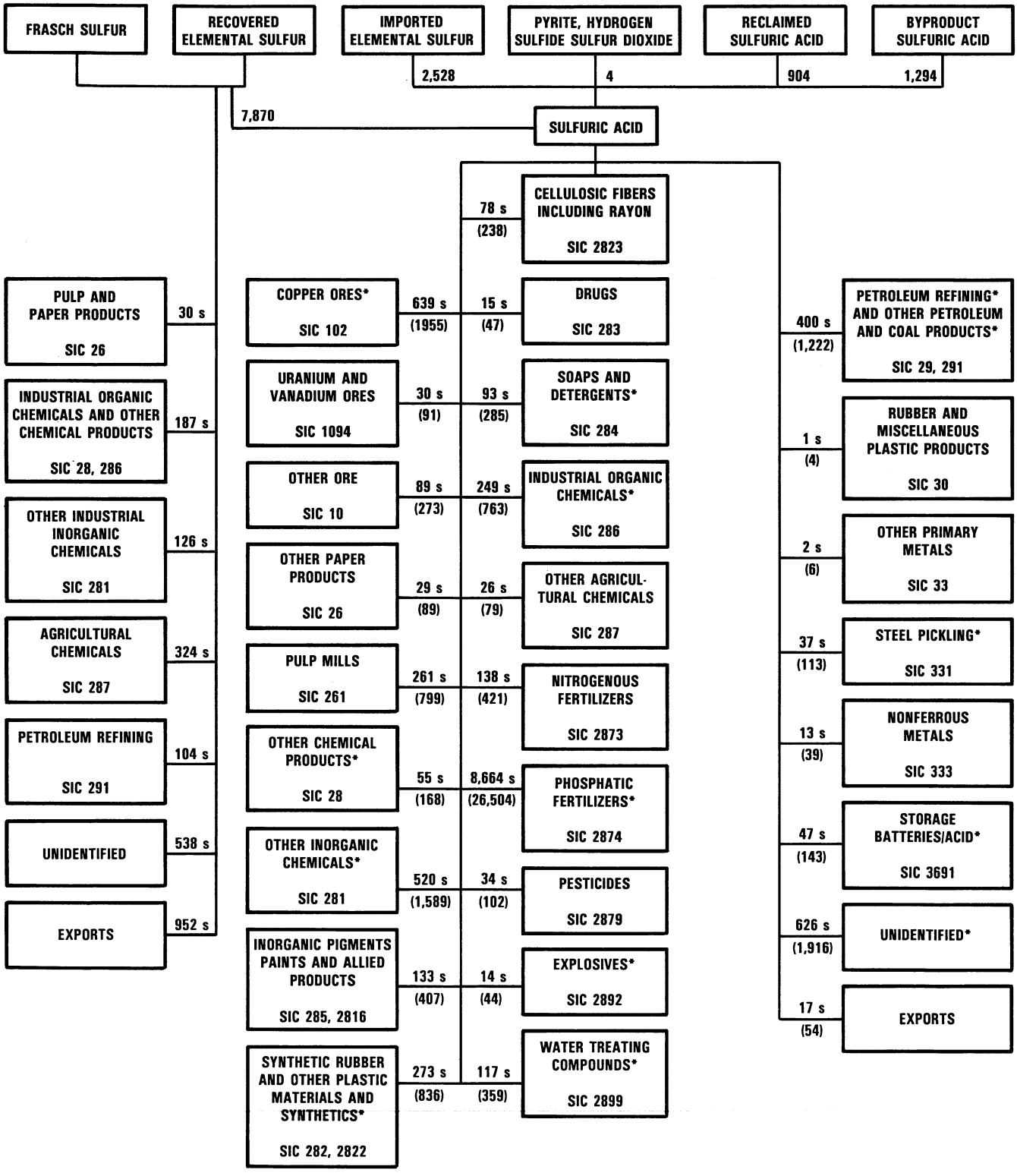


FIGURE 4

SULFUR-SULFURIC ACID SUPPLY AND END-USE RALATIONSHIP IN 1990



#s - SULFUR CONTENT THOUSAND METRIC TONS
(#) - 100% SULFURIC ACID THOUSAND METRIC TONS
* - SOURCES OF SPENT ACID FOR RECLAIMING

greater than exports, were mostly by rail from Canada. The tonnage increased 35% from the quantity reported in 1989; the value of imported sulfuric acid, however, increased by 45%. Approximately 520,000 tons of acid was imported into the Tampa, FL, area, which more than doubled the Tampa acid imports of the previous year. Two sulfuric acid terminals had been established there in 1989.

World Review

Industry Structure.—In 1990, the sulfur industry was divided into two sectors, discretionary and nondiscretionary. In one, the mining of sulfur or pyrites was the sole objective; this voluntary production of native sulfur or pyrites was based on the orderly mining of discrete deposits, with the objective of obtaining as nearly a complete recovery of the resource as economic conditions permit. In the other, sulfur or sulfuric acid was recovered as an involuntary byproduct, the quantity of output subject to demand for the primary product irrespective of sulfur demand. In 1990, involuntary sources represented about 65% of the elemental sulfur produced worldwide, and the combination of recovered elemental sulfur and byproduct sulfuric acid equaled more than 58% of total world production of sulfur in all forms.

Large quantities of Frasch sulfur were produced from mines in only five countries: Iraq, Mexico, Poland, the U.S.S.R, and the United States. Poland and the U.S.S.R. also produced significant quantities of native sulfur using conventional mining techniques; small quantities of native sulfur were produced in Asia, Europe, and South America. Pyrites were the prime sulfur source in China, Spain, and the Republic of South Africa and an important source in Scandinavia and the U.S.S.R.

Recovered elemental sulfur was the predominant sulfur source in Canada, France, the Federal Republic of Germany, Kuwait, Saudi Arabia, and the United States. Additionally, recovered elemental sulfur was an important source in Iran, Iraq, Japan, and the U.S.S.R.

International sulfur trade was dominated by a limited number of exporting countries; exports from Canada, Poland, Saudi Arabia, Mexico, the United States, the Federal Republic of Germany, Iraq, and France, in descending order of the quantity shipped, accounted for 90% of sulfur trade in 1990. Major sulfur importers in 1990 were the United States, Morocco, India, the U.S.S.R., Tunisia, Brazil, the United Kingdom, France, and Jordan, in descending order of importance.

TABLE 12

SULFURIC ACID SOLD OR USED IN THE UNITED STATES, BY END USE

(Thousand metric tons of 100% H_2SO_4)

SIC	End use	1989	1990
102	Copper ores	1,797	1,955
1094	Uranium and vanadium ores	134	91
10	Other ores	123	273
261	Pulpmills	859	799
26	Other paper products	119	89
285, 2816	Inorganic pigments and paints and allied products	423	407
281	Other inorganic chemicals	872	1,589
282, 2822	Synthetic rubber and other plastic materials and synthetics	1,172	836
2823	Cellulosic fibers, including rayon	159	238
283	Drugs	78	47
284	Soaps and detergents	260	285
286	Industrial organic chemicals	876	763
2873	Nitrogenous fertilizers	285	421
2874	Phosphatic fertilizers	26,436	26,504
2879	Pesticides	99	102
287	Other agricultural chemicals	89	79
2892	Explosives	52	44
2899	Water-treating compounds	353	359
28	Other chemical products	240	168
29, 291	Petroleum refining and other petroleum and coal products	2,088	1,222
30	Rubber and miscellaneous plastic products	5	4
331	Steel pickling	181	113
333	Nonferrous metals	151	39
33	Other primary metals	6	6
3691	Storage batteries (acid)	140	143
	Unidentified	1,403	1,916
	Total domestic	38,400	38,492
	Exports	33	54
	Grand total	38,433	38,546

Capacity.—The data in table 21 are rated capacity for Frasch mines, elemental sulfur mining facilities and attendant beneficiation plants, pyrites mines and plants, sulfur and/or sulfuric acid recovery units associated with petroleum refineries, natural gas processing plants, metal smelting operations, electric powerplants, and coke ovens as of December 31, 1990. 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 1990 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,

TABLE 13

SULFUR AND SULFURIC ACID SOLD OR USED IN THE UNITED STATES, BY END USE

(Thousand metric tons, sulfur content)

SIC	End use	Elemental sulfur [1]		Sulfuric acid (sulfur equivalent)		Total	
		1989	1990	1989	1990	1989	1990
102	Copper ores	—	—	588	639	588	639
1094	Uranium and vanadium ores	—	—	44	30	44	30
10	Other ores	—	—	40	89	40	89
20	Food and kindred products	W	W	—	—	W	W
26, 261	Pulpmills and paper products	8	30	320	290	328	320
28, 285, 286, 2816	Inorganic pigments, paints and allied products, industrial organic chemicals, other chemical products	[2]122	[2]187	138	133	260	320
281	Other inorganic chemicals	188	126	285	520	473	646
282, 2822	Synthetic rubber and other plastic materials and synthetics	W	W	383	273	383	273
2823	Cellulosic fibers, including rayon	—	—	52	78	52	78
283	Drugs	—	—	25	15	25	15
284	Soaps and detergents	W	W	85	93	85	93
286	Industrial organic chemicals	—	—	286	249	286	249
2873	Nitrogenous fertilizers	—	—	93	138	93	138
2874	Phosphatic fertilizers	—	—	8,642	8,664	8,642	8,664
2879	Pesticides	—	—	32	34	32	34
287	Other agricultural chemicals	277	324	29	26	306	350
2892	Explosives	—	—	17	14	17	14
2899	Water-treating compounds	—	—	115	117	115	117
28	Other chemical products	—	—	78	55	78	55
29, 291	Petroleum refining and other petroleum and coal products	142	104	683	400	825	504
30	Rubber and miscellaneous plastic products	—	—	2	1	2	1
331	Steel pickling	—	—	59	37	59	37
333	Nonferrous metals	—	—	49	13	49	13
33	Other primary metals	—	—	2	2	2	2
3691	Storage batteries (acid)	—	—	46	47	46	47
	Exported sulfuric acid	—	—	11	17	11	17
	Total identified	737	771	12,104	11,974	12,841	12,745
	Unidentified	372	538	459	626	831	1,164
	Grand total	1,109	1,309	12,563	12,600	13,672	13,909

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.

TABLE 14

SULFURIC ACID FROM SMELTERS SOLD OR USED IN THE UNITED STATES, BY END USE

(Thousand metric tons of 100% H_2SO_4)

SIC	End use	1989	1990
102	Copper ores	1,403	1,882
1094	Uranium and vanadium ores	114	73
10	Other ores	25	107
26, 261	Pulp mills and other paper products	167	124
2816	Inorganic pigments	W	W
281	Other inorganic chemicals	197	171
2823	Cellulosic fibers	W	W
283	Drugs	W	W
2873	Nitrogenous fertilizers	72	W
2874	Phosphatic fertilizers	658	689
287	Other agricultural chemicals	49	37
2899	Water-treating compounds	134	183
28	Other chemical products	22	20
291	Petroleum refining	18	9
331	Steel pickling	W	W
333	Nonferrous metals	W	28
3691	Storage batteries (acid)	25	28
	Unidentified	869	1,117
	Total domestic	3,753	4,468
	Exports	W	W
	Grand total	3,753	4,468

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

TABLE 15

YEAREND SULFUR STOCKS OF U.S. PRODUCERS

(Thousand metric tons)

Year	Frasch	Recovered	Total[1]
1986	2,532	216	2,748
1987	2,122	194	2,316
1988	954	158	1,112
1989	1,109	193	1,301
1990	1,177	245	1,423

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

TABLE 16

REPORTED SALES VALUES OF SHIPMENTS OF SULFUR, F.O.B. MINE OR PLANT

(Dollars per metric ton)

Year	Frasch	Recovered	Average
1986	123.79	92.06	105.22
1987	107.15	79.63	89.78
1988	99.24	77.03	85.95
1989	100.18	78.70	86.62
1990	91.17	73.89	80.14

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.

Canada.—Shipments of sulfur in all forms were about 7.9 million tons, or 1 million tons greater than production. Elemental sulfur exports increased from 5.8 million tons in 1989 to 6.3 million tons in 1990; offshore exports from Vancouver, British Columbia, increased from 4.65 million tons in 1989 to about 4.85 million tons; Canada remained the world's largest sulfur exporting country.

Natural gas processing plants in Alberta continued to supply the major share of Canadian sulfur production. In Alberta, gas-recovered sulfur output increased slightly to 4.77 million tons. Sulfur production from gas plants in British Columbia increased to a record high of more than 412,000 tons.

Mobil Oil Canada Ltd., Norcen Energy Resources Ltd., PanCanada Petroleum Ltd., and Shell Canada Ltd. began test operations on the Bearberry, Alberta, demonstration project to develop the capability to extract sulfur from the field's ultrasour gas (90% H_2S). A 200-ton-per-day pilot plant was completed in late 1990, and a 5-year study was planned by the developers. The sulfur resource at Bearberry was estimated to be between 70 and 100 million tons.

Shell Canada received approval for its plan to develop the Caroline gas-condensate field near Sundre, Alberta. The Caroline field has been estimated to contain about 2 trillion cubic feet of sour natural gas (30% to 35% H_2S), and development of the field was expected to be completed during 1993.

Iraq.—Sulfur production and exports were adversely affected by the United Nation's trade embargo that was instituted after Iraq invaded Kuwait in early August.

Mexico.—Frasch sulfur production decreased slightly from that of 1989.

TABLE 17

U.S. EXPORTS[1] OF ELEMENTAL SULFUR, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1989		1990	
	Quantity	Value	Quantity	Value
Australia	6	1,344	9	1,521
Belgium-Luxembourg	172	20,270	181	21,132
Brazil	204	23,066	201	26,869
Canada	49	3,551	22	3,763
China	62	6,500	8	702
Colombia	8	893	19	1,817
Denmark	13	2,039	(2)	39
France	1	42	32	2,692
Greece	—	—	19	3,105
India	79	5,293	150	14,311
Korea, Republic of	8	2,413	2	2,143
Mexico	155	14,883	232	19,502
Morocco	26	1,423	(2)	8
Senegal	89	7,753	12	1,095
South Africa, Republic of	38	3,981	(2)	85
Taiwan	37	3,634	25	2,987
Tunisia	30	3,261	20	1,841
Other	r50	r6,780	36	5,714
Total[3]	1,024	107,126	972	109,327

r Revised.
[1] Includes exports from the Virgin Islands.
[2] Less than 1/2 unit.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

Efforts continued to expand production from the recently commissioned Otapan Mine, and exploration for new resources continued. Sulfur imports from Canada and the U.S. west coast were about 490,000 tons, which did not appear in official Mexican trade statistics.

Morocco.—Morocco was a major world importer of elemental sulfur because of consumption at its phosphate fertilizer facilities at Safi and Jorf Lasfar. Imports increased from 0.96 million tons in 1989 to approximately 2.38 million tons in 1990. A major dispute concerning phosphoric acid prices and exports to India in 1989 had curtailed phosphoric acid production and the need for sulfur imports.

Poland—Sulfur exports increased from 3.65 million tons in 1989 to 3.81 million tons. Approximately 1.5 million tons was shipped to Eastern Europe and 0.7 million tons to Western Europe; most of the remainder was shipped to Brazil, India, Morocco, and Tunisia.

Poland was the largest world producer of native sulfur, with major mines at Jeziorko, Grzybow, and Machow. The Machow open pit mine continued to operate with an ever increasing overburden to sulfur ore stripping ratio; because of the social, political, and economic restructuring that began in Poland during 1990, Machow may have a limited life. The construction of the new Osiek Mine was delayed for environmental reasons. The mine should come on-stream in two phases, one in 1992 and the second in 1993.

Saudi Arabia.—Sulfur production from natural gas processing plants and oil refineries increased slightly. Exports increased substantially from 939,000 tons in 1989 to 1.61 million tons. India, Morocco, and Tunisia received about three-fourths of Saudi sulfur exports.

U.S.S.R.—Production of sulfur in all forms decreased substantially. Technical problems and environmental concerns continued to restrict the output from Astrakhan natural gas processing facility to 25% of capacity. Although construction on the second phase to double the size of the Astrakhan facility was complete, the second phase was not commissioned because of the problems plaguing the first phase. The first of three gas processing plants at the Tengiz oil-gas-condensate field near the northeast shore of the Caspian Sea was completed; each plant had a design annual sulfur capacity of 450,000 tons.

OUTLOOK

World sulfur demand, from 1991 to the year 2000, is forecast to increase at an annual rate of 1.4% to 1.8% per year. World demand is projected to attain 63.5 million tons in 1995 and increase to more than 70 million tons in the year 2000. In the short term, U.S. sulfur demand is forecast to decline from 13.1 million tons consumed in 1990; demand will probably decrease to 12.4 million tons in 1991 and increase only marginally thereafter. U.S. sulfur demand is forecast to be 12.5 million tons in 1995 and reach 13.2 million tons in the year 2000.

Agriculture is by far the most important of the sulfur end-use categories, accounting for more than 70% of U.S. demand and 57% of world consumption. The principal individual requirement is for the manufacture of phosphatic fertilizers, in which sulfuric acid is the essential intermediate chemical product. The production of phosphoric acid by the wet acid process involves the acidulation of phosphate rock with sulfuric acid. The phosphoric acid is primarily an intermediate product that is used to manufacture a spectrum of high-grade fertilizers; the acid itself may also be used for direct application to soil to supply the needed plant nutrition. Other fertilizers that require sulfuric acid in their production, but in comparably lower quantities, include ammonium and potassium sulfates and single super phosphate, which is produced by the partial acidulation of phosphate rock to form a lower analysis fertilizer, on a nutrient basis, than is produced from phosphoric acid. Nonfertilizer sulfur uses in agriculture include direct application of sulfur and

TABLE 18

U.S. EXPORTS OF SULFURIC ACID (100% H_2SO_4), BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	9,101	$331	792	$93
Canada	29,802	1,223	71,141	4,882
Chile	38,447	1,836	3,825	129
Dominican Republic	1,944	125	221	43
Ecuador	54	16	6,157	317
Israel	5,316	250	2,988	300
Jamaica	1,696	145	3,062	276
Korea, Republic of	9,379	1,976	5,546	1,877
Liberia	1,499	125	461	124
Mexico	14,551	762	11,815	650
Morocco	—	—	4,251	140
Netherlands	27	58	1,503	81
Netherlands Antilles	7,255	497	1,656	86
Panama	1,747	101	4,223	214
Saudi Arabia	1,416	49	6,856	273
Spain	3,995	132	83	3
Taiwan	5,924	309	1,142	278
Thailand	840	50	10,538	409
Trinidad and Tobago	611	20	594	20
United Kingdom	1,321	49	86	10
Venezuela	—	—	20,194	873
Other	r10,704	r666	4,375	437
Total	145,629	[1]8,721	161,509	11,515

rRevised.
[1] Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 19

U.S. IMPORTS OF ELEMENTAL SULFUR, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1989		1990	
	Quantity	Value[1]	Quantity	Value[1]
Canada	1,149	80,577	1,424	87,278
Mexico	1,086	125,166	1,129	116,789
Other[2]	25	3,723	18	2,383
Total	2,260	[3]209,465	2,571	206,450

[1] Declared customs valuation.
[2] Includes Chile, the Dominican Republic, France, Gabon, the Federal Republic of Germany, India, Japan, and the Netherlands in 1989; and Argentina, France, the Federal Republic of Germany, Japan, the Netherlands, and Venezuela in 1990.
[3] Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

sulfuric acid to soils, pesticide manufacture, and for animal feed supplements. More than 90% of U.S. agricultural sulfur demand and about 80% of world agricultural sulfur consumption was for the manufacture of phosphoric acid in 1990.

World demand for phosphate fertilizers is forecast to increase at an annual rate of slightly less than 2% for the remainder of the century. 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 1990, 4.5 million tons of sulfur was required to manufacture the phosphatic fertilizers exported from the United States compared with 3.91 million tons of sulfur for domestic phosphoric fertilizer use. Sulfur demand for domestically consumed phosphates is forecast to increase to about 4.8 million tons by 1995 and remain relatively stable thereafter. The export component is not expected to repeat the strong performance of 1990 until sometime after 1995, if at all during the 1990's, because of increasing foreign competition in world markets. U.S. sulfur consumption for agricultural purposes could drop significantly if domestic phosphate fertilizers' producers are not able to compete successfully in the international arena.

The broad spectrum industrial or nonagricultural sulfur use category accounted for about 30% of U.S. sulfur consumption and more than 43% of world sulfur demand. While significant variations in demand for the diverse elements within this broad category are expected in the United States and other geographic areas, world industrial demand is expected to average a 1% to 1.2% increase annually through the remainder of the century, reaching 28 million tons in the year 2000.

The necessity for the removal of sulfur from solid, liquid, and gaseous effluents for environmental protection has caused the production of sulfur and sulfur compounds from these sources to exceed production from primary sources of supply. The long-term prospect is that 85% or more of the world sulfur supply will come from environmentally regulated sources and that output from these sources will be produced regardless of world sulfur demand. As a result, it is probable that, after the turn of the century, no new operation that produces sulfur as its primary product will be developed, except where it may be deemed necessary for political or social reasons.

In 1980, voluntary sources of production, Frasch, native sulfur, and pyrites, accounted for 50% of world output of about 55 million tons. In 1990,

TABLE 20

U.S. IMPORTS OF SULFURIC ACID (100% H_2SO_4), BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Argentina	2,970	$30	3,638	$36
Canada	931,001	29,586	1,280,313	46,076
Germany, Federal Republic of	2	5	74,835	3,048
Ireland	454	188	—	—
Italy	—	—	24,801	1,323
Japan	111,887	4,590	36,251	1,356
Korea, Republic of	3	6	—	—
Mexico	163,125	6,143	151,273	5,924
Netherlands	10,117	481	21,563	944
Norway	—	—	10,560	439
Poland	—	—	3,728	147
Spain	14,618	888	41,527	1,649
Sweden	32	8	31,354	1,225
Switzerland	19,575	1,108	—	—
Taiwan	57	25	6	5
United Kingdom	8	1	9,069	346
Other	(2)	(2)	700	64
Total[3]	1,253,849	43,060	1,689,618	62,581

[1] Declared c.i.f. valuation.
[2] Revised to zero.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

these same sources supplied only 37% of world production of 57.7 million tons. Not only did the voluntary producers share of production decrease, the volume of output fell by 3.62 million tons or more than 15%; U.S. Frasch production accounted for most of the drop, plunging from 6.39 million tons to 3.73 million tons. Additionally, world sulfur stocks fell from about 27 million tons to about 9 million tons during the period 1980–90; more than 17 million tons was removed from vatted Canadian stocks, which had been built during the 1970's at natural gas processing plants.

It is anticipated that, in the short term, world sulfur demand will surpass output and that stocks will continue to decline. A temporary severe shortage could develop by 1992. Any sulfur shortage would be of short duration because of the size and number of new production facilities planned or under development.

In Canada, projects nearing completion should raise output from existing gas plants 400,000 to 500,000 tons by 1992. The development of the Caroline gasfield should increase Canadian capacity by 1.2 million tons in 1993. The development of the Osiek Mine in Poland should result in a net increase in Polish sulfur output of 100,000 tons by 1993. The new associated gas processing facility at Tengiz (Tengiz I–1990, Tengiz II–1992, Tengiz III–1993) should be capable of producing 1.2 million tons per year by 1993. If the technical problems with Astrakhan I can be remedied, both Astrakhan I and II should be on-stream by yearend 1992, producing 4 million tons per year compared with the estimated 700,000 tons produced at Astrakhan in 1989. Freeport McMoRan plans to have its new Main Pass 299 mine on-stream by early 1992 and be producing at a rate of more than 2 million tons per year by early 1993, increasing U.S. Frasch capability 1 million tons compared with that of 1990. 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

TABLE 21

WORLD SULFUR ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990, RATED CAPACITY, SULFUR IN ALL FORMS[1]

(Thousand metric tons, sulfur content)

	Capacity
North America:	
Canada	8,400
United States	12,320
Total	20,720
Latin America:	
Brazil	500
Chile	440
Mexico	2,775
Other	675
Total	4,390
Europe:	
Belgium	400
Finland	620
France	1,850
Germany, Federal Republic of	2,530
Italy	830
Netherlands	350
Poland	4,900
Spain	1,550
Sweden	544
Turkey	613
U.S.S.R.	11,000
United Kingdom	500
Yugoslavia	750
Other	1,724
Total	28,161
Africa:	
South Africa, Republic of	1,000
Other	270
Total	1,270
Asia:	
China[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	70,031

[e] Estimated.
[1] Includes capacity at operating plants as well as plants on standby basis.

TABLE 22

U.S. SULFUR SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
WORLD PRODUCTION[1]											
United States	11,866	12,145	9,787	9,290	10,652	11,609	11,087	10,539	10,746	11,592	11,560
Rest of World	43,117	41,405	40,772	40,480	41,847	42,162	r42,649	r46,043	r47,782	r47,125	46,108
Total	54,983	53,550	50,559	49,770	52,499	53,771	r53,736	r56,582	r58,528	r58,717	57,668
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Production:											
Frasch mines	6,390	6,348	4,210	3,202	4,193	5,011	4,043	3,202	3,174	3,888	3,726
Recovered elemental:											
Natural gas processing	1,757	1,971	1,960	2,371	2,407	2,373	2,246	2,536	2,501	2,537	2,336
Petroleum refining	2,316	2,288	2,444	2,584	2,807	2,940	3,570	3,624	3,943	3,973	4,200
Other forms	1,403	1,538	1,173	1,133	1,245	1,285	1,228	1,176	1,128	1,194	1,298
Total all forms	11,866	12,145	9,787	9,290	10,652	11,609	11,087	10,539	10,746	11,592	11,560
Industry stocks, Jan. 1	4,239	3,056	3,546	4,218	3,223	2,419	2,799	2,748	2,316	1,112	1,301
Imports	2,523	2,522	1,905	1,695	2,557	2,104	1,347	1,599	1,996	2,260	2,571
Total U.S. supply	18,628	17,723	15,238	15,203	16,432	16,132	15,233	14,886	15,058	14,964	15,432
Distribution of U.S. supply:											
Industry stocks, Dec. 31	3,094	3,546	4,218	3,223	2,419	2,799	2,748	2,316	1,112	1,301	1,423
Exports	1,782	1,392	961	992	1,334	1,365	1,895	1,242	1,223	1,024	972
Demand	13,659	12,785	10,059	10,988	12,679	11,968	10,586	11,323	12,712	12,685	13,056
Apparent surplus (+), deficit (−) of supply[2]	+93	—	—	—	—	—	+4	+5	+11	−46	-19
U.S. DEMAND PATTERN											
Agriculture:											
Phosphoric acid	8,499	7,748	6,415	7,113	8,621	7,872	6,973	7,556	8,404	8,642	8,664
Other	634	659	566	703	603	686	683	642	598	431	522
Total	9,133	8,407	6,981	7,816	9,224	8,558	7,656	8,198	9,002	9,073	9,186
Drugs and food products	36	19	15	35	27	56	65	32	27	28	18
Soaps, detergents, and water treatment	228	284	287	257	167	215	249	204	221	200	215
Plastics and synthetic products	371	301	347	479	457	314	338	352	458	501	421
Paper products	348	302	267	262	295	286	266	294	288	328	320
Paints	257	149	178	128	113	111	119	118	122	138	133
Metal mining and processing	687	626	448	319	510	442	376	426	567	723	773
Explosives	13	14	15	20	39	31	30	49	44	17	14
Petroleum refining	1,023	1,230	935	819	954	913	947	973	958	825	504
Iron and steel production	103	88	86	94	88	69	69	67	74	59	37
Storage batteries (acid)	34	57	53	58	58	67	50	41	51	46	47
Other	1,426	1,308	447	701	747	906	421	569	900	747	1,388
Total industrial demand	4,526	4,378	3,078	3,172	3,455	3,410	2,930	3,125	3,710	3,612	3,870
Total U.S. primary demand	13,659	12,785	10,059	10,988	12,679	11,968	10,586	11,323	12,712	12,685	13,056

r Revised.

[1] Sulfur in all forms.

[2] The difference between total U.S. distribution of supply and total U.S. supply.

sulfur surplus will probably develop in 1993, a surplus that could persist for much of the remainder of the century. World sulfur production will likely attain a level of 68 million tons in 1995 and exceed 72 million tons in the year 2000.

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TABLE 23

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1986	1987	1988	1989	1990[e]
Algeria: Byproduct, natural gas and petroleum[e]	20	20	20	20	20
Australia:					
Byproduct:					
Metallurgy	174	194	[e]200	[e]200	200
Petroleum	10	9	[e]9	[e]10	10
Total	184	203	[e]209	[e]210	210
Austria:					
Byproduct:					
Metallurgy	11	10	11	12	12
Natural gas and petroleum	29	25	36	[r]37	37
Gypsum	24	13	—	—	—
Total[4]	64	48	48	[r]49	49
Bahrain: Byproduct, petroleum	46	48	48	[e]48	48
Belgium: Byproduct, all sources[e]	300	300	310	320	320
Bolivia: Native	5	9	7	8	1
Brazil:					
Frasch	6	6	6	6	6
Pyrites	92	77	103	[r]72	90
Byproduct:					
Metallurgy	100	153	152	[r]164	160
Petroleum	74	77	61	[r]60	60
Total[4]	[r]271	313	322	[r]301	316
Bulgaria:[e]					
Pyrites	80	80	70	70	70
Byproduct, all sources	62	65	60	60	60
Total	142	145	130	130	130
Canada:					
Byproduct:					
Metallurgy	[r]758	[r]851	[r]944	[r]896	1,029
Natural gas	5,161	5,268	[r]5,415	[r]5,161	[5]5,194
Petroleum[e]	129	142	152	[r 5]149	223
Tar sands	424	426	485	491	[5]501
Total[e]	[r]6,472	[r]6,687	[r]6,996	[r]6,697	6,947
Chile:					
Native:					
Refined	13	15	17	16	[5]28
From caliche	44	22	21	[e]20	21
Byproduct, metallurgy	[r]41	[r]335	[r]416	[r e]400	400
Total	[r]98	[r]372	[r]454	[r e]436	449
China:[e]					
Native	300	300	300	300	300
Pyrites	2,500	3,700	3,900	4,000	4,000
Byproduct, all sources	300	500	550	600	600
Total	3,100	4,500	4,750	4,900	4,900

See footnotes at end of table.

TABLE 23—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1986	1987	1988	1989	1990[e]
Colombia:					
Native	36	41	43	r46	45
Byproduct, petroleum[e]	10	10	5 8	8	8
Total[e]	46	51	51	r54	53
Cuba: Byproduct, petroleum[e]	5	5	5	5	5
Cyprus:[6] Pyrites	25	41	51	r26	26
Czechoslovakia:[e]					
Native	6	6	6	6	6
Pyrites	60	60	60	r50	50
Byproduct, all sources	5 42	r40	r40	r40	40
Total	r108	r106	r106	r96	96
Denmark: Byproduct, petroleum	13	r13	r14	r e14	15
Ecuador:[e]					
Native	4	5	5	4	4
Byproduct:					
Natural gas	5	5	5	5	5
Petroleum	5	5	5	5	5
Total	14	15	15	14	14
Egypt: Byproduct, natural gas and petroleum[e]	7	8	8	8	8
Finland:					
Pyrites	275	r313	r271	r365	360
Byproduct:					
Metallurgy[e]	260	r230	240	r230	230
Petroleum	42	e40	47	r41	42
Total[e]	5 577	r583	r558	r636	632
France:					
Byproduct:					
Natural gas	r957	r883	r775	r647	650
Petroleum[e]	180	200	226	r239	235
Unspecified[e]	180	180	180	r150	160
Total[e]	r1,317	r1,263	r1,181	r1,036	1,045
Germany, Federal Republic of:					
Western states:					
Byproduct:					
Metallurgy[e 7]	300	300	310	315	320
Natural gas	998	r1,029	r952	e1,050	1,000
Petroleum[e]	190	210	205	210	215
Unspecified[e]	285	285	280	310	300
Total[e]	1,773	r1,824	r1,747	1,885	1,835
Eastern states: Byproduct, all sources[e]	315	315	315	290	265
Greece:[e]					
Pyrites	66	70	r70	70	70
Byproduct:					
Natural gas	r135	r135	r135	r135	135
Petroleum	5	5	5	5	5
Total	r206	r210	r210	r210	210

See footnotes at end of table.

TABLE 23—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1986	1987	1988	1989	1990[e]
Hungary:[e]					
Pyrites	1	1	1	1	1
Byproduct, all sources	10	10	10	10	10
Total	11	11	11	11	11
India:					
Pyrites	8	14	12	r16	16
Byproduct:[e]					
Metallurgy	120	120	125	125	125
Petroleum	1	—	1	5	5
Total[e 4]	129	134	138	r145	145
Indonesia:[6] Native	5	4	r4	4	4
Iran:[e]					
Native	30	30	30	30	30
Byproduct, natural gas and petroleum	250	300	300	300	300
Total	280	330	330	330	330
Iraq:[e]					
Frasch	600	707	700	900	800
Byproduct, natural gas and petroleum	200	250	350	370	250
Total	800	5957	1,050	1,270	1,050
Israel: Byproduct, natural gas and petroleum	29	40	r68	r68	64
Italy:[e]					
Pyrites	5309	r5314	r5310	r320	300
Byproduct, all sources[8]	r185	r190	r190	r190	190
Total	r494	r504	r500	r510	490
Japan:					
Pyrites	158	79	r71	r62	553
Byproduct:					
Metallurgy	r1,255	r1,250	r1,268	r1,384	1,450
Petroleum	985	r1,020	r1,093	r1,176	1,200
Total[4]	r2,399	r2,349	r2,432	r2,623	2,703
Korea, North:[e]					
Pyrites	200	200	200	200	200
Byproduct, metallurgy	30	30	30	30	30
Total	230	230	230	230	230
Korea, Republic of:[e]					
Byproduct:					
Metallurgy	55	55	55	55	55
Petroleum	35	35	35	36	36
Total	90	90	90	91	91
Kuwait: Byproduct, natural gas and petroleum[e]	260	310	360	575	400
Libya: Byproduct, natural gas and petroleum[e]	14	14	14	r15	15

See footnotes at end of table.

TABLE 23—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1986	1987	1988	1989	1990[e]
Mexico:					
Frasch	1,588	1,806	1,628	r1,528	1,450
Byproduct:					
Metallurgy[e]	134	154	240	r286	290
Natural gas and petroleum	r456	r501	510	r555	600
Total[e]	r2,178	r2,461	2,378	r2,369	2,340
Namibia: Pyrites	134	74	135	e130	125
Netherlands: Byproduct, petroleum[e]	250	r211	r215	r260	280
Netherlands Antilles: Byproduct, petroleum[e]	40	60	60	60	60
New Zealand: Byproduct, all sources	e1	e1	4	r1	4
Norway:					
Pyrites	181	179	r152	r122	125
Byproduct:					
Metallurgy	67	e80	e80	r75	75
Petroleum[e]	13	15	10	r13	15
Total[e]	[5]261	274	r242	r210	215
Oman: Byproduct, unspecified[e]	16	17	17	17	17
Pakistan:					
Native	1	1	1	r—	—
Byproduct, all sources[e]	26	26	25	25	25
Total[e]	27	27	26	r25	25
Peru:[e]					
Native	([5] [9])	([9])	([9])	([9])	([9])
Byproduct, all sources	66	66	66	66	66
Total	66	66	66	66	66
Philippines:					
Pyrites	113	158	e160	e195	185
Byproduct, metallurgy[e]	120	140	150	185	185
Total[e]	233	298	310	380	370
Poland:[10]					
Frasch	4,437	4,410	r4,411	r4,300	4,200
Native	550	694	r679	r660	650
Byproduct:[e]					
Metallurgy	170	170	150	150	140
Petroleum	30	30	20	20	20
Gypsum[e]	20	20	20	20	20
Total[e]	5,207	5,324	r5,280	r5,150	5,030
Portugal:					
Pyrites	r141	r123	r110	r91	95
Byproduct, all sources[e]	5	5	5	r3	3
Total[e]	r146	r128	r115	r94	98

See footnotes at end of table.

TABLE 23—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1986	1987	1988	1989	1990[e]
Qatar: Byproduct, natural gas	49	53	[e]54	[r e]52	52
Romania:[e]					
Pyrites	150	150	150	150	130
Byproduct, all sources	140	130	120	120	100
Total	290	280	270	270	230
Saudi Arabia: Byproduct, natural gas and petroleum	1,446	1,432	[r]1,378	[e]1,400	1,500
Singapore: Byproduct, petroleum[e]	50	50	50	55	55
South Africa, Republic of:					
Pyrites	499	468	[r]505	[r]461	[5]452
Byproduct:					
Metallurgy[e]	108	105	[r]113	[r]104	111
Petroleum[e 11]	110	110	120	120	125
Total	717	683	[r]738	[r]685	[5]688
Spain:					
Pyrites	1,195	960	[r]1,057	[r]938	950
Byproduct:[e]					
Coal (lignite) gasification	2	2	2	2	2
Metallurgy	210	225	[r]110	[r]110	125
Petroleum	8	8	8	8	8
Total[e]	1,415	1,195	[r]1,177	[r]1,058	1,085
Sweden:					
Pyrites	227	[r]215	[r]286	[r e]233	235
Byproduct:[e]					
Metallurgy	[5]125	[r]130	125	125	125
Petroleum	[5]49	50	45	[r]40	40
Total[e]	[5]401	395	[r]456	[r]398	400
Switzerland: Byproduct, petroleum	3	4	[e]4	[e]4	4
Syria: Byproduct, natural gas and petroleum[e]	35	40	40	40	40
Taiwan: Byproduct, all sources	63	89	86	76	80
Trinidad and Tobago: Byproduct, petroleum[e]	5	5	5	5	5
Turkey:					
Native	[r]40	39	[r]30	[r]23	20
Pyrites	4	22	[r]75	[r e]83	85
Byproduct:					
Petroleum	7	9	16	13	16
Unspecified[e]	[r]22	[r]11	[r]5	[r]49	55
Total[e]	[r]73	[r]81	[r]126	[r]168	176

See footnotes at end of table.

TABLE 23—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1986	1987	1988	1989	1990[e]
U.S.S.R.:[e]					
Frasch	1,100	1,100	1,100	1,100	1,000
Native	[r]2,400	[r]2,400	[r]2,400	[r]2,350	2,000
Pyrites	2,090	2,150	2,150	2,150	1,900
Byproduct:					
Metallurgy	1,050	1,250	1,375	1,350	1,200
Natural gas	1,625	2,400	3,290	2,500	2,500
Petroleum	400	450	450	450	425
Total	[r]8,665	[r]9,750	[r]10,765	[r]9,900	9,025
United Arab Emirates: Abu Dhabi:[e]					
Byproduct:					
Natural gas	104	97	[r]100	[r]70	100
Petroleum	11	8	[r]10	[r]10	10
Total	115	105	[r]110	[r]80	110
United Kingdom:					
Byproduct:					
Metallurgy	58	51	55	[e]55	50
Petroleum	105	119	129	[e]130	135
Total	163	170	184	[e]185	185
United States:					
Frasch	4,043	3,202	3,174	3,888	[5]3,726
Pyrites	W	W	W	W	W
Byproduct:					
Metallurgy	919	1,003	1,125	1,190	[5]1,294
Natural gas	2,246	2,536	2,501	2,537	[5]2,336
Petroleum	3,570	3,624	3,943	3,973	[5]4,200
Unspecified	309	173	3	4	[5]4
Total[4]	11,087	10,539	10,746	11,592	[5]11,560
Uruguay: Byproduct, petroleum[e]	2	2	2	2	2
Venezuela: Byproduct, natural gas and petroleum	99	[e]125	125	[e]125	125
Yugoslavia:					
Pyrites and pyrrhotite	320	258	252	[e]255	250
Byproduct:[e]					
Metallurgy	175	175	170	170	170
Petroleum	3	3	3	3	3
Total[e]	498	436	425	428	423
Zaire: Byproduct, metallurgy[e]	39	35	35	35	34
Zambia:					
Pyrites	8	19	27	[e]29	29
Byproduct, metallurgy[e]	74	74	74	74	74
Total[e]	82	93	101	103	103
Zimbabwe:[e]					
Pyrites	25	21	18	[r]25	25
Byproduct, all sources	5	5	5	5	5
Total	30	26	23	[r]30	30

See footnotes at end of table.

TABLE 23—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1986	1987	1988	1989	1990[e]
Grand total[4]	r53,736	r56,582	r58,528	r58,717	57,668
Of which:					
Frasch	11,774	r11,231	r11,019	r11,722	11,182
Native	r3,434	r3,566	r3,543	r3,467	3,109
Pyrites	r8,861	r9,746	r10,196	r10,114	9,822
Byproduct:					
Coal (lignite) gasification	2	2	2	2	2
Metallurgy	r6,353	r7,120	r7,553	r7,720	7,884
Natural gas	r11,280	r12,406	r13,227	r12,157	11,972
Natural gas and petroleum, undifferentiated	r2,845	r3,065	r3,209	r3,513	3,359
Petroleum	r6,386	r6,577	r7,004	r7,177	7,515
Tar sands	424	426	485	491	501
Unspecified sources	r2,332	r2,408	r2,271	r2,336	2,304
Gypsum	44	33	20	20	20

[e] Estimated. [r] Revised. W Withheld to avoid disclosing company proprietary data; included with "Byproduct: Unspecified sources."

[1] Table includes data available through May 17, 1991.

[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 may also produce byproduct sulfur from crude oil and natural gas extraction. No complete listing of other nations that may produce byproduct sulfur from metallurgical operations (including processing of coal for metallurgical use) can be compiled, but the total of such output is considered as small. Nations listed in the table that may have production from sources other than those listed are identified by individual footnotes.

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

[5] Reported figure.

[6] In addition, may produce limited quantities of byproduct sulfur from oil refining.

[7] 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."

[8] Includes recovery from gypsum, if any.

[9] Less than 1/2 unit.

[10] 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.

[11] Estimates for 1986–90 include byproduct production from synthetic fuels.

TALC AND PYROPHYLLITE

By Robert L. Virta

Mr. Virta, a physical scientist with 15 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, mineral data assistant; and international data tables were prepared by William Zajac, Chief, Section, International Data.

Domestic production of talc and pyrophyllite increased slightly from that of 1989 to 1,267,167 metric tons. Sales of crude and processed talc decreased 4% to 1,021,004 tons in tonnage and decreased 3% in value. Sales of pyrophyllite increased slightly. Imports for consumption decreased 17% in tonnage to 65,099 tons and decreased 9% in value to $11,056,000. Exports decreased 25% in tonnage to 238,000 tons and increased 14% in value to $32,909,000. During the past 10 years, talc and pyrophyllite production averaged 1,075,000 tons; sales, 972,000 tons; domestic consumption, 948,000 tons; exports, 242,000 tons; and imports, 49,000 tons. The major use for talc was in ceramics, which accounted for 28% of the domestic consumption, followed by paint, 18%; paper, 17%; roofing, 11%; plastics, 6%; and other, 20%. The major use for pyrophyllite was in ceramics, followed by refractories, insecticides, paint, plastics, and rubber.

DOMESTIC DATA COVERAGE

Domestic production and sales data for talc and pyrophyllite are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. mines and mills. Survey forms were sent to 18 companies that operated 52 mines and mills. Seventeen companies that account for approximately 99% of the domestic production responded to the survey. Production data for the nonrespondent were estimated from reported prior-year production levels adjusted by trends in employment and other guidelines.

ANNUAL REVIEW

Legislation and Government Programs

The Occupational Safety and Health Administration (OSHA) extended an administrative stay on its 1986 regulation governing worker exposure to the nonasbestiform varieties of actinolite, anthophyllite, and tremolite through August 31, 1991. During the stay, OSHA continued to analyze the impact of using the asbestos standard to regulate the nonasbestiform varieties of the minerals. An exposure limit of two fibers per cubic centimeter will remain in effect during the stay.[1]

The Mine Safety and Health Administration (MSHA) continued to review its proposed revisions to its air quality, chemical substances, and respiratory pro-

TABLE 1

SALIENT TALC AND PYROPHYLLITE STATISTICS

(Thousand metric tons and thousand dollars)

	1986	1987	1988	1989	1990
United States:					
Mine production, crude:					
Talc	1,106	1,080	1,136	1,172	1,185
Pyrophyllite	75	83	97	81	82
Total[1]	1,181	1,163	1,234	1,253	1,267
Value:					
Talc	$29,687	$27,265	$29,364	$27,731	$31,068
Pyrophyllite	$1,540	$1,607	$1,820	W	W
Total	$31,227	$28,872	$31,185	[2]$27,731	[2]$31,068
Sold by producers, crude and processed:					
Talc	971	975	940	1,065	1,021
Pyrophyllite	75	82	93	79	80
Total[1]	1,046	1,057	1,033	1,145	1,101
Value:					
Talc	$111,924	$113,394	r$115,899	$114,453	$110,585
Pyrophyllite	$3,366	$3,712	$4,164	W	W
Total[1]	$115,290	$117,107	$120,063	[2]$114,453	[2]$110,585
Exports[3] (talc)	212	255	260	319	238
Value	$16,302	$19,607	$21,391	$28,949	$32,909
Imports for consumption (talc)	47	48	79	78	65
Value	$8,715	$10,348	$12,268	$12,128	$11,056
Apparent consumption[4]	1,016	956	1,054	1,012	1,054
World: Production	r7,755	r7,799	r7,956	r8,271	e8,251

e Estimated. r Revised. W Withheld to avoid disclosing company proprietary data.

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

[2] Does not include value for pyrophyllite.

[3] Excludes powders—talcum (in package), face, and compact.

[4] Production, plus imports, minus exports, plus adjustments in Government and industry stock. Does not include imported pyrophyllite.

tection standards. The proposed permissible 8-hour time weighted average exposure limit is 2.5 milligrams per cubic meter for talc (containing no asbestos), 3 milligrams per cubic meter for respirable soapstone, and 6 milligrams per cubic meter for total soapstone dust. The nonasbestiform varieties of tremolite, anthophyllite, and actinolite would be covered under the proposed respirable mine dust standard.[2]

MSHA issued a proposed rule that would create a hazard communication standard. Mine operators would be required to provide information to their employees concerning any hazards that chemicals, including talc, produced or used on the premises through labeling, material safety data sheets, and employee training.[3]

Issues

The health risk posed by nonasbestiform varieties of tremolite, anthophyllite, and actinolite continued to be a concern for a portion of the talc industry. OSHA is evaluating whether to regulate the nonasbestiform amphiboles as asbestos, regulate nonasbestiform amphiboles under a separate standard, or not to regulate nonasbestiform amphiboles.

Production

Talc.—Thirteen companies operating 22 mines in 10 States produced talc, soapstone, and steatite. These companies generally were structured to cover all aspects of talc mining, from mining to processing. Only a few companies hired custom grinders to mill the ore. The largest of the domestic producers were Cyprus Industrial Minerals Co. Inc., Dal Minerals, Gouverneur Talc Co., Montana Talc Co., and Pfizer Inc. The major producing deposits were in Montana, New York, Texas, and Vermont.

Commercial talc production was from deposits that were formed through hydrothermal alteration of ultrabasic rocks and low-grade metamorphism of siliceous dolomites. They generally occur as lenses or pods in the country rock. Magnesite, quartz, chlorite, magnetite, serpentine, anthophyllite, tremolite, dolomite, and actinolite may be present as accessory minerals.

Most of the domestic talc production was from open pit mining operations. Underground mining was used only when a large waste rock to ore ratio made open pit mining uneconomical. Typically, overburden was removed, and blasting was used to fracture the ore. The companies then used selective mining and manual or automated sorting to produce a high-grade feed for the mill. Jaw crushers were used to reduce the size of the mill feed, and ball mills or roller mills were used to produce the final product. Fluid-energy mills or pulverizing mills were used for ultrafine grinding of the talc ore. In a few instances, the ore was calcined prior to milling to increase its whiteness.

Flotation processes were used when the desired product purity was not obtained by using conventional processing. The milled ore was chemically treated, passed through rougher and cleaner cells to separate the talc from the gangue material, dried in a flash dryer, and ground in a pulverizer. Ore composition, reagent type, pulp density, pH of the flotation system, and residence time in the flotation circuits determined flotation efficiency.

Cyprus Industrial Minerals Co. announced that it would close its Hammondsville mine. The decision to close the underground mine, which has operated for about 40 years, was made for safety and economic reasons.[4]

U.S. mine production of crude talc increased slightly in tonnage and 12% in value. Mines that operated in Montana, New York, Texas, and Vermont accounted for 96% of domestic talc production. Montana led all States in the tonnage and value of talc produced.

Pyrophyllite.—Pyrophyllite was produced by three companies operating four mines in two States. 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 increased slightly in tonnage. North Carolina accounted for most of the domestic production.

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.

Talc was used as a filler in polypropylene compounds. It served to improve the modulus and impact strengths of the product, improve the stability of the

TABLE 2

CRUDE TALC AND PYROPHYLLITE PRODUCED IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1989		1990	
	Quantity	Value	Quantity	Value
Georgia (talc)	26	W	W	W
Montana (talc)	454	12,717	474	18,883
Texas (talc)	242	4,564	250	4,844
Other[1 2]	528	10,338	543	7,342
Total[2 3]	1,253	27,731	1,267	31,068

W Withheld to avoid disclosing company proprietary data; included in "Other."
[1] Includes Alabama, Arkansas, California, New York, North Carolina, Oregon, Vermont, and Virginia.
[2] Does not include value for pyrophyllite.
[3] Data may not add to totals because of independent rounding.

product under ultraviolet light, and reduce the price of the final product. Products had higher modulus and impact strengths, higher deflection temperatures under load, and lower coefficient of thermal expansion when finely ground talc was used with high crystallinity polypropylene.[5]

Domestic producers reported that overall sales (including direct exports) declined 4% in tonnage to 1,021,004 tons and 3% in value to $110,584,808 in 1990. The major consumer of talc was the construction industry, with applications in ceramic tiles and sanitaryware, joint compounds, paint, plastics, and roofing. The end-use distribution was ceramics, 28%; paint, 18%; paper, 16%; roofing, 11%; plastics, 6%; cosmetics, 4%; and insecticides, refractories, rubber, and other, 17%. The greatest decrease in demand was in ceramics, cosmetics, and plastics applications. Some decline was expected due to a sluggish U.S. economy, but it is doubtful that the entire decrease can be attributed to a sluggish economy. It is likely that some sales to the ceramic, cosmetic, and plastic industries were reported under the "Other" category, which increased in 1990. More than 90% of the companies responded to the end-use portion of the 1990 annual survey, representing approximately 95% of the data in table 3.

TABLE 3

END USES FOR GROUND TALC AND PYROPHYLLITE

(Thousand metric tons)

Use	1989			1990		
	Talc	Pyrophyllite	Total[1]	Talc	Pyrophyllite	Total[1]
Ceramics	308	70	377	235	W	235
Cosmetics[2]	50	—	50	36	—	36
Insecticides	—	11	11	6	W	6
Paint	143	—	143	155	W	155
Paper	138	5	143	143	—	143
Plastics	97	1	98	48	W	48
Refractories	1	21	21	3	W	3
Roofing	97	—	97	94	—	94
Rubber	20	([3])	21	20	W	20
Other[4]	100	10	109	109	W	109
Total[1]	953	[5]117	[5]1,070	849	[5]100	[5]849

W Withheld to avoid disclosing company proprietary data.
[1] Data may not add to totals shown because of independent rounding.
[2] Incomplete data. Some cosmetic talc known to be included in "Other."
[3] Less than 1/2 unit.
[4] Includes art sculpture, asphalt filler and coatings, crayons, floor tile, foundry facings, rice polishing, stucco, and other uses not specified.
[5] Includes imported pyrophyllite.

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.

U.S. consumption of pyrophyllite increased slightly in tonnage in 1989. The largest portion of domestically produced ground pyrophyllite was used in ceramics, followed by refractories, insecticides, paint, plastics, and rubber. The end-use distribution did not change significantly from previous years.

Markets and Prices

Talc prices varied depending on the quality and on the degree and method of processing. The unit value of crude talc was $25 per ton. The average unit value of processed talc was $108 per ton. The average unit values of crude and processed pyrophyllite were higher in 1990 than in 1989. Unit values for imported crude and ground talc ranged from $33 per ton to $410 per ton for quantities greater than 100 tons. The average unit value for all imported talc was $170 per ton. Unit values for exported talc ranged from $16 per ton to $1,576 per ton for quantities greater than 100 tons and averaged $138 per ton for all exports.

Prices, quoted by the American Paint & Coatings Journal, December 26, 1990, in U.S. dollars per metric ton for paint-grade talc in carload lots ranged from $99 to $243. Approximate equivalents, in dollars per metric ton, of price ranges quoted in Industrial Minerals (London), December 1990, for talc, c.i.f. main European ports, ranged from $165 to $336.

Foreign Trade

Talc exports decreased 25% in tonnage and increased 14% in value. Mexico remained the largest importer of talc, followed by Canada, Japan, and Belgium-Luxembourg. Talc imports decreased 17% in tonnage and 9% in value. Australia and Canada provided 82% of all talc imports.

World Review

The United States remained the world's largest talc producer, and Japan remained the largest pyrophyllite producer. China, Japan, and the United States accounted for 43% of the world's talc and pyrophyllite production.

The production and consumption of

TABLE 4

PRICE OF TALC

(U.S. dollars per metric tons)

Canada: Fine micron, Hegman No. 6	226
Montana: Ultrafine grind, Hegman No. 6	243
New York:	
Nonfibrous, bags, mill:	
98% through 325 mesh	99
99.6% through 325 mesh	115
Trace retained on 325 mesh	182
Norwegian:	
Ground (ex store)	168–185
Micronized (ex store)	221–309
French, fine-ground	212–336
Italian, cosmetic-grade	309
Chinese, normal (ex store):	
UK 200 mesh	254
Uk 325 mesh	265
New York, paint, minimum 20-ton lot	165

Sources: American Paint & Coatings Journal, Dec 26, 1990, Industrial Minerals (London), Dec. 1990.

TABLE 5

U.S. EXPORTS OF TALC[1]

(Thousand metric tons and thousand dollars)

Year	Belgium-Luxembourg		Canada[2]		Japan		Mexico		Other[3]		Total[4]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1986	14	1,273	54	4,411	20	1,707	102	4,464	24	4,447	212	16,302
1987	27	2,482	55	5,000	24	2,405	101	4,182	47	5,538	255	19,607
1988	27	3,942	62	5,079	30	3,849	97	3,225	44	5,296	260	21,391
1989	30	4,766	81	5,614	35	4,710	107	6,601	65	7,258	319	28,949
1990	45	6,109	43	6,995	31	4,233	e82	e8,006	37	7,566	238	32,909

e Estimated.
[1] Excludes powders—talcum (in package), face, and compact.
[2] Probably includes shipments in transit through Canadian ports.
[3] Includes 59 countries in 1990.
[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		Talc n.s.p.f.	Total unmanufactured[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1988:	31,988	$2,617	46,221	$7,679	1,182	$880	$1,090	79,391	$12,268
1989:									
Australia	6,999	500	6,001	540	—	—	NA	13,000	1,040
Brazil	—	—	228	40	116	57	NA	344	97
Canada	116	35	46,559	6,808	133	112	NA	46,808	6,964
China	5,080	366	576	157	748	540	NA	6,404	1,063
Italy	—	—	2,647	630	—	—	NA	2,647	630
Korea, Republic of	137	26	1,233	209	—	—	NA	1,370	235
Other[2]	4,084	533	2,871	881	188	695	NA	7,143	2,109
Total[1]	16,416	1,460	60,115	9,265	1,185	1,404	NA	77,716	12,128
1990:									
Australia	5,449	554	7,014	373	—	—	NA	12,463	927
Brazil	37	17	190	30	35	25	NA	262	72
Canada	76	12	39,665	5,880	895	857	NA	40,636	6,750
China	6,364	486	58	7	706	446	NA	7,128	939
Italy	2,625	677	7	6	—	—	NA	2,632	683
Korea, Republic of	—	—	527	122	—	—	NA	527	122
Other[3]	102	19	1,141	1,015	208	531	NA	1,451	1,564
Total[1]	16,652	1,765	48,602	7,432	1,844	1,859	NA	65,099	11,056

NA Not available.
[1] Data may not add to totals shown because of independent rounding.
[2] Includes 19 countries.
[3] Includes 24 countries.

Source: Bureau of the Census.

talc in Australia and East Asia was reviewed. The paper focussed on high-quality deposits in Australia, China, and the Republic of Korea, whose producers account for approximately one-third of the world's talc production. The region possesses large reserves, high-quality deposits, and a good location with regard to growing markets, although technological deficiencies and supply reliability are weaknesses of the industry.[6]

Capacity.—The data in table 6 are annual rated capacity for mines and refineries as of December 31, 1990. 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.

Australia.—South Australia supplied most of the talc for Australia's domestic demands despite accounting for only 9% of Australia's total production. Production comes primarily from the Mount Fitton deposit, 470 miles north of Adelaide. The Mount Fitton deposit was formed through the hydrothermal alteration of dolomite and marble rocks. It is 10 to 15 meters wide, 20 meters high, and several hundred meters long. Conventional open pit methods are used to mine the deposit. Approximately 70% of production is used in pharmaceutical and paint products.[7]

Ireland.—Ivernia West PLC acquired a major shareholding in Talc Technology Ltd., owner of the Westport talc deposit. The talc deposit is composed of 50% talc, 33% breunerite, 10% antigorite, 2% dolomite, and 5% magnesite and contains approximately 5.5 million tons of talc. If development permits are approved, the mine production initially will be 40,000 tons per year.[8]

Sweden.—Handöls Taljstens AB, now under private ownership, produces approximately 20,000 tons of talc-chlorite for animal feed, roofing, plastics, and fertilizers. Research is being conducted to separate talc from chlorite through flotation processing. The processed talc will be suitable for paper applications. Primary tests indicate that the talc can be upgraded from 60% talc to 97% talc with a brightness of 92% to 93%.[9]

TABLE 7

WORLD TALC AND PYROPHYLLITE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990

(Thousand metric tons)

Country	Rated capacity[1]
North America:	
Canada	299
United States	1,361
Total	1,660
Latin America:	
Argentina	45
Brazil	454
Mexico	36
Other	36
Total	571
Europe:	
Austria	136
Finland	363
France	363
Italy	163
Norway	136
U.S.S.R.	544
Other	236
Total	1,941
Africa:	
Egypt	13
South Africa, Republic of	18
Other	1
Total	32
Asia:	
China	1,179
India	454
Iran	32
Japan	1,633
Korea, North	1
Korea, Republic of	998
Other	82
Total	4,378
Oceania:	
Australia	227
World total	8,809

[1] Includes capacities of operating plants as well as plants on standby basis.

Venezuela.—A talc deposit was discovered on Margarita Island, off the coast of Venezuela. Further investigations are being carried on the commercial viability of the deposit. Venezuela currently does not produce talc.[10]

Current Research

The flotation process can be better controlled with the use of on-line monitoring. On-line processing enables the operator to immediately detect changes in the operation and make the necessary adjustments to ensure a constant product quality. X-ray fluoresence is used to determine elemental compositions of the flotation slurry at various stages in the flotation process. Greater control is obtained when coupled with on-line brightness determinations.[11]

The use of column flotation to process industrial minerals was reviewed. The paper discussed the processing of andalusite, chromite ore, fluorite, graphite, manganese oxide ore, phosphate ore, potash, and talc. A talc ore composed of 50% talc and ground to 80% less than 45 micrometers was upgraded to 73% talc by using two stages of column flotation. This result is a 6% improvement over conventional flotation using five stages. A Korean talc ore composed of 73% talc and ground to less than 45 micrometers was upgraded to 83% by using a single stage of column flotation. Recovery of the same ore using three stages of conventional flotation was 45% to 65%.[12]

OUTLOOK

The average annual growth in domestic demand for talc and pyrophyllite was 1.2% between 1981 and 1990. Demand averaged between 900,000 and 1,000,000 tons per year for this period. Relative increases and decreases in demand have been the result of minor market fluctuations rather than long-term trends. Demand for talc and pyrophyllite is expected to continue to fluctuate around 1 million tons per year in the near future.

Ceramics will continue to be the major domestic end use for talc, followed by consumption in paint, paper, plastics, roofing, and cosmetics, in de-

scending order. For pyrophyllite, the major domestic end uses will continue to be in ceramics and refractories.

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TABLE 8

TALC AND PYROPHYLLITE: WORLD PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Metric tons)

Country[2]	1986	1987	1988	1989	1990[e]
Argentina:					
Pyrophyllite	2,812	1,260	671	r1,310	1,300
Steatite[e]	300	300	250	250	250
Talc	22,353	27,103	r26,108	r26,658	26,000
Australia:					
Pyrophyllite	8,588	6,036	5,750	e5,000	5,000
Talc	179,467	206,865	199,631	e195,000	200,000
Austria: Steatite	133,319	129,959	132,974	r133,078	130,000
Brazil:[3]					
Agalmatolite	131,036	104,536	r122,531	e120,000	120,000
Pyrophyllite	87,250	51,114	r60,070	r162,000	170,000
Talc	r349,528	425,513	r378,463	r433,000	430,000
Burma: Steatite	56	22	e25	r e20	20
Canada (shipments): Pyrophyllite, soapstone, talc	123,037	r136,418	r146,489	r146,000	146,000
Chile: Talc	2,257	980	1,070	r835	1,000
China: Unspecified[e]	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Colombia: Pyrophyllite, soapstone, talc	9,013	11,927	12,800	r9,196	10,000
Egypt: Pyropyllite, talc, soapstone, steatite	8,800	e6,600	7,268	r7,146	7,000
Finland: Talc	284,179	319,000	379,000	e380,000	380,000
France: Talc	r324,660	e328,800	r e320,000	r329,960	330,000
Germany, Federal Republic of:					
Western states: Talc (marketable)	21,884	19,785	r19,500	r13,000	15,000
Greece: Steatite	17,310	1,507	e1,600	r10,518	10,000
Hungary: Talc[e]	16,000	15,000	13,000	12,000	12,000
India:					
Pyrophyllite	r58,884	51,724	r64,923	r97,264	95,000
Steatite	r378,683	359,448	r417,493	r414,268	416,000
Iran: Talc[e]	31,000	31,000	31,000	30,000	30,000
Italy: Steatite and talc	151,206	150,718	158,722	r146,000	145,000
Japan:					
Pyrophyllite	1,270,112	1,241,069	1,244,491	r1,233,600	4 1,231,195
Talc	63,851	55,899	r49,797	r55,665	4 61,550
Korea, North: Unspecified[e]	170,000	170,000	170,000	170,000	170,000
Korea, Republic of:					
Pyrophyllite	587,049	690,819	673,776	r770,298	750,000
Talc	210,631	161,052	146,478	r162,098	160,000
Mexico: Talc	24,301	17,469	r13,645	r13,908	13,800
Nepal: Talc[5]	8,780	r3,359	4,430	r6,728	6,500
Norway: Talc[e]	100,000	100,000	100,000	100,000	100,000
Pakistan: Pyrophyllite	23,021	23,278	37,429	r38,290	40,000
Paraguay: Unspecified	130	180	150	200	200
Peru:					
Pyrophyllite	7,354	705	e1,000	e750	750
Talc	1,754	1,447	e1,500	e1,250	1,300
Philippines: Talc	e1,000	—	r27	—	—

See footnotes at end of table.

TABLE 8—Continued

TALC AND PYROPHYLLITE: WORLD PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Metric tons)

Country[2]	1986	1987	1988	1989	1990[e]
Portugal: Talc	[r]5,908	7,292	7,187	[r]8,063	[4]7,926
Romania: Talc[e]	65,000	65,000	65,000	60,000	55,000
South Africa, Republic of:					
Pyrophyllite	4,606	3,467	3,162	[r]3,942	[4]2,759
Talc	8,641	8,005	10,111	[r]11,596	[4]11,179
Spain: Steatite	[r]73,914	75,307	[r]68,979	[r e]75,000	75,000
Sweden: Talc and steatite	11,233	16,981	[e]16,000	[e]16,000	16,000
Taiwan: Talc	21,552	22,102	21,603	[r]22,559	22,000
Thailand:					
Pyrophyllite	36,165	37,749	37,285	[r]39,799	39,000
Talc	2,886	4,101	4,843	[r]7,242	7,200
U.S.S.R.: Talc[e]	520,000	530,000	530,000	530,000	500,000
United Kingdom: Talc	12,352	12,529	14,182	[r]15,413	15,000
United States:					
Pyrophyllite	75,000	83,000	97,000	81,301	[4]82,025
Talc	1,106,000	1,080,000	[r]1,136,347	1,171,871	[4]1,185,142
Uruguay: Talc	1,255	1,648	[e]1,600	[e]1,600	16,000
Zambia: Talc	266	258	73	[r]114	200
Zimbabwe: Talc	797	516	976	[r]1,513	1,500
Total	[r]7,755,180	[r]7,798,847	[r]7,956,409	[r]8,271,303	8,250,796
Of which:					
Pyrophyllite	2,160,841	2,190,221	2,225,557	2,433,554	2,417,029
Steatite	603,582	566,543	621,321	633,134	631,270
Talc	3,386,302	3,444,723	3,475,571	3,590,073	3,588,297
Unspecified	1,604,455	1,597,360	1,633,960	1,614,542	1,614,200

[e] Estimated. [r] Revised.

[1] Table includes data available through May 14, 1991.

[2] In addition to the countries listed, Czechoslovakia and Turkey produce talc, but information is inadequate to make reliable estimates of output levels.

[3] Total of beneficiated production, salable direct shipping production, and that consumed by producers.

[4] Reported figure.

[5] Data based on Nepalese fiscal year beginning mid-July of year stated.

THALLIUM

By Thomas O. Llewellyn

Mr. Llewellyn, a physical scientist with the U.S. Bureau of Mines, has been the commodity specialist for thallium since 1987. Domestic survey data were prepared by Eraina C. Dixon, mineral data assistant.

In 1990, domestic demand for thallium metal was met by import. Thallium is a trace element with an estimated average abundance of 2.2 parts per million in zinc sulfide ores and is a byproduct recovered from flue dust and residues collected in the smelting of zinc as well as copper and lead. There are a number of rare thallium minerals found in nature that have no commercial importance as sources of thallium metal.

PRODUCTION

Although thallium was contained in ores mined or processed in the United States, it was not recovered domestically as a marketable product in 1990.

CONSUMPTION AND USES

Based on import data and discussions with metal traders, the domestic consumption of thallium in 1990 was estimated to be 700 kilograms, about 26% lower than that of 1989.

Thallium was used in superconductivity research, gamma radiation-detection equipment, additives for changing the refractive index and density of glass, low-temperature mercury-thallium alloy switches, high-density liquids, alloys, photosensitive devices, and radioactive isotopes for cardiovascular diagnostic procedures. It appears that all foreign countries have stopped using thallium sulfate as an ingredient in rodenticide because of its high toxicity to humans.

MARKETS AND PRICES

Thallium metal was sold at various prices during the year according to its purity. Metal traders reported that the average price of thallium metal in 100-kilogram lots was $190 per kilogram for 99.99%-pure thallium metal. The average value per kilogram of unwrought thallium metal and waste and scrap imported into the United States was estimated to be about $137 per kilogram.

FOREIGN TRADE

In 1990, thallium materials were imported only from Belgium. Effective January 1, 1990, the import duty for unwrought thallium and waste and scrap (Harmonized Code 8112.91.6000) was 5.5% ad valorem for most favored nations (MFN) and 25% ad valorem for non-MFN.

Thallium producers are granted a depletion allowance of 14% on both domestic and foreign production.

TABLE 1

U.S. IMPORTS FOR CONSUMPTION OF THALLIUM, BY COUNTRY

Country	Unwrought and waste and scrap	
	Gross weight (kilograms)	Value
1989:		
Belgium	1,135	$116,402
Germany, Federal Republic of	15	3,104
Japan	23	3,895
Total	1,173	123,401
1990:		
Belgium	450	61,482

Source: Bureau of the Census.

RESERVES

World production data for thallium were not available. The U.S. reserves in zinc ores were estimated to be about 32,000 kilograms. Rest-of-the-world reserves were estimated to be 345,000 kilograms of thallium.

CURRENT RESEARCH

The first patent in the United States for high-temperature superconductor compound formulations, based on thallium, was granted in 1989 to International Business Machines Corp., Armonk, NY.[1] In 1990, researchers at the University of Arkansas, Fayettesville, AR, who were regarded as the discoverers of thallium-base superconductors were notified by the U.S. Patent Office that a patent would be issued for their thallium-base superconductor formulations discovered in 1988.[2] On June 27, 1990, E.I. du Pont de Nemours & Co., Wilmington, DE, received a U.S. patent for a high-temperature superconducting material containing thallium, barium, copper, and oxygen.[3]

TOXICITY

Thallium metal and its compounds are highly toxic; they should be handled with extreme care and require the use of rubber gloves. It can be absorbed into the human body by skin contact, ingestion, or by inhaling dust or fumes. The element is not quickly eliminated from the body; therefore, absorption of subtoxic quantities eventually may accumulate to a toxic level.

OUTLOOK

The United States is not expected to resume recovery of metal thallium within the next 2 to 5 years. The toxicity of thallium is the factor that was expected to continue to influence domestic dependence on foreign sources for its supply.

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[2] Stipp, D. Superconductor Patent Is Won by University. Wall Street Journal. V. CCXV, No. 91, May 9, 1990, p. B4.

[3] Copalkrishnan, J., and M. A. Subramanian. Superconducting Compositions Tl_2 Ba_2 Cu_{6+x} and Process for Manufacture. U.S. Patent 4,929,594, May 29, 1990.

THORIUM

By James B. Hedrick

Mr. James B. Hedrick, a geologist and physical scientist with the Federal Government for 13 years, has been the commodity specialist for thorium since 1982. Domestic survey data were prepared by Mr. Kevin Bacon, mineral data assistant; and international data tables were prepared by Mr. Harold Willis, international data coordinator.

Domestic consumption of refined thorium products increased. Thorium was recovered primarily from the rare-earth ore monazite, a byproduct of processing heavy-mineral sands for titanium and zirconium minerals or tin minerals. Thorium was recovered as a byproduct during processing for the rare-earth elements. Only a small portion of the thorium produced worldwide is used: most is discarded as waste. Major monazite-producing countries were Australia, Brazil, China, India, Malaysia, the Republic of South Africa, Thailand, and the United States. None of the domestically produced monazite was refined in the United States. Essentially all of the thorium compounds and alloys used by the domestic industry were derived from either imports or U.S. Government stocks.

Limited demand for thorium, relative to the rare earths, continued to create an extensive world oversupply of thorium residues. Excess thorium, not designated for commercial use, was either stored for potential use as a nuclear fuel or disposed of as a radioactive waste. Major nonenergy uses were refractory applications and lighting applications. The only domestic thorium-fueled commercial reactor discontinued operation in late 1989 and was decommissioned during 1990.

Thorium's natural radioactivity represented a significant problem to those companies involved in its mining, processing, and use.

DOMESTIC DATA COVERAGE

Domestic mine production data for thorium-bearing monazite are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. operations. This is the "Rare Earths, Thorium, and Scandium" survey. The one mine to which a survey form was sent responded, representing 100% of mine production. Mine production data for thorium are withheld to avoid disclosing company proprietary data. Statistics on domestic thorium consumption are developed by surveying various processors and end users, evaluating import-export data, and analyzing Government stockpile shipments.

LEGISLATION AND GOVERNMENT PROGRAMS

The calendar year 1990 included the U.S. Government fiscal years for 1990 and 1991. Public Law 101-189, the National Defense Authorization Act for Fiscal

TABLE 1

SALIENT U.S. REFINED THORIUM STATISTICS

(Metric tons of ThO_2, unless otherwise specified)

	1986	1987	1988	1989	1990
Exports:[1]					
Metal, waste and scrap	17.01	20.41	2.74	NA	NA
Compounds[2]	NA	NA	NA	8.25	0.22
Imports:[1]					
Compounds, gas mantles, metals	19.71	30.69	13.23	33.34	18.60
Shipments from Government stockpile excesses	—	—	3.06	—	2.17
Consumption, reported nonenergy applications[3]	72.38	39.41	63.63	57.20	65.51
Prices, yearend, dollars per kilogram, ThO_2:[4]					
Nitrate, mantle-grade	$13.60	$10.10	$13.80	(5)	$16.55
Oxide, 99% grade	$40.00	$41.00	$45.00	(5)	$55.00

NA Not available.

[1]Because of implementation of the Harmonized Tariff System begun in Jan. 1989, import and export catagories for 1989 and later are not necessarily comparable to those of previous years.

[2]Data not available prior to Jan. 1989.

[3]All domestically consumed thorium was derived from imported metals, alloys, and compounds; monazite containing thorium has been imported annually but has not recently been used to produce thorium products.

[4]Source: Rhône-Poulenc, Inc.

[5]Data withheld by company.

Years 1990 and 1991, continued the authorization for disposal of all stocks of thorium nitrate in excess of the National Defense Stockpile (NDS) goal of 272,155 kilograms (600,000 pounds). Thorium nitrate in excess to goal at yearend 1990 was 2,946,185 kilograms (6,495,225 pounds).

The National Defense Authorization Act also legislated a limit of $180 million on the value of materials disposed of during each fiscal year.

PRODUCTION

Associated Minerals (USA) Ltd., a wholly owned subsidiary of the Australian-based firm Renison Goldfields Consolidated Ltd. operated a dredging operation at Green Cove Springs, FL. Associated Minerals was the principal producer of thorium-containing monazite in the United States. Monazite produced by Associated Minerals was a byproduct of processing mineral sands for titanium and zirconium minerals.

Imperial Mining Co., a minor producer of byproduct monazite and xenotime, closed its operations at midyear. The Marion, NC, mine was primarily an industrial sand and gravel and gold producer. The operation closed reportedly as a result of Imperial's failure to obtain State permitting for a closed cyanide leach system for gold recovery.

CONSUMPTION AND USES

Domestic thorium producers reported consumption of an estimated 65.5 metric tons of thorium oxide equivalent in 1990, an increase of 8.3 tons from the 1989 level. Nonenergy uses accounted for all of the total consumption. The increase was the result of higher demand in lighting applications. The approximate distribution of thorium by end use, based on data supplied by producer, processors, and several consumers, was as follows: refractory applications, 70%; lamp mantles and lighting, 26%; metallurgical applications, 1%; welding electrodes and other applications, 3%.

Thorium oxide (thoria) has the highest melting point of all metal oxides, 3,300° C, a property that contributed to its use in several refractory applications. Applications included high-temperature ceramics, investment molds, and crucibles.

Thorium nitrate was used in the manufacture of mantles for incandescent "camping" lanterns and in natural gas and oil lamps. Thorium mantles provide an intense white light that is adjusted to the yellow region of the visible spectrum by a small addition of cerium. The lamp mantle was thorium's first commercial use in the 1890's.

Thorium nitrate was also used to produce thoriated tungsten welding electrodes. Thoriated tungsten electrodes were used to join stainless steels, nickel alloys, and other alloys that require a continuous and stable arc to achieve precision welds.

The nitrate form was also used to produce thoriated tungsten elements used in the negative pole of magnetron tubes. Thorium was used because of its ability to emit electrons at relatively low temperatures when heated in a vacuum. Magnetron tubes were used to emit electrons at microwave frequencies to heat food in microwave ovens and in tracking radar and communication radar.

Thorium was used in other types of electron-emitting tubes, elements in special use light bulbs, high-refractivity glass, radiation detectors, computer memory components, catalysts, photoconductive

TABLE 2

U.S. COMPANIES WITH THORIUM PROCESSING AND FABRICATING CAPACITY

Company	Plant location	Operations and products
Atomergic Chemetals Corp.	Plainview, NY	Produces oxide, fluoride, metal.
Bettis Atomic Power Laboratory	West Mifflin, PA	Nuclear fuels, Government research and development.
Cerac Inc.	Milwaukee, WI	Produces ceramics.
Chicago Magnesium Casting Corp.	Blue Island, IL	Magnesium-thorium alloys.
Coleman Co. Inc.	Wichita, KS	Produces thoriated mantles.
Controlled Castings Corp.	Plainview, NY	Magnesium-thorium alloys.
General Atomics Inc.[1]	San Diego, CA	Nuclear fuels.
W.R. Grace & Co., Davison Chemical Div.	Chattanooga, TN	Capability to produce compounds from monazite.
GTE Sylvania	Towanda, PA	Produces thoriated welding rods.
Hitchcock Industries Inc.	South Bloomington, MN	Magnesium-thorium alloys.
Phillips Elmet	Lewiston, ME	Produces thoriated welding rods.
Rhône-Poulenc Basic Chemicals Co.	Freeport, TX	Produces thorium nitrate from an intermediate compound of monazite.
Spectrulite Consortium Inc.	Madison, IL	Magnesium-thorium alloys.
Teledyne Cast Products	Pomona, CA	Do.
Teledyne Wah Chang	Huntsville, AL	Produces thoriated welding rods.
Union Carbide Corp., Nuclear Div.	Oak Ridge, TN	Nuclear fuels; test quantities.
Wellman Dynamics Corp.	Creston, IA	Magnesium-thorium alloys.
Westinghouse Materials Co. of Ohio[2]	Cincinnati, OH	Capability to produce compounds and metals; manages DOE thorium stocks.

[1]Formerly G A Technologies.
[2]Manager of Department of Energy stocks.

films, target materials for X-ray tubes, and fuel-cell elements. Thorium fluoride was used in the manufacture of carbon arc lamps. Carbon arc lamps were used in searchlights, movie projectors, and cinematography lighting.

Most thorium used in metallurgical applications was alloyed with magnesium. Magnesium-thorium alloys used by the aerospace industry are lightweight and have high-strength and excellent creep resistance at elevated temperatures. Small quantities of thorium were used in dispersion-hardened nickel alloys for high-strength, high-temperature applications.

Thorium was used as a nuclear fuel in the thorium-232/uranium-233 fuel cycle. Only a few foreign-based nuclear reactors continue to operate with this fuel cycle.

STOCKS

Government stocks of thorium nitrate in the NDS were 3,219,457 kilograms (7,097,687 pounds) on December 31, 1990. The NDS goal at yearend was 272,155 kilograms of thorium nitrate (600,000 pounds). Stocks in excess of goal were authorized for disposal.

The U.S. Department of Energy's inventory at yearend was 2,268,322 kilograms of thorium oxide equivalent contained in ore, metal, and various compounds.

PRICES

The price range of Australian monazite (minimum 55% rare-earth oxide, including thoria, f.o.b.),[1] as quoted in Australian dollars (A$),[2] increased from A$780 to A$880 per ton at yearend 1989 to A$800 to A$900 per ton at yearend 1990. Changes in the United States-Australia foreign exchange rate in 1990, resulting from a slightly weaker Australian dollar, caused the corresponding U.S. dollar to be up $0.03 against the Australian dollar at yearend. The U.S. price range, converted from Australian dollars, increased slightly from US$616 to US$695[3] per ton in 1989 to US$618 to US$695[4] per ton in 1990.

Thorium prices quoted by Magnesium Elektron, Flemington, NJ, at yearend 1990 were $87.29 per pound for thorium hardener (80% Mg-20% Th) in single drum quantities and $16.26 per pound for thorium-containing HZ-32 magnesium alloy ingot.

WORLD REVIEW

Australia

Rhône-Poulenc SA of France abandoned its plans to build a $150 million rare-earth and thorium separation plant at Pinjarra, Western Australia. Environmental concerns related to the disposal of naturally radioactive thorium halted the project in 1988. Rhône-Poulenc reported that the primary problem in securing project approval was the Australian Government's lack of strict environmental regulations: allowing opposition a free range of targets.[5]

Renison Goldfields continued development of its Eneabba West mineral sands deposit in Western Australia. Production from the mine, including thorium-containing monazite, is expected in 1991.

Brazil

Production of thorium-containing monazite concentrates in 1988 was 2,817 tons: 2,038 tons from the State of Rio de Janerio, a decrease from the 1987 production of 3,271 tons; 779 tons from the State of Bahia, a decrease from the 884 tons of monazite produced in 1987; and no production from the State of Espírito Santo, down from 177 tons in 1987.

Measured reserves of monazite increased to 48,281 tons in 1988 from 36,806 tons in 1987. Estimated thorium content of the 1988 reserves was 3,138 tons of thorium oxide equivalent. The increase in reserves was the result of additional tonnages added from the Sao Joao da Barra deposit in the State of Rio de Janeiro. Additional monazite reserves were in the States of Bahia, Espírito Santo, and Minas Gerais.[6]

Japan

Imports of Malaysian ilmenite were suspended because of unacceptable radiation levels from thorium and uranium in the concentrate. The radioactivity was traced to other mineral sands in the concentrate, primarily monazite, zircon, and xenotime. The Malaysia Chamber of Mines is negotiating to resume shipments, claiming that the radiation levels are with in acceptable limits.

OUTLOOK

The nonenergy uses of thorium are expected to decrease. Industry users continue to search for suitable substitutes, and the long-term outlook for demand is for a significant decline. Because of its natural radioactivity, new applications for thorium are not being developed, the result of high costs associated with handling, storing, monitoring, and disposal. The current trend to safeguard the environment is expected to continue, and additional regulations to control thorium's use are expected. Laws banning certain applications of other hazardous materials, including asbestos, mercury, and lead, have recently been enacted.

Thorium's domestic use in energy applications dropped to zero in 1990. The only domestic thorium-fueled reactor was decommissioned during the year, and no short-term domestic use as a nuclear fuel is foreseen. The long-term outlook for thorium in domestic energy applications is dismal: uranium is expected to remain the only nuclear fuel used by the domestic industry.

[1]Free-on-board.

[2]Metal Bulletin (London). Non-Ferrous Ores in Europe. No. 7445, Dec. 29, 1989, p. 28.

[3]Values have been converted from Australian dollars (A$) to U.S. dollars (US$) at the exchange rate of A$1.2660= US$1.00 based on yearend 1989 foreign exchange rates reported in the Wall Street Journal.

[4]Values have been converted from Australian dollars (A$) to U.S. dollars (US$) at the exchange rate of A$1.2945= US$1.00 based on yearend 1990 foreign exchange rates reported in the Wall Street Journal.

[5]Industrial Minerals (London). Rhône Poulenc RE Interest. No. 267, Dec. 1989, p. 68.

[6]Anuário Mineral Brasileiro 1988. Monazita. pp. 264-265. (Translated from Portuguese).

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TABLE 3

U.S. FOREIGN TRADE IN THORIUM AND THORIUM-BEARING MATERIALS[1]

(Quantity in kilograms unless otherwise specified)

	1988		1989		1990		Principal destinations and sources, 1990
	Quantity	Value	Quantity	Value	Quantity	Value	
EXPORTS							
Thorium ore, monazite, concentrate	e490,314	$310,384	e50,000	$29,780	(2)	(2)	
Metals[3]	2,406	54,271	NA	NA	NA	NA	
Compounds[4]	NA	NA	8,247	221,323	220	$68,409	Japan 130; Switzerland 30; Liechtenstein 30; United Kingdom 15; other 15.
IMPORTS							
Ore and concentrate metric tons	1,924	1,154,498	774	530,294	800	685,650	Indonesia 800.
ThO_2 content	127,220	XX	48,240	XX	56,000	XX	
Compounds:	20,001	380,255	33,344	943,692	18,598	594,811	France 16,998; United Kingdom 1,590; Federal Republic of Germany 6; Canada 4.
Oxide equivalent, in gas mantles[e 5]	862	284,673	NA	NA	NA	NA	
Other	663	213,677	NA	NA	NA	NA	
Metals and alloys	15,167	NA	NA	NA	NA	NA	
Unwrought, waste and scrap	77	2,550	NA	NA	NA	NA	

[e]Estimated. NA Not available. XX Not applicable.

[1]Because of the implementation of the Harmonized Tariff System begun in Jan. 1989, import and export catagories are not necessarily comparable to those in previous years or may no longer be available.

[2]No exports were reported for this catagory in 1990.

[3]Unwrought, wrought, waste and scrap.

[4]Data unavailable prior to Jan. 1989.

[5]Based on the manufacture of 2,205 gas mantles per kilogram of thorium oxide.

Sources: Bureau of the Census and a producer.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF MONAZITE, BY COUNTRY

Country	1986		1987		1988		1989		1990	
	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	2,660	$978	—	—	382	$237	180	$117	—	—
India	300	128	—	—	—	—	—	—	—	—
Indonesia	—	—	—	—	1,144	687	794	557	800	$686
Malaysia	—	—	527	$298	197	125	—	—	—	—
Thailand	—	—	594	329	201	105	—	—	—	—
Total	2,960	1,106	1,121	627	1,924	1,154	974	674	800	686
REO content[e]	1,628	XX	617	XX	1,058	XX	536	XX	440	XX

[e]Estimated. XX Not applicable.

Source: Bureau of the Census. REO content estimated by the Bureau of Mines.

TABLE 5

MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons, gross weight)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Australia	14,822	12,813	11,872	e13,500	14,500
Brazil	3,618	4,332	2,817	1,900	2,000
India[e]	4,000	4,000	4,000	r4,300	4,500

See footnotes at end of table.

TABLE 5—Continued

MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons, gross weight)

Country[2]	1986	1987	1988	1989[p]	1990[e]
Malaysia	5,959	2,908	2,920	2,948	3,500
Mozambique[e]	3	—	—	—	—
South Africa, Republic of[e]	1,000	1,200	1,200	[r]1,200	1,200
Sri Lanka[e]	200	200	200	200	200
Thailand	1,609	458	590	631	650
United States	W	W	W	W	W
Zaire	7	97	168	175	170
Total	[r]31,218	[r]26,008	23,767	24,854	26,720

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

[1]Table includes data available through Apr. 23, 1991.

[2]In addition to the countries listed, China, Indonesia, North Korea, the Republic of Korea, Nigeria, and the U.S.S.R. may produce monazite, but output, if any, is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels.

TIN

By James F. Carlin, Jr.

Mr. Carlin, a physical scientist with the Branch of Metals, has been the commodity specialist for tin for 11 years. Domestic survey data were prepared by Elsie Isaac, mineral data assistant; and international data tables were prepared by William L. Zajac, Chief, Section of International Data.

Tin was one of the earliest metals known to humankind. Tin occurs in nature mostly as the oxide mineral cassiterite. Tin metal is commonly used as a protective coating or as an alloy with other metals. It finds applications in products and processes as diverse as tin cans, solder for electronics, tin chemicals, bronze fittings, and flat-glass production. Its strategic importance is exemplified by the fact that it is the largest dollar-volume holding of all metals in the National Defense Stockpile (NDS).

In 1990, for the 10th consecutive year, there was an excess of tin on the world market. Excess stocks were believed to have increased somewhat to about 45,000 metric tons of tin at yearend. Legal conflicts that had continued for 4 years, pitting tin dealers and banks against the London Metal Exchange (LME) and the International Tin Council (ITC), connected to the 1985 "tin crisis," ended as all parties agreed to a settlement.

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 continued low tin prices caused numerous mines to close. In the United States, there was increased interest in the recycling of used tin cans largely because of dwindling landfill space. The opening of several new detinning facilities stimulated recycling activity. Despite the adoption of terms of reference for a proposed International Tin Study Group (ITSG), no action was taken to bring the group into realization.

DOMESTIC DATA COVERAGE

Domestic consumption data for tin are developed by the Bureau of Mines from a voluntary survey of U.S. tin users. Of the 318 consumers to which a survey request was sent, 318 responded.

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 99.85% 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 tin-lead alloy.

Tinplate is commonly shipped as coil, solder as ingot, bronze as strip or plate, and brass as any of these forms. Each of these semifinished products is then used to fabricate a wide variety of end-use items. Brass and bronze are also produced in cast forms. Tin usually becomes a very small, but essential, part of the end-use item's weight or cost.

Industry Structure

At least 35 countries mine or smelt tin. Virtually every continent has an important tin-mining country. Most operations are privately owned, but many are publicly owned. A similar situation exists in the tin-smelting industry.

In the major Southeast Asian tin-producing countries, small, labor-intensive, high-unit-cost mines, such as gravel-pump mines, produce a significant proportion of total output. In these same countries, massive, expensive dredges also are used. Large, privately owned mining enterprises operate in Southeast Asia, but many of the operations are also Government-owned. The four largest tin mining companies in the market economy countries are Paranapanema in Brazil, the Malaysian Mining Corp., P.T. Timah in Indonesia, and Corporación Minera de Bolivia (COMIBOL).

An agreement establishing the Association of Tin Producing Countries (ATPC) came into force on August 16, 1983. The five charter members were Bolivia, Indonesia, Malaysia, Thailand, and Zaire. Australia and Nigeria joined later. The stated objectives of the ATPC were to obtain fair returns for tin producers and adequate and stable supplies at reasonable prices for tin consumers, to facilitate cooperation in the marketing of tin, and to enhance the growth of tin use. Members stated that they viewed the ATPC as complementary and supportive of the activities of the ITC. The Tin Council was an association of leading world tin producer and user countries that attempted to stabilize tin prices and supply-demand from 1956 until its demise in 1989. In recent years, the most visible activity of the ATPC has been to attempt to reduce the world oversupply of tin through a series of supply rationalization schemes. These programs have essentially featured export-control limits placed on the seven member countries. While these programs have succeeded in drastically reducing the huge tin oversupply, they have not eliminated it largely because major producers like 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 account-

TABLE 1

SALIENT TIN STATISTICS

(Metric tons unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Production:					
Mine	W	W	W	W	W
Smelter	3,213	[1]3,905	[1]1,467	[e]1,000	—
Secondary[e]	14,850	16,159	[r]15,275	[r]14,340	17,275
Exports[2]	1,547	1,318	1,209	904	658
Imports for consumption:					
Metal	35,768	41,150	43,493	33,988	33,810
Ore (tin content)	3,936	2,953	2,837	216	—
Consumption:					
Primary	33,327	35,620	37,529	[r]36,603	36,616
Secondary	10,197	8,599	8,072	9,853	7,747
Stocks, yearend, U.S. industry	13,857	14,464	15,023	[r]14,668	17,671
Prices, average cents per pound:					
New York market	294.12	309.01	330.91	397.28	287.69
Metals Week composite	[3]383.22	418.78	441.42	520.18	386.29
London	NA	NA	NA	[4]382.00	281.00
Kuala Lumpur	[3]272.26	303.45	319.86	387.12	276.02
World: Production:					
Mine	[r]173,170	[r]181,316	[r]204,606	[r]233,773	[e]219,333
Smelter:					
Primary	[r]182,289	[r]189,156	[r]214,860	[r]230,624	[e]231,864
Secondary	15,591	[r]16,224	[r]19,482	[r]19,133	[e]17,940

[e]Estimated. [r]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data; U.S. mine production for 1985-89 was negligible.
[1]Reported figure.
[2]Excludes reexports.
[3]Prices quoted for 10 months only.
[4]The London Metal Exchange resumed trading as of June 1, 1989.

ed for by a relatively few soldermaking firms. During the past decade, both the tinplate and the solder industries have undergone considerable consolidation. In the tin chemical field, while there are a number of companies, one firm dominates.

The other domestic tin-using industries are diverse, such as the brass, bronze, solder, and flat-glass industries, and are represented by hundreds of firms and plants. Most are located 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, canfield-dite, 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 may also contain placer accumulations of tin; such placers are mined offshore in Indonesia and Thailand. No extensive tin placer deposits have been found in the conterminous United States.

Technology

Exploration.— Historically, prospecting for tin has been carried out by the time-honored methods of panning, drilling, and pitting. As rich deposits were exhausted and the costs of exploration rose, the search for tin required more sophisticated methods. Geophysical and geochemical analyses have been employed to cover large areas more rapidly, isolating areas of possible tin deposits so that drilling can be more effective and less costly.

Mining.—Principal methods for mining placer deposits are bucket-line dredging and gravel-pump operations, although hydraulicking and various open pit methods are also used. The bucket-line dredges used are floating dredges similar to those used to mine other placer deposits. The ore is excavated and transported by buckets to the interior of the dredges, washed on screens, and concentrated in jigs and on shaking tables. Tailings are discharged at the rear of the dredges to fill in the mined pond, and the crude tin concentrate is sent to the dressing shed for final concentration.

Although gravel-pump and hydraulic mining both use water jets to break up the tin-bearing material, the methods of conveying the material to the launders differ. In gravel-pump mining, a pump is used, whereas hydraulicking employs the pressure developed by a natural head of water. In each method, the material is washed through a riffled launder, called a palong in Malaysia, where the cassiterite is collected by the riffles and the waste is washed away.

In open pit operations, the material is excavated by power shovels and transported on a conveyor belt to the washing plant for treatment.

Vein tin deposits are mined by methods similar to those used in the hard-rock mining of other nonferrous ores. Access to the ore bodies is by adits and shafts. The ore is broken by conventional drilling and blasting and transported from the mine to a concentrator for treatment.

Processing.—The crude tin concentrate from placer mining is further upgraded by washing, tabling, and magnetic or electrostatic separation. The final product is virtually pure cassiterite.

Tin ore from lode deposits is reduced to the necessary size by conventional crushing and grinding. The ore is concentrated by gravity methods involving screening, classification, jigging, and tabling. The gravity concentrate is usually of lower grade than placer concentrate owing to associated sulfide minerals. The sulfide minerals are removed by flotation or magnetic separation, with or without roasting, to produce a second-stage concentrate.

Cassiterite in placer deposits is fairly coarse grained, and recoveries range from 90% for gravel-pump mines to 95% for dredging operations. However, the cassiterite in vein deposits is very fine grained and is difficult to recover by gravity concentration. Cassiterite ore at mines in Australia, Bolivia, the Republic of South Africa, and the United Kingdom are floated, but recoveries are seldom above 70%. Recovery of the tin content in Bolivia is reportedly as low as 50%.

Cassiterite is reduced to tin by heating with carbon at 1,200° to 1,300° C. The almost pure cassiterite concentrate from placer deposits is smelted directly. Other concentrates, particularly from Bolivia, contain impurities that must be removed before smelting. This is usually done by roasting the tin concentrates with or without fluxes, followed by acid leaching. During roasting, most of the sulfur and arsenic are removed as oxides. Bismuth, copper, iron, and zinc oxides are removed by leaching the roasted concentrate with sodium carbonate or sulfate and leaching with water. Antimony, bismuth, lead, and silver may be removed by a chloridizing roast, followed by an acid leach.

In modern tin-smelting plants, reverberatory furnaces are used to smelt primary tin concentrate and to resmelt the slag for additional tin recovery. Although blast and electric furnaces are also used to smelt tin concentrate, reverberatories are often preferred because of better control, cleaner slags, and superior efficiency in smelting finely divided materials. Electric furnaces are often favored for energy-saving reasons, especially for smaller smelters.

Tin smelting is a batch operation. A typical charge consists of cassiterite concentrate, a carbon reducing agent, and limestone and silica fluxes. From 10 to 12 hours is required to smelt a charge. When smelting is complete, the molten batch is tapped into a settler, from which the slag overflows into cast-iron pots. The molten tin from the bottom of the settler is cast into slabs or pigs for refining.[2]

The slag, containing 10% to 25% tin, is resmelted to yield a slag containing less than 1% tin.

Heat treatment is the most widely used refining method and consists of heating the tin from smelters on an 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 re-treated 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 can-making plants. In the detinning of flat tinplate, generally the tinplate scrap is treated with a hot solution of caustic soda in the presence of an oxidizing agent to dissolve the tin as sodium stannate. The base steel is then washed and compacted into bales for shipment. The tin may be recovered from the stannate solution as metal, sodium stannate crystals, or tin oxide. Because of advantages in processing costs and production of a high-purity metal, the common practice is electrolysis of the stannate solution to yield metallic tin. The refined tin averages as high as 99.99% purity, with antimony, iron, and lead as common impurities.

Until recent years, the detinning of used tin cans was not performed on an economic, high-volume basis because cans were often in a crushed condition and had enamel coatings and food particles attached that made effective detinning impossible. However, in the late 1980's, techniques were developed to detin these used tin cans. The most common method is to shred the cans into small popcorn-sized pieces and then proceed with the caustic soda treatment.

Most scrap tin is alloyed tin (such as solder, brass-bronze, or babbitt) that is recycled in its own alloy industry. These producers refine out undesired elements from the scrap charge or may use additions to build up desired elements.

Byproducts and Coproducts

In some tin placer deposits, large amounts of columbium, tantalum, and rare-earth minerals are associated with the cassiterite. Some lode tin deposits contain numerous other materials such as copper, lead, silver, and zinc, usually in the form of sulfides.

Tin has been recovered as a coproduct of molybdenum mining at the Climax lode mine in Colorado. Small quantities have been produced as a coproduct of placer gold-mining or tailings-cleanup operations in Alaska or South Dakota. It has been produced as a byproduct of lead-zinc mining in Ontario and British Columbia, Canada.

In some major tin-producing countries, such as Malaysia and Thailand, tantalum contained in tin smelter slags is a major source of tantalum supply.

Substitutes

Alternative materials, often less costly, have been a significant factor in the downward trend in domestic tin consumption over the past two decades. Aluminum and chromium-coated tin-free steel were two materials used to replace tinplate in beverage cans over the past two decades. Other substitutes for tinplate include enameled steel, glass, paper, and plastics. Nonmetallic materials, aluminum, copper, and galvanized steel have largely replaced terneplate for roofing and both tinplate and terneplate for other construction. In general, no satisfactory substitutes have been found for tin in solder, although lowering the tin content of the solder may be possible in some applications. Aluminum alloys, other copper-base alloys, and plastics could be substituted for some bronzes. Low-tin aluminum-, copper-, or lead-base bearing alloys and roller or ball bearings may be substituted for babbitt metal. Other chemicals may replace some tin chemical compounds for use as fungicides, biocides, marine antifouling paints, or polyvinyl chloride stabilizers.

ANNUAL REVIEW

Legislation and Government Programs

The NDS continued in its second year of being managed by the Secretary of Defense, with day-to-day operations guided by the Defense Logistics Agency (DLA).

The DLA sold 2,145 tons of tin from the stockpile in 1990. Through June 30, disposals were payment materials in support of the ferroalloy upgrading program (this tin swap program started April 11, 1984); after June 30, disposals were direct sales to the marketplace. Direct sales to the public (primarily dealers and industrial users) were held each day, with orders for lots of 5 tons or more being accepted daily between 1:00 p.m. and 3:00 p.m. at the price set by the DLA for that day. Pickup points for the stockpile tin were Point Pleasant, WV; Curtis Bay, MD; Hammond, IN; and Stockton, CA. The DLA had authority from Congress to dispose of about 7,000 tons of tin in fiscal 1990 and a further 7,000 tons in fiscal 1991. At yearend 1990, the NDS inventory was 168,496 tons, and the stockpile goal was 42,674 tons.

On May 8 and May 16, separate bills were introduced by Senators Bradley (S. 2593) and Reid (S. 2637) in the U.S. Senate; both bills called for either a ban or reduction in the use of lead in certain products, including solder. A series of hearings were held at which industry representatives presented their views, and, as a result of these, the bills' particulars took a slightly different direction. Consideration of the bills continued through the end of the year. Certain features of the bills 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 finds application in such defense-related fields as solder for printed circuit boards in aircraft and night-vision weaponry and brass or bronze fittings and gears for naval needs. Tin in the NDS is stored in warehouses around the country, often close to plants that would use the tin during wartime.

It is considered unlikely that domestic tin deposits will yield significant amounts of tin in the next 10 years, so strategic needs must be met by imports, the NDS, and recycling.

Issues

The United Nations Conference on Trade and Development (UNCTAD) expressed concern that only 5 of the original 37 tin producer and consumer countries that had agreed in early 1989 to the terms of reference for an International Tin Study Group had thus far provided formal acceptance. These five countries represented only 30% of the total world tin trade, whereas a 70% minimum target was agreed to at the UNCTAD meeting in April 1989.

Production

The Cache Creek Mine, located in the Tofty District near Manley Hot Springs, AK, was the only mine in the United States to produce significant amounts of tin concentrates. The tin was recovered as a byproduct of gold mining. The mine, owned by Shoreham Resources, Inc., Houston, TX, was in its first year of production. The total output from the mine amounted to only a small fraction of domestic tin requirements.

The United States was believed to be the world's largest producer of secondary tin. Tin metal recovered from new tinplate scrap and from used tin cans was the only type of secondary tin available in the marketplace as free tin; other secondary tin was available in scrap materials as an alloying ingredient. Secondary tin from recycled fabricated parts was used in many kinds of products and was a major source of material for the solder and the brass and bronze industries. The Steel Can Recycling Institute in Pittsburgh, PA, funded and operated by five domestic tinplate producers, sought to advance the collection, preparation, and transportation of can scrap. Also, they expanded a program of installing representatives in several regions of the United States to work with municipalities, scrap dealers, and detinners to promote the recycling of tin cans.

Until 1989, generally all domestic detinning operations treated only new (factory-generated) tinplate scrap. This usually came from steel plant tin mills or can plants. Little or no old scrap, such as that from used (post-consumer) tin cans, was detinned. This was partly due to relatively inexpensive and nearby landfills, which in earlier years could readily accept municipal trash, but mostly it was due to technical difficulty in processing the cans. These used cans typically have enamel coatings, outside paper wrappers, remnants of food particles, and are often crushed, making it difficult to treat them effectively with chemical detinning solutions on a high-volume basis. However, in recent years, new scrap preparation procedures were developed, especially a new shredding method, that permitted detinning of used tin cans. Also, municipalities, by the late 1980's, faced increased costs for disposing of trash in landfills and dwindling landfill sites. These developments began to set the stage in 1990 for large-scale detinning of used tin cans. The domestic detinning industry responded with the construction of several new plants.

Proler International Corp. started up the world's largest detinning facility in Houston, TX. The new plant was capable of recycling 163,000 tons of tinplated steel cans and clippings per year, the equivalent of 2.5 billion tin cans per year. The operation involved the shredding of feedstock followed by continuous detinning in a series of rotating cylinders. The separated products were sold to various foundries and steelmakers. Plans were announced for the establishment of a new $260 million steel minimill, a joint venture of Proler International Corp., Birmingham Steel Corp., and Danielli & C. Officine Meccaniche S.p.A. (Italy). An important feature of the new operation was to be the assured supply of detinned can scrap generated by Proler's new Houston detinning plant. The new minimill was to be constructed on the site of the shuttered former USX Corp.'s Baytown, TX, steelworks. Plans were delayed when Birmingham Steel withdrew from the deal, although the two remaining partners sought a replacement.

AMG Resources Corp. started its new tin can recycling plant at St. Paul, MN. The facility had an electrolytic detinning system with a capacity to process up to 40,000 tons of tin cans annually.

Consumption and Uses

Primary tin consumption remained about the same as in the prior year. The only significant increases were in the categories of solder and tinning, and the only significant decline occurred in the category of brass and bronze. Tinplate remained the largest use item for primary tin, followed by solder and tin chemicals. The use of secondary tin declined perhaps owing to continuing low prices for primary tin.

Tinplated steel and tin-free steel accounted for 29% of the 126 billion cans shipped domestically and aluminum accounted for 71%; these were the same market shares as in 1989. Aluminum held an overwhelming advantage in the beverage can market, while steel predominated in the food can and the general-line markets. Steel cans notably increased their market penetration of the soft drink can market, accounting for 8% of 53 billion cans, compared with 6% of 49 billion cans in 1989.[3]

Statistics released by the Steel Can Recycling Institute illustrated some aspects of the current domestic status of tinplate. Canned food accounted for 12% of grocery sales in the United States, encompassing 1,500 different foods and items. Tinplate held about 92% of this canned food market, about 99% of the general-line can market, and about 8% of the growing soft drink market. Ball Corp. made a $1 billion takeover bid for Con-

TABLE 2

SECONDARY TIN RECOVERED FROM SCRAP PROCESSED AT DETINNING AND OTHER PLANTS IN THE UNITED STATES

		1989	1990
Tinplate scrap treated	metric tons	W	W
Tin recovered in the form of:			
Metal	do.	r563	186
Compounds (tin content)	do.	W	W
Total	do.	r563	186
Weight of tin compounds produced	do.	W	W
Average quantity of tin recovered per metric ton of tinplate scrap used	kilograms	1.98	2.73
Average delivered cost of tinplate scrapper	per metric ton	$60.41	$112.57

rRevised. W Withheld to avoid disclosing company proprietary data.

TABLE 3

TIN RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY FORM OF RECOVERY

(Metric tons unless otherwise specified)

Form of recovery	1989	1990
Tin metal[1]	r563	186
Bronze and brass[e 2]	r9,423	13,397
Lead and tin alloys:		
Antimonial lead	r967	742
Babbitt	116	28
Solder	3,225	2,876
Type metal	46	46
Other alloys[3]	W	W
Total	r4,354	3,692
Tin content of chemical products	W	W
Grand total	e r14,340	e17,275
Value (thousands)[e 4]	$125,597	$109,566

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.
[1]Includes tin metal recovered at detinning and other plants.
[2]Includes tin recovered from copper, lead, and tin-base scrap.
[3]Includes foil, terne metal, and cable lead.
[4]Based on Metals Week composite price.

TABLE 4

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
1988r									
Copper-base scrap	9,259	155,725	13,793	142,265	156,058	8,926	560	5,525	6,085
Brass mills[2]	4,476	W	W	W	W	4,769	630	—	630
Foundries and other plants	4,849	19,934	W	W	14,585	4,818	W	630	630
Total tin from copper-base scrap	XX	XX	XX	XX	XX	XX	1,190	6,155	7,345
Lead-base scrap	35,821	895,088	59,428	843,604	903,032	27,877	1,560	5,135	6,695
Tin-base scrap[3]	20	102	W	64	W	27	1,175	60	1,235
Grand total[4]	XX	XX	XX	XX	XX	XX	3,925	11,350	15,275
1989r									
Copper-base scrap	8,926	145,092	10,844	137,758	148,602	5,416	450	5,300	5,750
Brass mills[2]	4,769	41,314	41,314	—	41,314	4,833	585	—	585
Foundries and other plants	4,818	23,005	W	W	22,522	5,301	W	700	700
Total tin from copper-base scrap[4]	XX	XX	XX	XX	XX	XX	1,035	6,000	7,035
Lead-base scrap	27,877	1,081,927	66,847	1,018,147	1,084,994	24,810	1,755	5,440	7,200
Tin-base scrap[3]	27	119	W	110	110	W	W	105	105
Grand total[4]	XX	XX	XX	XX	XX	XX	2,795	11,545	14,340
1990									
Copper-base scrap	5,416	147,518	11,185	135,568	146,753	6,181	440	5,155	5,595
Brass mills[2]	4,833	11,931	11,931	—	11,931	2,810	290	—	290
Foundries and other plants	5,301	26,983	9,991	16,692	26,683	5,601	470	710	1,180

See footnotes at end of table.

TABLE 4—Continued

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				
1990—Continued[r]									
Total tin from copper-base scrap[4]	XX	XX	XX	XX	XX	XX	1,200	5,860	7,065
Lead-base scrap	28,810	1,128,439	61,902	1,068,677	1,130,579	26,670	1,625	7,350	8,975
Tin-base scrap[3]	W	41	W	31	W	5	W	W	W
Grand total[4]	XX	XX	XX	XX	XX	XX	4,035	13,200	17,275

[e]Estimated. [r]Revised. 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; Bureau of Mines not at liberty to publish separately.
[4]Data may not add to totals shown because of independent rounding and data concealed in "W."

TABLE 5

U.S. CONSUMPTION OF PRIMARY AND SECONDARY TIN

(Metric tons)

	1986	1987	1988	1989	1990
Stocks, Jan. 1[1]	9,336	9,876	10,217	9,242	13,485
Net receipts during year:					
Primary	35,475	38,401	39,421	[r]37,760	38,248
Secondary	11,636	11,707	12,472	10,901	9,538
Scrap	6,346	6,635	6,707	8,168	5,828
Total receipts	53,457	56,743	58,600	[r]56,829	53,614
Total available	62,793	66,619	68,817	[r]66,071	67,099
Tin consumed in manufactured products:					
Primary	33,327	35,620	37,529	[r]36,603	36,616
Secondary	10,197	8,599	8,072	9,853	7,747
Total	43,524	44,219	45,601	[r]46,456	44,363
Intercompany transactions in scrap	354	512	630	424	316
Total processed	43,878	44,731	46,231	[r]46,880	44,679
Stocks, Dec. 31 (total available less total processed)	18,915	21,888	[r]22,586	[r]19,191	22,420

[r]Revised.
[1]Includes tin in transit in the United States.

tinental Can Europe Ltd., a subsidiary of Peter Kiewit Sons Inc., but later withdrew it owing to financing problems. Reportedly, Kiewit still hoped to sell its packaging industry operations.

In a major merger in the container industry, Crown Cork & Seal Co. Inc. purchased the food and beverage metal can divisions of Continental Can Co. Inc. Crown paid $336 million and assumed certain liabilities. Continental operated more than 30 plants domestically and employed about 4,000 persons. Crown operated 104 plants worldwide and had 15,000 employees, with revenues of $1.9 billion. The purchase made Crown the largest U.S.-owned maker of metal cans and the second largest maker of metal cans in the United States after Pechiney (France). Both Crown and Continental were major users of tinplate. The purchase followed other consolidation moves in the past 2 years among major can makers in the world.

Stocks

The LME announced approval of Baltimore, Chicago/Toledo, and Bridgeport/New Haven as locations for the siting of LME warehouses. The LME started to take applications from warehouses in these areas. The decision to expand the LME warehouse network, which already covered Europe, Japan, and Singapore, was a natural consequence of the LME's role as a facilitator of global pricing and hedging for major metals. The U.S. warehouses could accept aluminum, nickel, tin, and zinc.

Markets and Prices

Marketing of tin metal in the United States was performed mostly through trading firms, which imported the tin from a variety of countries and warehoused it in this country until they sold it to consumers. Some tin was also marketed directly in the United States by large foreign producers who maintained sales offices here and sold their tin metal, usually on a 1-year contract basis, only to the largest users. Among these direct-sale operations were Indo-Metal Corp. and Renison Consolidated Goldfields Corp. Most traders and direct-sale operations were based in the New York, NY, area.

Among the ranks of trading firms, the year saw a significant shakeout. Burdened by competition from too many tin trading firms and by continuing low tin prices, an estimated 10 firms closed their operations.

The price of tin metal, as published in Metals Week, remained in a narrow band all year. The LME remained the primary trading focus for tin, trading having been reintroduced there in 1989 following its early 1986 suspension related to the 1985 tin market "collapse." The Kuala Lumpur Commodities Exchange in Malaysia continued as an active tin trading forum.

TABLE 6

TIN CONTENT OF TINPLATE PRODUCED IN THE UNITED STATES

Year	Tinplate waste (waste, strips, cobbles, etc., gross weight) (metric tons)	Tinplate (all forms)		
		Gross weight (metric tons)	Tin content[1] (metric tons)	Tin per metric ton of plate (kilograms)
1986	120,186	2,068,246	8,660	4.2
1987	141,842	2,302,173	10,357	4.5
1988	149,054	2,375,809	11,582	4.9
1989	153,542	2,263,769	11,764	5.2
1990	156,419	2,467,205	11,750	4.8

[1]Includes small tonnage of secondary tin and tin acquired in chemicals.

Foreign Trade

Imports of tin concentrates declined to zero, as expected in view of the conversion of the TexTin Corp. smelter in Texas City, TX, away from tin processing. Bolivia replaced Brazil as the major source of tin metal imports. Brazil ranked second, followed by China, Indonesia, Malaysia, and Mexico.

Imports of tin in all forms (ore and concentrate, metal, and waste and scrap) remained free of U.S. duty.

TABLE 7

U.S. CONSUMPTION OF TIN, BY FINISHED PRODUCT

(Metric tons of contained tin)

Product	1989			1990		
	Primary	Secondary	Total	Primary	Secondary	Total
Alloys (miscellaneous)[1]	W	W	W	W	W	W
Babbitt	511	283	794	552	211	763
Bar tin	619	—	619	603	—	603
Bronze and brass	1,575	2,118	3,693	1,160	2,003	3,163
Chemicals	W	W	W	6,275	W	6,275
Collapsible tubes and foil	W	W	W	W	W	W
Solder	10,806	5,564	16,370	11,567	4,011	15,578
Tinning	r1,505	W	r1,505	1,707	W	1,707
Tinplate[2]	11,764	W	11,764	11,750	W	11,750
Tin powder	711	W	711	563	W	563
Type metal	W	W	W	W	W	W
White metal[3]	1,074	W	1,074	1,045	W	1,045
Other	8,038	1,888	9,926	1,394	1,522	2,916
Total	r36,603	9,853	r46,456	36,616	7,747	44,363

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 8

U.S. INDUSTRY YEAREND TIN STOCKS

(Metric tons)

	1986	1987	1988	1989	1990
Plant raw materials:					
Pig tin:					
Virgin[1]	5,754	6,466	7,013	r6,807	10,671
Secondary	3,021	2,333	1,440	2,253	1,219
In process[2]	1,377	1,289	1,056	1,032	1,044
Total	10,152	10,088	9,509	r10,092	12,934
Additional pig tin:					
Jobbers-importers	1,272	1,890	3,387	3,536	2,467
Afloat to United States	2,433	2,486	2,127	1,040	2,270
Total	3,705	4,376	5,514	4,576	4,737
Grand total	13,857	14,464	15,023	r14,668	17,671

rRevised.
[1]Includes tin in transit in the United States.
[2]Data represent scrap only, tin content.

TABLE 9

MONTHLY COMPOSITE PRICE OF STRAITS TIN FOR DELIVERY IN NEW YORK

(Cents per pound)

Monthly	1989			1990		
	High	Low	Average	High	Low	Average
January	471.75	458.59	464.35	417.12	384.10	402.87
February	522.38	470.72	491.66	388.64	374.29	380.40
March	567.27	511.28	543.09	402.36	382.52	387.71
April	647.85	583.57	642.13	404.51	386.45	394.17
May	643.34	590.16	621.18	394.03	385.81	389.37
June	624.31	593.67	607.96	385.46	368.38	376.34
July	585.18	552.47	569.10	372.98	361.47	367.30
August	561.55	427.97	517.89	401.62	382.66	390.26
September	512.87	482.35	493.57	401.14	375.57	380.19
October	501.62	448.91	477.14	405.54	390.69	399.32
November	437.78	402.63	418.80	400.13	381.94	394.40
December	428.82	339.68	413.34	379.83	366.01	373.21
Average	XX	XX	520.18	XX	XX	386.29

XX Not applicable.
Source: Metals Week.

World Review

Capacity.—The data in table 13 represent rated annual production capacity for mines and smelters on December 31, 1990. Rated capacity was defined as the maximum quantity of product that can be produced in a specific period on a normally sustainable, long-term operating rate, based on the physical equipment of the plant and routine operating maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Estimates of the rated capacities of mines and smelters were based on discussions with officials from private industry, on past and present production rates, and on published capacity data.

Australia.—The Renison Bell Mine in Tasmania, owned by Renison Consolidated Goldfields Ltd., remained the largest tin mine, accounting for more than 90% of total mine output. Renison Bell was the world's largest hard-rock underground tin mine and a relatively low-cost producer with substantial high-grade reserves. Late in the year, Renison announced it would reduce its tin output from about 7,000 to 5,500 tons annually of tin-in-concentrate; the firm declared it was forced to do so because its costs were increasing while tin prices were falling.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TIN, TIN MANUFACTURERS, TINPLATE AND TERNEPLATE, AND TINPLATE SCRAP[1]

Year	Miscellaneous tin and tin manufacturers			Tinplate and terneplate		Tin compounds		Tinplate scrap	
	Tinfoil, tin powder, flitters, metallics, tin and manufacturers, n.s.p.f.	Dross, skimmings, scrap, residues, tin alloys, n.s.p.f.		Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
	Value (thousands)	Quantity (metric tons)	Value (thousands)						
1988	$1,013	1,542	$6,054	299,287	$185,319	838	$5,439	19,513	$1,930
1989	4,570	10,270	34,695	321,883	216,516	314	2,720	10,785	1,903
1990	2,086	6,788	35,291	293,426	199,036	426	2,493	8,488	1,782

[1]Because of the implementation of the Harmonized Tariff System beginning in Jan. 1989, categories for 1988 are not necessarily comparable with those in 1989 and 1990.

Source: Bureau of Census.

TABLE 11

U.S. EXPORTS OF TIN, TINPLATE, AND TERNEPLATE IN VARIOUS FORMS; EXPORTS OF INGOTS, PIGS, BARS; EXPORTS OF TINPLATE SCRAP[1]

Year	Tinplate and terneplate[2]		Ingots, pigs, and bars[3]		Tin scrap and other tin-bearing material except tinplate scrap[4]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1988	297,629	$295,002	1,209	$9,838	43,297	$21,848
1989	178,884	101,279	904	8,915	100,703	54,135
1990	145,396	78,687	658	3,344	106,288	55,913

[1]Because of the implementation of the Harmonized Tariff System beginning in Jan. 1989, export categories for 1988 are not necessarily comparable with those in 1989 and 1990.

[2]Tinplate circles, strips, and cobbles are included with exports of tinplate and terneplate in 1988.

[3]Ingots and pigs only in 1989 and 1990; excludes bars.

[4]Includes bars, rods, profiles, wire, powders, flakes, tubes, and pipes in 1989 and 1990.

Source: Bureau of the Census.

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF TIN, BY COUNTRY

Country	Quantity (metric tons)	Value (thousands)
1989		
Concentrates (tin content):		
China	67	$459
Peru	149	1,479
Total	216	1,938
Metal (unwrought tin):		
Australia	1,420	11,079
Austria	100	773
Bolivia	4,795	40,019
Brazil	10,572	86,827
Canada	123	1,060
Chile	464	4,100

See footnotes at end of table.

Renison's entire output of tin concentrate was believed to have been toll-smelted in Malaysia. Renison continued direct sales of refined tin to large American consumers from an affiliate office in Green Cove Springs, FL.

Greenbushes Ltd. continued to mine tin and tantalum near Perth. This operation produced about 200 to 300 tons of tin-in-concentrate annually in recent years. A major project to develop underground access to the tin-tantalite ore body at the Greenbushes tin-tantalite operation in Western Australia was approaching completion by yearend. Improvements included the construction of a 300,000-ton-per-year integrated mining and processing operation. It was expected that when completed, tin output would be

TABLE 12—Continued

U.S. IMPORTS FOR CONSUMPTION OF TIN, BY COUNTRY

Country	Quantity (metric tons)	Value (thousands)
1989		
Metal (unwrought tin)—Continued		
China	4,793	$42,485
Hong Kong	467	3,810
India	100	736
Indonesia	5,162	45,537
Italy	120	1,133
Japan	360	2,681
Malaysia	2,392	20,193
Mexico	1,860	16,727
Singapore	456	3,726
Thailand	180	1,803
United Kingdom	391	3,559
Other	233	1,869
Total	33,988	[1]288,118
1990		
Metal (unwrought tin):		
Australia	1,660	10,352
Bolivia	8,472	52,581
Brazil	6,535	41,558
Chile	628	4,662
China	4,339	26,280
Germany, Federal Republic of:		
Eastern states	60	374
Hong Kong	284	1,688
India	280	1,918
Indonesia	4,695	28,872
Malaysia	3,873	24,474
Mexico	2,614	20,630
United Kingdom	227	1,568
Other	143	906
Total	33,810	215,863

[1]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

increased to about 1,200 tons annually, with one-half of that coming from the underground mine.

Bolivia.—The tin industry continued to recover from the low production levels of 1986-87, when suddenly depressed tin prices lead to a massive restructuring of the mine and smelter sectors.

Historically, the Huanuni tin mine, located in the Department of Oruro, has been the richest underground tin mine in Bolivia. The mine was closed in 1986, but reopened in mid-1988 following modernization. The capacity of the mine was 3,600 tons of tin-in-concentrate annually, with the output being delivered to the Vinto metallurgical complex of Corporación Minera de Bolivia (COMIBOL). Huanuni had reported reserves of 42,800 tons.

Other important mines included the Bolivar tin-zinc-silver mine in the Department of Oruro; development work was proceeding here in an attempt to increase the reserves, which were reported as 10,900 tons of tin. Also important were the Catavi-Siglo tin mine in the Department of Potosí, leased by COMIBOL to 4 cooperatives employing 4,500 miners, and the Caracoles tin mine in the Department of Potosí, with reported reserves of 3,900 tons.

COMIBOL, the Government-owned mining company, announced the invitation of private bids for the leases of several of its key operations. Among the mines offered were Huanuni, Caracoles, and the tailings at Catavi-Siglo. COMIBOL would retain ownership of the mines. The decision to privatize these mines was taken in light of the low prices for tin and coproduct metals and low productivity. The approved companies would be required to provide job guarantees to workers as part of the contracts. The condition of job guarantees was an attempt by COMIBOL to curb resistance from the militant Bolivian miners union.

COMIBOL closed its Viloco tin mine in the Quimsa Cruz region near La Paz. The mine was operated by COMIBOL's subsidiary Empresa Minera Subsidiaria La Paz. The Government-owned smelting organization, ENAF, announced that its smelter was running at only one-third of its capacity of 32,000 tons of tin metal annually. ENAF also postponed plans to refurbish part of the smelter to increase production from about 10,000 tons now to 15,000 tons annually.

Pan-Andean Ltd., an Irish exploration firm, signed a joint agreement with COMIBOL calling for Pan-Andean to spend $175,000 testing the viability of recovering gold, silver, and tin from three tailing dumps in the Telemayu region.

At yearend, the Congress in Bolivia was preparing to pass a bill that would change the country's mining code, with special emphasis on attracting overseas firms for joint-venture exploration. The bill, which reportedly had support from varied interests, would give the executive branch the final authority to set fiscal parameters for these joint ventures. Currently, this power was in the legislative branch. Bolivia's present code permits only national mining interests to explore in a 50-kilometer-wide zone along the country's borders, unless otherwise authorized by Congress. The new code would allow foreign investment in these zones. One feature of the new code would prohibit neighboring countries from participating in exploration consortiums for any project within 50 kilometers of any Bolivian border. Observers indicated this feature was intended to blunt the alleged intrusion of Brazilian mining firms into Bolivia.

During the year, reports continued of an active market in smuggling tin concentrates from Brazil into Bolivia. As a result, some tin mined in Brazil shows up on statistical tables as being of Bolivian origin.

TABLE 13

TIN: WORLD ANNUAL MINE AND PRIMARY SMELTER CAPACITY, BY CONTINENT AND COUNTRY, DECEMBER 1990

(Metric tons)

Continent and country	Mine capacity	Smelter capacity
North America:		
Canada	5,000	—
Mexico	600	7,000
United States	300	—
South America:		
Argentina	1,000	1,000
Bolivia	20,000	32,000
Brazil	60,000	50,000
Peru	8,000	—
Europe:		
Czechoslovakia	1,000	1,000
Germany, Federal Republic of:		
Eastern states	2,000	4,000
Netherlands	—	7,000
Portugal	6,000	2,000
Spain	—	14,000
U.S.S.R.	20,000	20,000
United Kingdom	5,000	12,000
Africa:		
Cameroon	200	—
Namibia	1,500	—
Niger	300	—
Nigeria	2,000	3,000
Rwanda	2,000	2,000
South Africa, Republic of	3,000	3,000
Swaziland	100	—
Tanzania	100	—
Uganda	100	—
Zaire	4,000	1,000
Zambia	100	—
Zimbabwe	2,000	2,000
Asia:		
Burma	2,000	1,000
China	45,000	45,000
Indonesia	35,000	32,000
Japan	—	2,000
Korea, Republic of	100	2,000
Laos	1,000	—
Malaysia	40,000	120,000
Thailand	30,000	44,000
Vietnam	1,000	1,000
Oceania: Australia	10,000	2,000
Total	308,400	410,000

Bolivia emerged in 1990, for the first time in many years, as the major exporter of tin to the United States.

Brazil.—Brazil was the world's leading tin producer from both mine and smelter (when one considers the smuggling aspect) for the third consecutive year. Tin mines and smelters were mostly privately owned. Tin was mined from both alluvial and lode deposits. Brazilian mines were generally considered the lowest cost to operate in the world. Brazil was not a member of the ATPC, but generally agreed to cooperate with the spirit of its guidelines and restrict its tin exports.

The Paranapanema Group was the largest private tin producer in the world, owning and operating five 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, the country's largest tin mine, used four Elliot bucket wheel dredges and mined to a depth of 6 to 8 meters. The mine site employed nine floating wash plants and seven gravel-pump plants. The dredging capacity was about 13 million cubic meters annually. Management was in the process of developing mining of a soft weathered tin ore, separate from the alluvium, and reportedly was considering constructing a tin smelter. Total investment at Pitinga was about $115 million.

Tin mining activity by "garimpeiros" or independent miners increased. Estimated to number 10,000, "garimpeiros" worked an area of about 6 by 12 kilometers in the State of Rondônia, with no specific limits to each person's mining area and with only limited control by the local government.

A new firm, Industria e Comercio Minerios e Metais Mineoeste Ltda., commenced operations at a new tin smelter at Guaíra in Paraná State. The smelter initially produced 10 tons daily of 99.91% pure tin metal, with output planned to expand to 25 tons daily within a year. Mineoeste had four rotary furnaces and planned to add four more later. Cassiterite concentrate for the new smelter was trucked 2,500 kilometers from the Bom Futuro, Tin Mine near Ariquemes. The smelter's output was initially aimed at the domestic market.

Rhodia S.A., the Brazilian subsidiary of Rhône-Poulenc Co. (France), announced it had sold three tin mines in Brazil to two São Paulo industrialists. The three tin mines in northeastern Pará State were operated by Mineraçao Canopus and Mineraçao São Francisco; and ownership passed to two officials of Silex, a São Paulo-based holding company. The new owners announced plans to make new investments in the three mines, which they estimated would soon be producing 2,400 tons of tin-in-concentrate. They planned to have the tin concentrate smelted in São Paulo.

TABLE 14

TIN: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
Argentina	379	186	446	405	400
Australia	8,508	7,691	7,009	7,709	[2]7,377
Bolivia	10,462	8,128	10,504	15,849	18,000
Brazil	26,246	[r]30,405	44,102	50,232	[2]39,149
Burma	1,495	939	529	501	2634
Burundi	—	5	50	106	110
Cameroon	9	8	5	[e]5	5
Canada	[r]2,450	[r]3,390	3,300	3,300	[2]3,464
China[e]	15,000	20,000	[r]29,500	[r]40,000	40,000
Chechoslovakia	200	550	515	562	550
Germany, Federal Republic of: Eastern states[e]	2,800	[r]3,200	[r]3,000	[r]2,000	1,500
Indonesia	24,497	26,093	29,590	31,263	[2]30,200
Japan	500	86	—	—	—
Korea, Republic of	1	3	—	—	—
Laos[e]	550	[r]450	[2]300	[2]281	275
Malaysia	29,135	30,388	28,866	32,034	[2]28,468
Mexico	585	369	274	159	25
Mongolia[e]	1,000	1,200	1,200	1,300	1,200
Namibia	880	1,097	1,182	1,120	800
Niger	80	94	119	71	70
Nigeria	630	844	432	350	350
Peru	4,817	5,263	4,378	5,053	[2]5,134
Portugal	196	64	81	63	[2]1,404
Rwanda	29	—	1	762	750
South Africa, Republic of	2,054	1,438	1,377	1,306	[2]1,140
Spain	296	71	66	64	249
Tanzania[e]	5	4	4	3	3
Thailand	[r]16,800	[r]14,852	14,225	14,922	[2]14,635
Uganda[e]	18	10	10	10	10
U.S.S.R.[e]	14,500	16,000	16,000	16,000	15,000
United Kingdom	4,276	4,003	3,454	3,846	[2]4,200
United States	W	W	W	W	W
Vietnam[e]	650	680	700	[r]850	900
Zaire[3]	2,650	2,378	2,775	2,346	2,250
Zambia	[e]2	17	1	1	1
Zimbabwe[e]	1,470	1,410	1,140	1,300	1,300
Total	[r]173,170	[r]181,316	204,606	233,773	219,333

[e]Estimated. [p]Preliminary. [r]Revised. 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 June 28, 1991.

[2]Reported figure.

[3]Nonduplicated total of content of concentrates plus smelter production.

Brumadinho closed all its tin mines, including the São Lourenço-Macisa Mine, the Cachoerinha Mine, and the Monte Negro Mine. The closures were attributed to low tin prices.

Although Cesbra closed no tin mines, it reportedly was considering closing its tin mine complex at Jacunda if low tin prices persisted.

Government officials reported that large quantities, perhaps 6,000 tons, of tin-in-concentrate were smuggled out of the country from the Bom Futuro site. Much of the illicit concentrate was believed to be trucked to the Madeira and Marmore Rivers, then barged across these rivers to neighboring Bolivia. This contraband tin is believed to have helped sustain the world tin oversupply and thus contributed to continuing low prices.

At the September meeting of the ATPC in Cochabamba, Bolivia, it had been expected that Brazil would announce its willingness to join. However, Brazil decided not to join the ATPC. The country's tin producers favored joining the ATPC only if the Government could

TABLE 15

TIN: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
Argentina:					
Primary	230	240	280	[e]280	200
Secondary[e]	135	100	100	100	100
Total[e]	365	340	380	380	300
Australia:					
Primary	1,399	563	439	424	450
Secondary	320	320	300	[e]300	300
Total	1,719	883	739	[e]724	750
Belgium: Secondary	2,712	3,900	4,972	[e]5,000	6,000
Bolivia: Primary	7,673	2,667	5,373	9,448	13,400
Brazil:					
Primary	[r]25,147	[r]29,446	41,857	44,240	40,000
Secondary[e]	200	200	250	250	250
Total[e]	[r]25,347	[r]29,646	42,107	[r]44,490	40,250
Burma: Primary	[r]649	[r]309	110	500	400
Canada: Secondary[e]	200	200	200	200	200
China: Primary[e]	15,000	20,000	29,500	[r]40,000	40,000
Czechoslovakia: Primary	240	[r]545	515	562	550
Denmark: Secondary[e]	100	100	100	100	100
Germany, Federal Republic of:[e]					
Eastern states: Primary	3,300	3,400	3,300	[r]4,000	3,000
Western states: Secondary	350	250	150	[r]300	300
Greece: Secondary[e]	40	40	40	40	40
India: Secondary	100	100	200	200	200
Indonesia: Primary	[r]22,083	24,200	28,365	29,916	[2]30,389
Japan: Primary	1,280	895	846	808	[2]816
Korea, Republic of: Primary[e]	300	400	400	800	800
Malaysia: Primary	43,788	44,363	49,945	50,630	50,000
Mexico: Primary	1,488	[r]1,734	1,538	1,590	1,600
Netherlands:					
Primary	5,104	3,834	3,478	4,529	5,500
Secondary[e]	214	[r]180	[r]180	[r]190	200
Total[e]	5,318	[r]4,014	[r]3,658	[r]4,719	5,700
Nigeria: Primary	91	560	566	258	250
Norway: Secondary[e]	60	60	55	100	100
Portugal: Primary	184	48	22	62	1,400
Singapore: Primary[e]	500	1,000	[r]900	[r]600	800
South Africa, Republic of:					
Primary	2,001	1,508	1,389	1,307	[2]1,152
Secondary[e]	350	350	400	400	350
Total[e]	2,351	1,858	1,789	1,707	1,502
Spain:					
Primary	1,965	1,671	806	1,767	1,800
Secondary[e]	200	200	200	200	200
Total[e]	2,165	1,871	[r]1,006	[r]1,967	2,000
Thailand: Primary	19,672	15,438	14,675	14,571	[2]15,512
U.S.S.R.:[e]					
Primary	16,000	18,500	18,500	18,000	16,000
Secondary	3,800	4,000	4,000	4,000	3,700
Total	19,800	22,500	22,500	22,000	19,700

See footnotes at end of table.

TABLE 15—Continued

TIN: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
United Kingdom:					
Primary	9,227	12,135	9,014	3,584	[2]6,100
Secondary	5,676	4,871	7,757	7,184	[2]5,900
Total	14,903	17,006	16,771	10,768	[2]12,000
United States:					
Primary	3,213	3,927	1,467	1,000	—
Secondary	1,134	1,353	578	569	W
Total	4,347	5,280	2,045	1,569	W
Vietnam: Primary[e]	620	645	600	[r]800	800
Zaire: Primary	56	[r]90	120	e[e]100	95
Zimbabwe: Primary	1,079	1,038	855	848	850
Grand total	197,880	205,380	234,342	249,757	249,804
Of which:					
Primary	182,289	189,156	214,860	230,624	231,864
Secondary	15,591	16,224	19,482	19,133	17,940

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]Data derived in apart from the Monthly Statistical Bulletin of the International Tin Council, London and, since 1988, 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.

[2]Reported figure.

regulate the unchecked output from the Bom Futuro Mine; otherwise, they reasoned, Brazil could not adhere to an ATPC-set production quota.

Burma.—Mining Corp. Two, based in Rangoon, was responsible for the country's entire production of tin, as well as tungsten, antimony, 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.

Following the electoral defeat of the military government early in the year, the investment climate in Burma reportedly improved. The tin deposits in the southern coastal region were of special interest. Thailand's Offshore and Exploration and Mining Co. and Burma's Mining Corp. Two signed three contracts for the exploration and production of tin offshore.

Canada.—The East Kemptville Tin Corp. Ltd., owned by Rio Algom Ltd., continued tin-mining operations at its open pit mine at East Kemptville, Nova Scotia. The mine contained 41 million tons of high-grade tin ore and 15 million tons of low-grade tin ore. The tin ore at the site was complex, and concentration by gravity and magnetic methods reportedly was difficult. In recent years, Rio improved the recovery rate by improving the grinding, dewatering, and gravity equipment and installation of a new flotation circuit. Reportedly, the mine increased its recovery rate to more than 70%, and its tin concentrates graded 50% tin.

Stelco Ltd., a major tinplate producer, suffered a 3-month strike at its Hilton Works in Hamilton, Ontario. Then, the United Steel Workers Union approved a new 3-year labor contract with the firm.

Cominco Ltd. produced a small quantity of tin-lead alloy at its Trail, British Columbia, smelter as a byproduct of the production of indium.

NovaGold Resources Ltd. signed a letter of intent with current owners Billiton Metals Canada Ltd. and Lac Minerals Ltd. to purchase the Mount Pleasant tin-molybdenum-tungsten property in New Brunswick. The letter of intent specified that Billiton and Lac would sell their interest in Mount Pleasant and fixed assets for $10 million, payable via a 15% net profit royalty from any production from the property. NovaGold would indemnify the two sellers against any future environmental liability. The mine had operated in the early 1980's as a molybdenum and tungsten producer and had closed in 1985. Babcock Contractors was undertaking a feasibility study on the property to evaluate prospects for starting production as a tin-base mine. Minable underground reserves at Mount Pleasant totaled 5.1 million tons grading 0.70% tin and 9 tons grading 0.40% tungsten and 0.20% molybdenum. In addition, drill-inferred near-surface reserves totaled 5 to 10 million tons grading 0.25% to 0.30% tin, 3% zinc, and smaller quantities of indium and bismuth.

China.—Yunnan Tin Corp., Gejiu City, Yunnan Province, was the largest tin producer. It operated 5 underground mines, 7 open pit mines, 10 mineral dressing plants, and 1 smelter, giving it an annual mine production capacity of 7.5 million tons of tin ore, while the smelter capacity was 20,000 tons of refined tin yearly. Both surface alluvial deposits and underground lode deposits were worked. After 100 years of exploitation, the high-grade alluvial deposits were virtually depleted. In 1990, low-grade alluvial tin ores of fine particle size, tailings, and underground lodes were the main sources.

Yunnan used reverberatory smelting of tin concentrate, pyrometallurgical refining of tin metal, electrolytic separation of tin-lead alloy, and tin slag fuming. It used a continuous electrothermal crystallizer

for removal of lead and bismuth, using the different melting and specific gravities of tin and lead-tin alloy; direct recovery of tin was increased by 6% over former methods, and staffing levels reduced by 50%. Several other tin smelters around the world utilized Yunnan crystallizer technology.

The Da Chang Tin Mining Bureau Mine in the southwest region of Guangxi continued its expansion program that was expected to eventually make it China's largest tin mine.

France.—Pechiney, the large aluminum and can producer, announced it was starting construction of a $50 million tinplate beverage can plant at Dunkirk. The plant was designed to consume 24,000 tons of tinplate annually and to produce 1,200 million cans annually. Startup was set for 1991. It was believed that Sollac, the flat-rolled products division of Government-owned Usinor, would be the main tinplate supplier.

Hong Kong.—Mainland Metals and Minerals Ltd. announced the startup of a new 7,200-ton-per-year tin smelter. The smelter was intended primarily to treat low-grade tin concentrates from China. It had two furnaces and an output of about 5,000 tons of tin metal annually.

India.—The State Mining Corp. of India and the Bhabha Research Centre at Hyderabad announced they were constructing a new tin smelter in Madhya Pradesh State.

The Asian Can Co. Ltd. announced plans to expand can production in northern India. Four major firms accounted for 70% of India's total canmaking capacity and supply 200,000 tons of cans annually to the domestic market. About 80% of the cans made in India are general line, with most of the productive capacity being around Bombay. Asian Can had three factories near New Delhi that solely produced general-line cans. Its planned expansion would make the firm the largest canmaker in India. The firm also planned to install a line for making three-piece beverage cans in 1991, making it the first firm to produce beverage cans in India.

Indonesia.—Tin mining was performed mostly offshore, usually by means of large-scale dredging. P.T. Tambang Timah (P.T. Timah), the Government-owned mining firm, ranked as one of the world's largest tin-mining organizations, accounted for about 80% of Indonesia's tin output. P.T. Timah's three primary tin production complexes were on the islands of Bangka, Belitung, and Singkep. The facility on Bangka Island accounted for 70% of the firm's tin production.

P.T. Timah announced plans to sell some of its onshore mining operations on Belitung and Singkep Islands to private firms. The move was expected to lower Timah's tin output by several thousand tons annually. The move was part of Timah's plan to overhaul facilities and reduce production costs. Reportedly, Timah was seeking $500 million in loans from the World Bank for the restructuring program. Priority was expected to be given to the modernization of old mining and smelting equipment. Timah also announced plans to transfer its headquarters from Jakarta to Bangka Island, the site of most of its tin operations. Timah employed about 1,000 persons at its headquarters.

Malaysia.—Malaysia Mining Corp. (MMC) remained the largest tin producer in the country, but continued low tin prices depressed its operations. MMC reduced the number of dredges in operation from 21 to 16; among those idled were two dredges at Berjuntai Tin Dredging, two dredges at Bidor Malaysia, and one dredge at Southern Kinta. During the year at least 30 gravel-pump mines closed down partly owing to high fuel prices.

Japan reportedly suspended imports of ilmenite from Malaysia because of its high radioactivity level. Ilmenite is a byproduct at many tin-mining operations in Malaysia, and its exports have been helping miners to offset the effects of currently depressed tin prices.

MMC, predominantly dependent on its tin operations until recent years, announced expansion of its exploration program to cover other base metals and gold in several countries, including Brazil, Burma, China, Laos, and Vietnam. Tin contributed only 26% to the firm's 1990 pretax profits.

Construction began on a second tinplating line at the tin mill operated by Perstima. The new line was expected to double the plant's capacity to 180,000 tons annually and was expected to be completed by 1991. Perstima was partially owned by Kawasaki Steel Co. of Japan, and the technology for the tinplating line was being supplied by Kawasaki. Perstima announced that the new line would be designed to permit later installations that could produce tin-free steel as well as tinplate. Tinplate demand in Malaysia was about 130,000 tons annually.

The Government announced it would eliminate export duties on tin metal as of January 1, 1991. The duty had been 10% to 12%. The action was taken to stimulate exports.

Mexico.—Tin mining occurred in the north-central region in the three adjoining States of Durango, Zacatecas, and San Luis Potosí. The country's major tin mine, the El Perro Mine, was owned by Cía. Minera 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 primarily from Canada and China.

Namibia.—During the first part of the year, the Uis Mine, owned by Industrial Minerals Mining Corp. Pty. Ltd., a wholly owned subsidiary of South African Iron and Steel Industrial Corp. Ltd. (Iscor) continued as the largest producer. Tin concentrates from Uis were shipped directly to the Vanderbijlpark steelworks in the Republic of South Africa, where they provided a large part of Iscor's tin for use in producing electrolytic tinplate. However, near yearend, Iscor closed the Uis Mine owing to continued depressed tin prices.

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.

One domestic solder plant used about 40 tons of tin annually, and the remainder of Nigerian tin production was exported.

Peru.—The only tin mine was the San Rafael Mine, near Juliaca, owned by Minsur S.A. The mine was located within the northern extension of the Bolivian tin belt. Tin grades averaged 1.8%.

Minsur announced that its plans to build a tin smelter had been postponed indefinitely. Most of Minsur's tin concentrates were shipped to Capper Pass (United Kingdom), Billiton (The Netherlands), or Metales Potosí (Mexico) for smelting.

Portugal.—The new Neves Corvo Mine, in its third year as a copper producer, began tin production in 1990. This mine was developed by Sociedad Minera de Neves Corvo (SOMINCOR), owned 51% by the Government-controlled Empresa de Desenvolvimento Mineiro E.P. and 49% by RTZ Corp. PLC. RTZ states that the tin reserves at this southern Portugal mine were about 2.8 million tons of tin ore with an average grade of 2.6%. The company planned to gradually increase the output to 5,500 tons in 1993. Because tin was a byproduct of copper, tin production costs could be among the lowest in the world. In 1990, mining was restricted to the Upper Corvo and Graca deposits.

Neves Corvo's tin ore was treated in two circuits. The first, treating a shale-hosted ore of 4% tin content, with a design capacity of 100,000 tons annually, suffered from equipment failures, but was expected to be at full capacity by mid-1991. The second circuit treated sulfide ore with high-copper grades and locally enriched tin (1.3% average) at a design throughput of 200,000 tons annually; it performed above design capacity. SOMINCOR sold concentrates ranging from 25% to more than 50% tin. SOMINCOR had a 3-year agreement with the Billiton tin smelter in the Netherlands to purchase about 30% of its 20% to 25% and about 20% of its 50% to 55% tin concentrates. Neves Corvo was expected to become the major tin producer in Europe once it achieved full capacity.

Industria de Estaños de Mangualda Ltd. announced the restart of its Neostano tin smelter, which was closed in 1986 because of financial problems. Plans called for eventual tin metal production of 2,000 to 2,400 tons annually.

Spain.—Estaños de Zamora announced a planned 70% increase by year-end in its tin smelter output. This was to be achieved by a modernization of its furnaces and construction of a new electrolysis line. Currently, most of its tin concentrates came from Burma, China, Nigeria, the United Kingdom, and Zaire. After the expansion, the firm expected to receive tin concentrates from SOMINCOR'S new Neves Corvo mine in Portugal. Most of the smelter's output of tin metal was sold to Ensidesa and Altos Hornos de Vizcaya in Spain's steel industry for making tinplate.

Taiwan.—Tong Yi Industrial Corp. began commercial production from its second 90,000-ton-per-year tinplate line. The firm imports from Japan about 100,000 tons of steel annually for its tinplate production; Kawasaki Steel Corp., which has an equity stake in Tong Yi, supplies about 50%, while Nippon Steel Corp. and NKK Corp. supply the balance.

Thailand.—Tin remained the principal mineral product and export, but in 1990, tin fell in relative importance as other industries gained. In Phuket, where 48 onshore mines were in operation in 1985, only one mine was still working. In neighboring Phangnga, less than 100 of a prior 550 mines still were worked.

Offshore mining declined also. The Jootee Offshore Mining Co., Ltd., in Phuket, shut down its modern bucket line dredge. Tonkah Harbor Ltd. lost its dredges in high seas. Aokan Thai Ltd. continued operating its two dredges with heavy losses. Dredger production at the Government-owned Offshore Mining Organization declined by one-half since 1989. Small illegal dredges numbered about 4,000 in 1978, but numbered only about 100 in 1990. Consolidated into a single fleet under the title Stin Andaman Co., the small dredgers worked a large offshore concession (Block 117) but the deposits proved to be negligible.

South Thailand accounted for 90% of the country's tin production. Onshore facilities, including gravel-pump and dry strip mines, produced 60% of Thai tin, and offshore bucket dredges and cutter section boats produced the remainder. Onshore gravel-pump mines, with their high operating costs, were particularly vulnerable to tin's price slump. Besides low tin prices and depleted tin ore beds, onshore miners were also squeezed by the sharp rise in diesel fuel and lubricant prices and by the need to file costly environmental impact statements. Thai tin mine operators virtually abandoned further tin exploration, preferring to invest instead in tourism, rubber, parawood, palm oil, and prawn cultivation.

Established in Phuket in the mid-1960's, Thaisarco, a subsidiary of Royal Dutch Shell Co. Ltd., smelted most of the domestically mined tin concentrates. The smelter had two electrical and four reverberatory furnaces, with a total plant capacity of 40,000 tons. This year, Thaisarco utilized only one electrical and one reverberatory furnace, as it operated well below capacity. Most of the smelter's revenue came from the sale of tin slag for the extraction of tantalum, but the price of tantalum declined by 50% in 1990. Thaisarco shipped 70% of its tin slag to Bayer Starck AG in Germany and the balance to Fansteel Corp. in the United States. In 1992, it was expected that the Thailand Tantalum Industry Co. would open its long-delayed tantalum processing plant in Mab Ta Put, Rayong Province, and then Thaisarco would be legally obligated to sell all of its tin slag to them.

In an effort to keep the smelter profitable, Thaisarco began experimenting with smelting tin ore from Africa, Burma, China, Laos, and South America. Should the project prove feasible, Thaisarco's furnaces would have to be adjusted to work the lower quality foreign concentrates, which typically assay at less than 60% tin compared to 74% tin for domestic material.

The Sea Exploration and Mining Co. Ltd. signed a production-sharing contract for exploration and production of tin in Burma's offshore mining block No. 4 in the Bokpyin area of the southern Tenasserim division.

The Thai Tinplate Co. (TTP) commissioned a new electrolytic tinplating line at its Samutprakharn plant, effectively adding another 150,000 tons annually to its capacity. Before the addition, the plant had a dual tin-free-steel-tinplate line with a capacity of 120,000 tons yearly and an older electrolytic tinplate line with a capacity of 90,000 tons yearly. The firm's output was 198,000 tons, of which 28% was tin-free steel (TFS). Kawasaki Steel Corp. of Japan had an equity stake in TTP and supplied the bulk of its blackplate.

U.S.S.R.—Tin mining was conducted mostly in the far eastern regions of the country. The Khingansk tin mine in eastern Siberia announced plans to expand its tin concentrate output to 3,000 tons annually by 1995 from 1,200 tons currently. Newly discovered deep-lying tin ore bodies extended the mine's life. Two 1,000-meter-deep shafts were sunk to access the new ore bodies with ore grades reportedly about 0.65% tin.

Government officials announced plans to rapidly expand tin mine operations, which would eliminate the need to import the metal and even allow the U.S.S.R. to begin exporting by 1995. Just north of the border with China, the Hingansk tin mine would be the source of most of the increased production. The Soviets had been ready to close the Hingansk Mine in 1971 after 26 years of extraction, but, in 1990, they discovered several deep deposits that reportedly hold high-quality tin ores. It was planned to begin extracting those ores by 1992, reaching maximum production rates by 1995. Hingansk produced 1,200 tons of tin-in-concentrate annually, in recent years.

United Kingdom.—Tin mining was concentrated in the Cornwall district, where mining costs were reportedly among the highest in the world.

Carnon Consolidated Ltd. operated the Wheal Jane and the South Crofty tin mines in Cornwall, but Carnon began diversifying away from a total dependence on tin mining. Most Carnon tin concentrates were shipped to the Billiton tin smelter at Arnhem, the Netherlands. At midyear, Carnon closed operations at Wheal Jane, citing the continuing low price of tin and the high cost of mining at Wheal Jane. The closure, following the recent shuttering of Geevor's tin mine at Pendeen, left South Crofty as the United Kingdom's only operating tin mine at yearend.

The Royal Cornish Consols United Tin Mines Cost Book Co. Ltd., with a reported 1.5 million shareholders, planned to start a new tin mine near St. Austell in Cornwall, where it owned 30 acres and leased an extra 1,500 acres of tin-bearing land nearby for eventual mining. The firm planned to exploit an ancient law to avoid taxes, including the newly proposed poll tax. Under the charter of the Pardon Treaty Agreement of 1508 between England and Cornwall, no laws passed by the English Government were valid in Cornwall without ratification by the Cornish Stannary Parliament. The Stannary Parliament, defunct for more than two centuries, was revived in 1990. Indications were that the British Government would try to thwart this attempt.

The Capper Pass tin smelter, owned by RTZ Corp., continued operating, having returned to profitability by its recent downsizing and restructing. Most of the feed for Capper Pass was imported low-grade and complex primary and secondary materials. In addition to producing normal purities of tin metal, the plant was also a refiner of tin to very high purities for specialized applications and produced a variety of byproduct metals such as bismuth and indium.

British Steel Corp., a major tinplate producer, announced that it would invest $5 million in a new Packaging Steel Development Centre (PACS) located near its steel plant at Port Talbot, Wales. The aim of the PACS would be to reproduce under full production conditions all the manufacturing and processes used by canmakers and to link this with the laboratory and testing facilities of the firm's tin mill.

British Steel Corp. acquired the Save-A-Can collection organization, which had 217 collection points for cans. The firm planned to expand this to 1,000 locations by 1994.

Current Research

In Japan, Otsuka Chemical Co., in Osaka, announced development of a new material for antistatic paints, a joint development by itself and the Research Institute for Production Development in Kyoto under a commission from the Government's Research and Development Corp. The electrically conductive composite material was fiberform potassium titanate, as fine as 10 to 20 microns, coated with tin oxide, and in powder form. The high-strength white-colored potassium titanate reinforced the transparent tin oxide. The powdered composite material could be mixed with pigments to make electrically conductive paint or used in sheet form in electronic and other advanced materials areas. Otsuka predicted that the new material would find applications not only in antistatic paint, but in electronic equipment and antistatic flooring material.

In Brunswick in the Federal Republic of Germany, Schmalback Lubeca AG announced the development of a new tinplate can for packaging nuts. Basically, it was an adaptation of a tinplate beverage can that kept the nuts fresh and unbroken. Lubeca developed a special process to replace atmospheric oxygen in the cans with inert gas, thereby overcoming the problem of rancidity caused by exposure to oxygen. Excess pressure in the can contributed to the rigidity and strength of the thin-walled tinplate container. A wide-opening pull tab enabled the nuts to be poured easily and hygienically into the hand, and the can was reclosable with a plastic slip lid. The 200-gram can was the same size as the most common beverage can and therefore suitable for distribution through beverage can vending machines.

The Wilkens Anderson Co., Chicago, IL, announced the successful introduction of a new "Sumetal Stannomatic" computerized instrument that provided instant measurement of the thickness of the tin coating on tinplate. A tin-chromium model was also available, which could determine the thickness of metallic chromium as well. Both models could be used to make in-process inspection checks.

The Davies Can Co. announced the development of a unique paint can, the "Trim-Rim." The principal novel feature of the design was the ringless top, which eliminated problems of paint accumulation. Other advantages claimed were easier filling and pouring, easier brush access to the contents, and less splatter and mess. A gasket in the lid provided an air-tight seal to prevent paint skinning, and the can had a welded side seam. Davis commenced construction of two new plants to make the new style cans in Covington, GA, and York, PA.

The Seymour Specialty Wire Co., Seymour, CT, announced development of a copper-nickel-tin wire alloy. This was a 15% Ni-8% Sn-77% Cu alloy, a spinodal material that could be age-hardened after forming. Seymour stated this alloy combined high-tensile strength with resistance to oxidation, stress relaxation, fatigue, and stress-corrosion cracking. In round wire form, these alloys were expected to challenge phosphor bronzes for applications as electronic leads, contact pins, and sockets. In flat wire form, they could compete with beryllium copper for eyeglass frames, circuit boards, and electronic-contact clips. The alloy could also be used for rivets, self-threading screws, and a variety of cold-headed parts.

OUTLOOK

Supply

The supply of tin for the United States is expected to continue to originate primarily in Asia and South America and to enter the country in the form of refined tin metal. While some promising tin deposits exist in the United States, primarily in Alaska, these are not expected to become major production sites during the next 10 years, especially if tin prices remain low. The NDS is expected to continue to be a modest source of tin supply because the stockpile goal is substantially lower than the current inventory. Increased scrap recovery, both through alloy recycling and detinning, is a possibility, and that could help ameliorate the Nation's dependence on imported tin.

Worldwide, the oversupply of tin that has existed since the early 1980's appears likely to persist for at least a few more years. The advent of several new tin mines in countries like Bolivia, Brazil, China, Portugal, and the U.S.S.R. appears likely.

Demand

The demand for primary tin in the United States is forecast to be static in the next few years. There appears to be some chance that tinplate may regain a small portion of the beverage can market in the next few years, especially if tin can recycling increases and if tinplate can maintain or widen its cost advantage over aluminum.

Among the major metals, tin has had a relatively good record as regards toxicity and the environment, and this aspect may help tin gain market share at the expense of more troublesome metals. In particular, if regulations continue to negatively impact the use of lead in applications such as solder, the demand for tin as the complimentary alloy component may increase.

Worldwide, new tinplating lines are being built in developing countries, and tinplate traditionally is a stronger competitor than aluminum in canmaking markets outside of the United States. Therefore, the outlook for overall tin demand is for modest growth of about 1% annually in the next few years.

Numerous research efforts in recent years have resulted in new applications for tin that could result in small-scale increases in tin consumption in future years, but there have 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 Shipments Report 1990. Washington, DC, 1990, pp. 2-3.

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TITANIUM

By Deborah A. Kramer

Ms. Kramer, a physical scientist with 7 years U.S. Bureau of Mines experience, has been the acting titanium specialist since April. Domestic survey data were prepared by Regina R. Coleman, mineral data supervisor, and Giovanni C. Jacarepaqua, mineral data assistant; international data tables were prepared by Virginia Woodson, international data coordinator.

The year 1990 represented the 200th anniversary of the discovery of titanium, although more than 100 years passed until its commercial use. Today, titanium dioxide (TiO_2) is used widely as a white pigment in paints, paper, and plastics, and titanium metal is an important component of commercial and military aircraft.

Because of a slowing economy, U.S. production and consumption of both TiO_2 pigments and titanium metal dropped slightly during 1990. The decline in consumption also had an effect on prices for pigments and metal, both of which also fell by yearend. Consumption of concentrates also fell, in line with the decreased demand for TiO_2 and titanium metal. U.S. TiO_2 producers increased their capacity during 1990 and planned to bring an additional 245,000 metric tons of annual capacity on-stream by the end of 1991. Capacity expansions for titanium metal production also were planned in the United States within the next few years.

World demand for TiO_2 was estimated to be nearly 3 million tons, with a total production capacity of about 3.3 million tons. The slight increase in world TiO_2 production capacity coupled with reduced demand helped to ease the tight supply-demand situation that had occurred during the past few years. Because of a tightening of waste disposal regulations, particularly in Europe, sulfate-process TiO_2 plants were either being replaced by chloride-process plants or additional waste-treatment facilities were being added.

TABLE 1
NATIONAL STOCKPILE PURCHASE SPECIFICATION: TITANIUM SPONGE OR GRANULES, SUMMARY OF CHEMICAL AND PHYSICAL REQUIREMENTS

	Type A[1]	Type B[1]	Type C[1]	Type D[1]
CHEMICAL REQUIREMENTS,[2] PERCENTAGE				
Nitrogen	0.010	0.015	0.015	0.008
Carbon	.020	.025	.020	.020
Sodium	—	—	.19	.01
Magnesium	.08	.50	—	.08
Lithium	—	—	—	.09
Aluminum	—	.07	—	—
Chlorine	.10	.20	.20	.10
Iron	.08	.10	.04	.04
Silicon	.04	.04	.04	.04
Hydrogen	.005	.03	.05	.02
Oxygen	.10	.10	.10	.07
Water	.02	.02	.02	.02
Other elements, total	.05	.05	.05	.05
Titanium	99.6	99.1	99.3	99.6
PHYSICAL REQUIREMENTS				
Brinell hardness number, maximum	100	120	120	100
Particle size distribution, percentage:				
Minus 3/4 inch	100	100	100	100
Minus 1/2 inch	95	95	95	95
Plus 100 mesh	95	95	95	95

[1]Type A—Magnesium reduced and finished by vacuum distillation; Type B—Magnesium reduced and finished by acid leaching or inert gas sweep distillation; Type C—Sodium reduced and finished by acid leaching; Type D—Electrolytic.
[2]All amounts are maximums except for titanium, which is a minimum.

Source: U.S. Department of Commerce, P-97-R7, June 2, 1982.

DOMESTIC DATA COVERAGE

Consumption data for titanium raw materials are developed by the U.S. Bureau of Mines from one voluntary survey of domestic operations. Of the 32 operations canvassed, 97% responded, representing 99.9% of the data in tables 6 and 11. Data for the one nonrespondent was estimated based on prior-year consumption levels.

BACKGROUND

Definitions, Grades, and Specifications

Ilmenite is the most abundant titanium mineral, with the chemical formula $FeTiO_3$ and theoretical composition of 52.7% TiO_2 and 47.3% FeO. However, the term "ilmenite" is also used to include material that has been oxidized and leached during weathering, containing up to 70% TiO_2, about 25% to 30% iron oxides, and about 5% of oxides of other elements. When the alteration is extreme, the residual material is essentially amorphous to finely crystalline TiO_2 and is called leucoxene.

Rutile is essentially crystalline TiO_2, and commercial concentrates usually contain about 95% TiO_2. Synthetic rutile or rutile substitutes are derived from ilmenite by processes involving oxidation and reduction treatments followed by leaching of iron. Synthetic rutile concentrates approach rutile in chemical composition but, being residual leached grains, are porous and composed of very fine crystallites, while natural rutile grains are usually single crystals.

Anatase also is crystalline TiO_2, but has a different crystal structure than rutile. Anatase is not yet available commercially, but large deposits of anatase-bearing ore in Brazil are being developed.

Commercially available titaniferous slags made by electric furnace smelting of ilmenite with carbon contain 70% to 85% TiO_2. Slags being produced at the end of 1990 were 80% TiO_2 slag from Sorel, Quebec; 85% TiO_2 slag from Richards Bay, Republic of South Africa; and 75% TiO_2 slag from Tyssedahl, Norway.

Titanium tetrachloride ($TiCl_4$), the intermediate compound from which titanium metal and chloride-process TiO_2 are manufactured, is a colorless to pale yellow liquid at room temperature, with a boiling point of 136° C.

Titanium sponge metal is the primary metal form obtained by vapor phase reduction of $TiCl_4$ with magnesium or sodium metal. It is called sponge because of its appearance and high porosity. Titanium ingot for forging into billet and mill products is obtained by melting sponge in a vacuum-arc furnace, with or without scrap titanium or alloying additions. Specifications for titanium sponge for the National Defense Stockpile (NDS) are given in table 1.

Titanium dioxide pigment is characterized by its purity, refractive index, particle size, and surface properties. The particle size is critical and must be closely controlled within the range of about 0.2 to 0.4 micrometer to develop optimum pigment properties. The superiority of TiO_2 as a white pigment is due mainly to its high refractive index and resulting light-scattering ability, which impart excellent hiding power and brightness. Titanium dioxide pigments are produced as two major types: rutile and anatase. Rutile-type pigment, less reactive with paint vehicles in sunlight than is the anatase type, is preferred for use in outdoor paints. Anatase pigment has a bluer tone than the rutile type, is somewhat softer, and is used mainly in indoor paints and in paper manufacturing.

Specifications for natural rutile for the NDS are shown in table 2. There are no

TABLE 2

NATIONAL STOCKPILE PURCHASE SPECIFICATION: SUMMARY OF RUTILE CHEMICAL AND PHYSICAL[1] REQUIREMENTS

	Percentage by weight (dry basis)
Chemical requirements:[2]	
Titanium dioxide	95.00
Ferric oxide	1.00
Silica	1.25
Phosphorous pentoxide	.05
Sulfur	.03
Zirconium dioxide	1.00
Alumina	.75
Vanadium pentoxide	.75
Chromium oxide	.75
Magnesium oxide plus calcium oxide	.25
Tin	.10
Manganese	.02
Columbium pentoxide	.60

[1]All rutile shall pass a U.S. Standard Sieve No. 30 (ASTM Designation E-11) with not more than 1% passing a U.S. Standard Sieve No. 200.

[2]All of the amounts are maximums except for titanium dioxide, which is a minimum. For radioactive identification, report for each lot the percent by weight of naturally occurring thorium, uranium, or combination of the two.

Source: U.S. Department of Commerce, P-49-R6, Nov. 3, 1981.

TABLE 3

COMPOSITION OF TYPICAL COMMERCIAL TITANIUM CONCENTRATES

(Weight percentage)

	Ilmenite				Slag		Rutile	Synthetic rutile		
	United States		Norway,	Australia,	Canada,	Republic of South Africa,	Australia, East	United States,	Australia, Western	Japan,
	New York	Florida	Tellnes	Bunbury	Sorel	Richards Bay	Coast	Kerr-McGee	Titanium	Ishihara
TiO_2 (total)	46.1	64.0	45.0	54.4	80.0	[1]85.0	95.2	94.15	92.0	96.1
Ti_2O_3	—	—	—	—	16.0	[2]25.0	—	—	10.0	—
Fe (total)	—	—	—	—	—	—	—	—	3.6	—
Fe (metallic)	—	—	—	—	—	—	—	—	.2	—
FeO	39.3	1.33	34.0	19.8	9.0	—	.9	—	—	—
Fe_2O_3	6.7	28.48	12.5	19.0	—	—	1.0	2.6	—	1.3
SiO_2	1.5	.28	2.8	.7	2.4	—	.2	1.3	.7	.5
Al_2O_3	1.4	1.23	.6	1.5	2.9	—	.02	.48	.7	.46
CaO	.5	.007	.25	.04	.6	[2].15	.07	.003	.03	.01
MgO	1.9	.20	5.0	.45	5.0	[2]1.3	.18	.2	.15	.07
Cr_2O_3	.009	—	.076	.02	.17	[2].3	.6	.16	—	.15
V_2O_5	.05	—	.16	.12	.57	[2].6	.01	.16	.12	.20
MnO	.5	—	.25	1.4	.25	[2]2.5	.008	.04	2.0	.03
S	.6	—	.05	.01	.06	—	.1	—	.15	—
Na_2O	—	—	—	—	—	—	.04	—	—	—
C	.22	—	.055	—	.05	—	.03	—	.15	—

See footnotes at end of table.

TABLE 3—Continued

COMPOSITION OF TYPICAL COMMERCIAL TITANIUM CONCENTRATES

(Weight percentage)

	Ilmenite				Slag		Rutile	Synthetic rutile		
	United States		Norway,	Australia,	Canada,	Republic of South Africa,	Australia,	United States,	Australia,	Japan,
	New York	Florida	Tellnes	Bunbury	Sorel	Richards Bay	East Coast	Kerr-McGee	Western Titanium	Ishihara
P_2O_5	0.008	0.12	0.04	0.02	—	—	0.8	—	—	0.17
ZrO_2	.01	—	—	—	—	—	.2	—	—	.15
Nb_2O_5	.01	.10	.01	.14	—	—	.03	—	—	.25
Ignition loss	1.3	—	—	.4	—	—	.1	0.6	—	—

[1]Minimum.
[2]Maximum.

Source: Technical publications and industry contacts.

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. Certain impurities such as chromium, columbium, manganese, phosphorus, and vanadium, however, can seriously impair pigment properties, so these impurities are an important consideration in the selection of concentrates for pigment production. Concentrates to be used for making $TiCl_4$ should be low in calcium and magnesium, which form high-boiling-point chlorides that cause trouble in fluid-bed chlorinators. Chemical compositions of typical commercial titanium concentrates are shown in table 3.

Industry Structure

The titanium industry is moderately integrated from raw materials to semifinished products. The world's largest TiO_2 producer, E. I. du Pont de Nemours & Co. Inc., obtains ilmenite, rutile, and leucoxene from its own mines in Florida and from various suppliers in other countries, mainly Australia. NL Industries Inc. for many years has supplied ilmenite to its European pigment plants from its mine at Tellnes, Norway. Since 1987, a smelting plant at Tyssedahl, Norway, has been processing part of the Tellnes ilmenite to produce titanium slag for the same market. The Tioxide Group PLC, United Kingdom, owns a 40% share of Westralian Sands Ltd. in Australia. In 1989, Hanson Industries PLC, United Kingdom, owner of SCM Chemicals Inc., acquired a 49% interest in Renison Goldfields Consolidated Ltd. (RGC), the major producer of titanium minerals in Australia. Also in 1989, a joint venture between Minproc Holdings Ltd. and Kerr-McGee Chemical Corp. was established to develop integrated operations in Western Australia involving the mining and concentrating of ilmenite, processing of the ilmenite to make synthetic rutile, and manufacture of TiO_2 from the synthetic rutile. Nearly all of the remaining TiO_2 pigment manufacturers buy their raw materials from independent producers of titanium concentrates.

None of the sponge metal producers outside China or the U.S.S.R. owns its own titanium mine. Titanium Metals Corp. of America (TIMET) purchases Australian rutile and manufactures $TiCl_4$, the intermediate compound universally used for commercial production of titanium metal. The other two U.S. titanium metal producers purchase $TiCl_4$ from a TiO_2 pigment manufacturer. Titanium mineral raw materials are purchased also for use in welding rod coatings, chemicals, and fiberglass.

The United States accounts for about 26% of the world's sponge production capacity. Overseas sponge producers and their share in total world capacity of about 117,000 tons in 1990 were the U.S.S.R., 44%; Japan, 23%; the United Kingdom, 4%; and China, 3%.

Titanium dioxide pigment output in 27 countries in 1990 came from about 60 separate facilities ranging in annual capacity from a few thousand tons to almost 300,000 tons. The United States accounted for 33% of the world's TiO_2 pigment capacity, followed by Japan, 10%; the Federal Republic of Germany, 10%; the United Kingdom, 9%; and France, 7%.

The world's four largest TiO_2 pigment producers are Du Pont with four plants in the United States and one in Mexico and a total annual capacity of about 700,000 tons; Tioxide with two domestic plants and facilities in Australia, Canada, France, Italy, Spain, and the Republic of South Africa and total capacity of 437,000 tons; SCM, with plants in Australia, the United Kingdom, and the United States and annual capacity of 412,000 tons; and Kronos Inc., with producing plants in Belgium, Canada, the Federal Republic of Germany, and Norway, with a total annual capacity of 313,000 tons.

U.S. companies, mainly Du Pont, SCM, Kronos, and Kerr-McGee, own or control about one-half of the world productive capacity for TiO_2 pigments. Tioxide controls about 13%. An estimated 6% is owned by governments of countries with centrally planned economies. The remaining 33% is owned principally by large chemical firms or groups such as Bayer AG of the Federal Republic of Germany, Ishihara Sangyo Kaisha Ltd. (ISK) of Japan, and Kemira Oy of Finland.

Technology

Exploration.—Hard-rock ilmenite deposits, because of their inherent magnetic properties, are readily amenable to the application of 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 200 or 300 feet. Intermediate holes are drilled to fill in major gaps in information on geologic structure or ore continuations. Drill cores are visually logged and split for chemical assay to determine TiO_2 and iron content.

Sand deposits of titanium minerals are mostly near continental margins where erosion of regional granitic and metamorphic rocks containing ilmenite and rutile has led to accumulation of these minerals in coastal plain sediments. Working and reworking of these sediments by ocean waves on beaches and in streams resulted in various degrees of sand sorting and concentration by particle size, density, and resistance to abrasion. Well-sorted sands are much more likely hosts for ilmenite, rutile, and other heavy minerals than are unsorted sands.

Titanium minerals are dark in color, and their concentration in predominantly quartz sands is often readily visible. Initial discovery has, therefore, often been made through surface observation. In exploration, hand panning of samples has been a very useful exploration tool.

Some titanium mineral ore bodies are detectable by ground or airborne magnetometer surveys or, if monazite or zircon is present, by low-level radiometric surveys.

Drilling to determine the extent of sand deposits in the first phase of development should be done to a depth of at least 50 feet and preferably 100 feet. The type of drill needed will depend on the nature of the ground, including the presence of clay, hard-pan, roots, stumps, and other organic material, as well as the depth of the water table.

Approximate minimum requirements for an economic sand deposit of titanium minerals include reserves of 300,000 to 1 million tons of TiO_2 content in rutile or ilmenite and heavy mineral content in the ore of 1% to 5%, depending on the mix of ilmenite, rutile, and other valuable minerals.

Mining and Concentration.—For mining sand deposits of titanium minerals, a dredge is usually used. This may be bucket-ladder type but is more likely to be suction type. The dredge floats in its own pond, digging forward and stacking tailings aft.

Rough concentration, the separation of heavy minerals from the lighter quartz-feldspar-mica fraction, is usually accomplished by wet-gravity methods. The Humphreys spiral has been standard for this separation since its introduction in about 1940, but pinched-sluice separators of various designs have also been used.

In Australia, the Reichert cone concentrator, which operates on the pinched-sluice principle, has been successful for large-tonnage operations. Flotation has also been used to some degree. For separating the minerals from stream-type deposits, jigs are usually chosen because they are the concentrating device least sensitive to extreme grain size variation.

The final wet-mill concentrate is dried, usually in a rotary kiln, prior to further treatment. The subsequent flowsheet depends on the mineral assemblage to be treated. Ilmenite and rutile are usually removed together by electrostatic separation. The ilmenite-rutile conductor fraction of dried wet-mill concentrate is then subjected to high-intensity magnetic separation, yielding a final ilmenite product. The rutile fraction is further cleaned by screening and additional electrostatic separation. Zircon and monazite products are recovered from the nonconductor fraction of the wet-mill concentrate by a combination of gravity, electrostatic, and high-intensity magnetic separation.

Ilmenite is 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 causes operating problems during chlorination, Sorelslag is not used to make $TiCl_4$.

At Richards Bay, Republic of South Africa, both rutile and ilmenite are produced from heavy-mineral sand deposits. The ilmenite, containing about 50% TiO_2, is relatively low in magnesium and calcium and is smelted with carbon in an electric furnace to produce an 85% TiO_2 slag. Because of its low content of the aforementioned impurities, the Richards Bay (RB) slag is acceptable for manufacturing $TiCl_4$ and is also a feed material for the sulfate pigment process.

Materials made from ilmenite that have a TiO_2 content approaching that of natural rutile are known as synthetic rutile or beneficiated ilmenite. Processes to produce rutile substitutes from ilmenite fall into three general classes: those in which the iron is completely reduced to metal and separated from the reaction mass either physically or chemically, those in which iron is reduced to the ferrous state and chemically leached away from the titanium, and those in which the ilmenite is selectively chlorinated to remove iron and other impurities. The RB slag described in the previous section may also be regarded as a rutile substitute because of its high grade (85% TiO_2) and suitability for the manufacture of $TiCl_4$.

Pigment Production.—Titanium dioxide pigment is produced commercially by two methods that require different raw materials. In the sulfate process, ilmenite or titanium slag is reacted with sulfuric acid; a portion of the iron sulfate formed may be crystallized and removed; and titanium hydroxide is precipitated by hydrolysis, filtered, and calcined. In the chloride process, rutile is converted to $TiCl_4$ by chlorination at 850° to 950° C in the presence of petroleum coke. All U.S. commercial chloride-process plants use fluid-bed chlorinators, although static-bed systems can be used for this purpose.

Titanium tetrachloride so prepared may be used either in making pigment, or with additional purification, for reduction to metal. In making pigment, the $TiCl_4$ is oxidized with air or oxygen at about 1,000° 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 reac-

tion. 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 material 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.

TABLE 4

TIME-PRICE RELATIONSHIPS FOR TITANIUM

(Yearend price, dollars per pound)

Year	Rutile pigment (Ti content)		Sponge metal	
	Actual prices	Based on constant 1982 dollars	Actual prices	Based on constant 1982 dollars
1970	0.45	1.07	1.32	3.14
1971	.45	1.01	1.32	2.97
1972	.45	.97	1.32	2.84
1973	.50	1.01	1.42	2.87
1974	.72	1.33	2.25	4.17
1975	.73	1.23	2.70	4.55
1976	.78	1.24	2.70	4.28
1977	.81	1.20	2.98	4.43
1978	.85	1.18	3.28	4.54
1979	.98	1.25	3.98	5.06
1980	1.05	1.23	7.02	8.19
1981	1.25	1.33	7.65	8.14
1982	1.25	1.25	4.60	4.60
1983	1.25	1.20	4.10	3.95
1984	1.25	1.16	4.10	3.81
1985	1.30	1.17	3.75	3.38
1986	1.37	1.20	4.10	3.60
1987	1.37	1.17	4.10	3.49
1988	1.60	1.32	4.50	3.71
1989	1.75	1.39	5.05	4.00
1990	1.67	1.27	4.75	3.61

Recycling.—Scrap titanium generally accounts for 40% to 50% of ingot production. Scrap is generated by producers of ingot and mill products and by consumers of mill products in fabricating finished products or components. It is estimated that up to 75% of titanium ingot metal becomes scrap during processing to finished parts. However, the proportion of scrap is gradually being lowered because of increased use of castings and other near-net-shape technologies.

Clean and well-segregated scrap, processed to remove impurities, is blended with sponge metal and alloying constituents and remelted to ingot. Remelting is mainly by vacuum-arc consumable-electrode processing. Electron-beam and plasma-arc cold-hearth melting is also used, especially for chips and turnings. Cold-hearth melting is very effective in ensuring removal of high-density inclusions, such as tungsten carbide tool particles, that settle out in the hearth area during melting. A substantial quantity of titanium scrap, particularly unprocessed turnings, is consumed directly or in making ferrotitanium for use in steel and other alloys.

Economic Factors

Prices.—The price of rutile pigment and titanium sponge in constant dollars decreased 20% and 14%, respectively, from 1969 through 1972, as shown in table 4. Reflecting a sharp increase in pigment demand, the constant dollar price rose 32% in 1974. The pigment price did not surpass that level until 1989, following 6 consecutive years of record-high demand. As the tight supply-demand situation eased in 1990, the constant dollar price dropped slightly. The titanium sponge price reached a record high in 1980 because of unprecedented demand for commercial aircraft, then dropped sharply in 1982 and 1983 following a severe downturn in the commercial aircraft market. Although sponge consumption was near record-high levels in 1989, the constant dollar price was several percent below the moderate levels of 1975-77. The decline in sponge consumption in 1990 was mirrored by a decrease in price. Published prices of titanium concentrates and products in 1989-90 are listed in table 15.

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 in 1989 was 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 in 1989 was 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 5 reflect results of the Tokyo Round of Multilateral Trade Negotiations completed in 1979 under which tariffs on many items were reduced in several stages during the period January 1, 1980, to January 1, 1987.

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 sands 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

TABLE 5

U.S. IMPORT DUTIES

Tariff item	HTS No.	Most favored nation (MFN) Jan. 1, 1990	Non-MFN Jan. 1, 1990
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.

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 oceans. Both U.S. sulfate-process producers now are using waste treatment plants that neutralize acid effluent with limestone and lime and produce gypsum and iron oxide byproducts. Such neutralization processes add about $100 per ton to the cost of the TiO_2 pigment product. The sale of all byproducts would recover only a small fraction of this cost.

On September 1, 1989, the Environmental Protection Agency (EPA) published a newly revised interpretation of the Bevill exclusion, which exempts mineral processing wastes from regulation under subtitle C of the Resource Conservation and Recovery Act (RCRA). EPA's revised interpretation addressed the definition of mineral processing and established high-volume and low-hazard criteria for waste streams to be retained within the Bevill exclusion.[1] Subsequent proposed rulemaking later in 1989, published in January 1990, applied this revised interpretation to 20 waste streams that were conditionally retained in the Bevill exclusion.[2] In the TiO_2-$TiCl_4$ sector, chloride processing waste solids were retained, passing both the high-volume and low-hazard criteria. However, other waste streams in this sector were not retained: sulfate process waste acids, having failed to pass the low-hazard criterion; and sulfate process waste solids, chloride process waste acids, and titanium leach liquor, which all failed the high-volume criterion. EPA estimated compliance costs for the sulfate process portion of the titanium dioxide sector to average 0.8% of the value of shipments for the affected facilities.

Toxicity.—Titanium is a nontoxic material, as demonstrated by the use of TiO_2 in cosmetics and the use of titanium for making pacemakers and other implant devices for humans. However, some titanium compounds can be hazardous; for example, $TiCl_4$, which reacts violently with water or moisture in the air, forming TiO_2 and hydrochloric acid.

Energy Requirements.—According to a 1975 study for the U.S. Bureau of Mines, energy requirements for alluvial mine production are about 5.1 million British thermal units (Btu's) per ton of TiO_2 in concentrate. Production of pigment requires about 75 to 112 million Btu's per ton of TiO_2, depending on the process and feed material used. Titanium sponge production uses from 408 to 466 million Btu's per ton of metal, of which about 248 to 270 million Btu's is required to regenerate the reductant and chlorine. The conversion of sponge metal to titanium ingot requires an additional 46 million to 57 million Btu's per ton of titanium ingot.[3]

ANNUAL REVIEW

Legislation and Government Programs

In October, the International Trade Administration of the U.S. Department of Commerce announced final results of its antidumping administrative review of titanium sponge imports from Japan for the periods November 1, 1986, to October 31, 1987, and November 1, 1987, to October 31, 1988. Antidumping margins for the 1986-87 period were as follows: Showa Titanium Co. Ltd., 2.07%; Toho Titanium Co. Ltd., 2.07%; and Osaka Titanium Co. Ltd., 0%. For the 1987-88 period, antidumping margins were as follows: Showa, 9.26%; Toho, 18.39%; and Osaka, 0%. A cash deposit of the estimated antidumping duties will be required on sponge from Showa and Toho based on the above margins.[4]

On September 28, 1990, Commerce announced its determination not to revoke the antidumping finding on titanium sponge from the U.S.S.R. In August, Commerce intended to revoke an antidumping finding on titanium sponge from the U.S.S.R. because of an apparent lack of concern by interested parties. Late in August, two U.S. sponge producers objected to the proposed revocation; Commerce no longer intended to revoke the finding. Titanium sponge from the U.S.S.R. will continue to be subject to antidumping duty deposits of 83.96% of declared value.

A draft report to Congress, prepared by EPA in August, presented recommendations on regulating the 20 waste streams that had been conditionally retained in the Bevill exclusion to RCRA. After evaluating three scenarios, which were based on some flexibility built into certain sections of RCRA, EPA recommended that chloride-process waste solids from $TiCl_4$ production be regulated under subtitle C- or subtitle D. After evaluating and responding to

TABLE 6

SALIENT TITANIUM STATISTICS

(Metric tons unless otherwise specified)

	1986	1987	1988	1989	1990
United States:					
Ilmenite concentrate:					
Imports for consumption	422,401	307,515	394,170	411,751	345,907
Consumption	731,436	744,266	679,008	659,584	688,948
Titanium slag:					
Imports for consumption	328,285	408,785	434,641	386,146	373,623
Consumption	250,677	251,423	300,013	414,830	390,537
Rutile concentrate, natural and synthetic:					
Imports for consumption	158,595	197,937	231,124	264,895	274,605
Consumption	298,601	320,505	352,356	366,143	369,454
Sponge metal:					
Production	15,787	17,849	22,270	25,225	24,679
Imports for consumption	1,475	924	1,364	903	1,093
Consumption	17,680	17,973	21,003	24,927	23,207
Price, Dec. 31, per pound	$3.90-$4.30	$4.00-$4.20	$4.25-$4.75	$4.80-$5.30	$4.50-$5.00
Titanium dioxide pigment:					
Production	844,274	878,558	926,746	1,006,581	978,659
Imports for consumption	183,862	174,219	r185,468	166,346	147,592
Consumption, apparent[1]	908,055	966,169	991,536	947,259	925,447
Price, Dec. 31, cents per pound:					
Anatase	77.0	77.0	95.0	102.0	99.0
Rutile	82.0	82.0	97.0	105.0	101.0
World: Production: (rounded)					
Ilmenite concentrate[2]	r3,420,300	r3,936,800	r4,034,700	r4,235,800	e4,050,900
Rutile concentrate, natural[2]	393,860	r439,180	r433,900	r454,140	e452,380
Titaniferous slag	1,285,000	1,575,000	1,725,000	1,765,000	e1,485,000

eEstimated. rRevised.

[1]Production plus imports minus exports plus stock decrease or minus stock increase.

[2]Excludes U.S. production data to avoid disclosing company proprietary data.

public comments, EPA would issue final regulations by January 31, 1991.[5]

Following an information meeting with representatives of major titanium sponge producers in the United States and Japan, the Defense Logistics Agency (DLA) announced that it would not proceed with its planned acquisition of titanium sponge for the NDS. DLA said the action was taken after the Department of Defense reevaluated its needs, and it was determined that current Government requirements could be met with existing inventories and present and future industrial capacities in the United States. DLA's February 9, 1990, proposal for acquisition of 2,177 tons of Type A sponge (magnesium reduced, vacuum distilled) was strongly opposed by the U.S. titanium industry and Congress because Type A sponge is currently produced only in Japan.

Strategic Considerations

Security of Supply.—Although imports supply a very large proportion of domestic consumption of titanium concentrates, these imports come predominantly from Australia and Canada, which have historically been reliable and politically stable suppliers.

Import reliance, defined as imports less exports plus adjustments for inventory changes, may be used as a measure of dependence on foreign sources of supply. Expressed as a percentage of consumption, import reliance for ilmenite, including high TiO_2 slag made from ilmenite, was 35% in 1980 but increased to about 80% in the 1982-84 period because of cessation of production at two U.S. ilmenite mines. Ilmenite import reliance through 1990 generally has been in the 70% to 80% range, although it dropped to about 60% in 1990. Import reliance for rutile declined from about 90% in 1980 to about 60% in 1983, and in later years it has remained in the 60% to 70% range because of increased production of synthetic rutile. However, this decline was at the expense of increased import reliance for ilmenite because the domestic synthetic rutile was made from Australian ilmenite.

Dependence on foreign rutile sources could be eased or eliminated in an emergency in two ways, using current commercial processing methods. Synthetic rutile could be made from domestic ilmenite now being mined in Florida or from ilmenite that could be mined from other deposits, such as the Tennessee ilmenite sand deposits. 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 1990, 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 1989, and the United States was a net exporter in 1990. Titanium concentrates currently used to make $TiCl_4$ for metal production are mostly imported rutile and synthetic rutile, but domestic concentrates could be used for this purpose in an emergency, possibly at higher cost.

Stockpile.—Rutile and titanium sponge metal are included in the list of strategic and critical materials for stockpiling purposes. Titanium sponge has been acquired periodically for the NDS from domestic producers and from producers in Japan and the United Kingdom. Rutile for the NDS was acquired mainly in the early sixties from Australia.

The Government's NDS goal for titanium sponge metal remained at 176,901 tons. The NDS inventory in December contained 23,555 tons of specification metal and 9,857 tons of nonspecification material. The NDS goal for rutile was unchanged at 96,162 tons. The total rutile stockpile inventory at yearend was 35,549 tons, including 51 tons of nonspecification material.

Issues

U.S. Ore Supply.—Although the United States has large reserves of titanium in the form of ilmenite, nearly all of U.S. titanium sponge production has been derived from imported rutile and synthetic rutile. This heavy reliance on foreign concentrates has developed because most producers of $TiCl_4$, the intermediate compound used to make titanium and a large part of the world's TiO_2 pigment, prefer rutile or synthetic rutile over ilmenite as plant feed material. Possible ways of better utilizing U.S. ilmenite resources and reducing U.S. dependence on foreign sources of titanium concentrates were discussed previously.

Fluctuations in Metal Demand.—A major problem affecting the titanium industry is the wide fluctuations in demand caused by changes in requirements for both military and commercial aircraft programs. Titanium sponge producers have repeatedly increased capacity in response to anticipated demand and have then been left with excess capacity when those programs were canceled or cut back. The most recent example of such a fluctuation was the historic peak in demand and price reached in 1980-81 and the subsequent collapse in 1982-84. The sharp rise and fall of demand and prices were believed to have been aggravated by overestimation of aircraft orders that did not materialize or were later canceled as the aircraft market deteriorated. Following the market collapse, some producers and consumers were left with high inventories to be worked off during a period of lower demand.

It has been suggested that the aerospace industry could help stabilize demand and match supply to demand by better long-range planning and forecasting of their requirements and greater use of multiyear contracts. In the event that additional capacity is needed quickly in a national emergency, incentives such as loan guarantees and a guaranteed floor price for purchases from new capacity could be used, as authorized under the Defense Production Act. Further diversification of titanium into nonaerospace industrial applications would also help stabilize titanium demand.

Production

Concentrates.—U.S. producers of ilmenite in 1990 were Associated Minerals (USA) Ltd. Inc. (AMU) at Green Cove Springs, FL; Du Pont at Starke and Highland, FL, both from mineral sands deposits; P. W. Gillibrand Co., Simi Valley, CA, as a coproduct of its rock, sand, and gravel operations; and Nord Ilmenite Corp., Jackson, NJ, from a previously mined mineral sands deposit.

AMU was the only U.S. producer of natural rutile. Kerr-McGee, Mobile, AL, was the sole domestic producer of synthetic rutile.

Interest continued in exploration and potential development of mineral sands in Virginia and North Carolina. AMU and RGC (USA) Minerals Inc., both members of the RGC group of companies (Australia), continued development of the Old Hickory mineral sands deposit in Dinwiddie and Sussex Counties in southern Virginia. These companies also were acquiring mineral rights to two deposits in North Carolina, near Aurelian Springs and Bailey. Minerals of value in these deposits were primarily ilmenite and zircon. If detailed drilling and feasibility test results are favorable, mining at one or more of these deposits could begin by 1993.

South East TiSand, a joint venture between Becker Minerals Inc. of England and Consolidated Rutile Ltd. of Australia, also was investigating heavy-mineral sands deposits in southern Virginia and North Carolina. TiSand was operating a pilot plant at Brink in Greensville County, VA, as an aid in determining processing plant design and the quality of concentrates that could be produced.

Piedmont Mining Co. Inc. announced a preliminary agreement with Corona Corp. for a joint venture to explore for and develop heavy-mineral sands deposits in the Carolinas. Piedmont has been investigating occurrences of such sands, containing titanium-bearing minerals and zircon, in eastern North Carolina since 1989.

Ferrotitanium.—Ferrotitanium was produced by Galt Alloys Inc., Canton, OH; HTP Co., Sharon, PA; and Shieldalloy Metallurgical Corp., Newfield, NJ. Two grades were produced—a 40%- and a 70%-titanium grade.

Metal.—In March, Baroid Corp., Houston, TX, became the sole owner of TIMET by purchasing Allegheny International's 30% interest in TIMET for $50 million. In November, Baroid completed the spinoff of its titanium and mining business, creating Tremont Corp., based in Denver, CO. Tremont included Baroid's bentonite mining operations in addition to TIMET.

TIMET purchased an equity interest in a metal distributor, Tisto GmbH, in the Federal Republic of Germany, which specializes in titanium and zirconium. This purchase complemented TIMET's 100%-owned subsidiaries in France and the United Kingdom. TIMET also completed a $3.5 million expansion of its technical laboratory in Henderson, NV, to provide additional services in titanium product and process development. Additionally, the company started operations at its Morristown, TN, bar, sheet,

TABLE 7

U.S. TITANIUM METAL PRODUCTION CAPACITY IN 1990

Company	Ownership	Plant location	Yearend capacity (metric tons)	
			Sponge	Ingot[1]
Howmet Corp., Titanium Ingot Div.	Pechiney, France	Whitehall, MI	—	6,300
International Light Metals Corp.	Martin Marietta Corp., 60%; Nippon Kokan K.K., 40%	Torrance, CA	—	5,000
A. Johnson Metals Corp.	Axel Johnson Group, Stockholm, Sweden	Lionville, PA	—	[2]1,800
Lawrence Aviation Industries Inc.	Self	Port Jefferson, NY	—	1,400
Oregon Metallurgical Corp. (Oremet)	Oremet employees, 67%; public, 33%	Albany, OR	6,800	10,000
RMI Co.	USX Corp., 50%; public, 50%	Ashtabula, OH	10,900	—
Do.	do.	Niles, OH	—	16,300
Teledyne Allvac	Teledyne Inc.	Monroe, NC	—	[3]5,700
Teledyne Wah Chang Albany	do.	Albany, OR	—	900
Titanium Metals Corp. of America	Baroid Corp.	Henderson, NV	12,700	15,900
Viking Metallurgical Corp.	Quanex Corp.	Verdi, NV	—	[2]3,200
Wyman-Gordon Co.	Self	Worcester, MA	—	2,300
Total			30,400	68,800

[1]Based on 7-day-per-week full production. Includes 61,700 tons vacuum arc double/triple melt, of which triple melt generally ranged from 10% to 30%. The remaining 7,100 tons was single-melt (electron-beam and plasma-arc) capacity for remelt electrodes and commercially pure ingot and slab.
[2]Single melt only.
[3]Includes 2,100 tons of single-melt capacity.

plate, and tube finishing facility in July. This facility was expected to be fully operational in early 1991.

In April, TIMET announced the signing of a $70 million debenture purchase agreement with a Japanese consortium, Union Titanium Sponge Corp. (USTC), to finance the construction of a new 10,000-ton-per-year titanium sponge plant. The new plant will be built in Henderson, NV, the site of TIMET's current sponge and ingot production facilities. USTC will provide state-of-the-art vacuum distillation technology, which was developed in Japan by Toho Titanium Co. Ltd., and will participate in construction of the new plant. Once the plant is operational, USTC will have the option of converting its debentures into 25% of the common stock of TIMET. The plant was scheduled for completion in 1993.

Oregon Metallurgical Corp. (Oremet) completed installation of two new reduction furnace systems, bringing its total annual sponge production capacity to 6,800 tons. Installation of two more reduction furnace systems, with an additional capacity of 1,400 tons per year, was deferred until the third quarter of 1991; this capacity was originally planned for yearend 1990 or early 1991.

Oremet reportedly signed a long-term agreement with SCM in November for SCM to continue to supply Oremet with $TiCl_4$ for its titanium sponge production. Under the terms of the agreement, SCM would be Oremet's sole supplier of $TiCl_4$. In December, RMI Titanium Co. also signed an agreement with SCM for SCM to remain the $TiCl_4$ supplier for its Ashtabula, OH, sponge plant. The multi-year agreement, effective January 1, 1992, includes provisions to permit RMI to construct its own $TiCl_4$ production plant in the future. In November, RMI had postponed previously announced plans to build a $TiCl_4$ facility because of uncertain economic conditions.

In April, RMI became a public company as a result of an initial public offering of the 7.5 million shares of the company's common stock held by Quantum Chemical Corp. Prior to the offering, RMI was operated as a 50-50 partnership between Quantum and USX Corp. USX retained its 7.5 million shares of RMI common stock.

Teledyne Allvac began operation of its new plasma-arc cold-hearth melting furnace for titanium, increasing its melting capacity by 60%. The company said that because of equipment scheduling problems, its new continuous bar mill will come on-stream by the second quarter of 1991 rather than in late 1990 as originally planned.

Dynamet Inc. expanded its facilities for production of shaped wire at its Washington, PA, headquarters at a cost of about $2 million. Dynamet, a manufacturer of titanium- and nickel-base alloy bar, wire, and precision forgings, has been producing shaped titanium wire for about 3 years, primarily for medical applications. Dynamet's shaped-wire process was described as being on the cutting edge of technology, so that increased production could open up new markets. One of these new markets was aerospace gas turbine manufacturing, where shaped wire could displace rounds and other finished machine parts. Production from Dynamet's expanded facilities began in November.

Titanium Dioxide Pigments.—U.S. production of TiO_2 pigments decreased about 3% in 1990. Producing plants operated at 90% of their nearly 1.1-million-ton-per-year capacity.

New U.S. TiO_2 pigment production capacity scheduled to be in operation in 1991 includes Du Pont's 110,000-ton-per-year expansion at DeLisle, MS; the new Kronos 82,000-ton-per-year plant at Lake Charles, LA; and SCM's 53,000-ton-per-year expansion at Ashtabula, OH. These additions will increase total U.S. TiO_2 capacity to about 1.33 million tons per year. Kerr McGee rescheduled completion of its planned 54,000-ton-per-year TiO_2 plant, at a still undisclosed location, to 1994.

TABLE 8

COMPONENTS OF U.S. TITANIUM METAL SUPPLY AND DEMAND

(Metric tons)

Component	1986	1987	1988	1989	1990
Production:					
Sponge	15,787	17,849	22,270	25,225	24,679
Ingot	31,836	33,762	38,856	41,306	36,809
Mill products	NA	NA	27,837	29,946	25,619
Exports:[1]					
Sponge	63	85	80	136	331
Other unwrought	188	204	210	1,173	3,102
Scrap	5,809	5,083	5,989	5,474	5,487
Ingot, slab, sheet bar, etc.	1,922	2,467	2,083	2,702	2,371
Other wrought	1,027	1,801	2,679	NA	NA
Other articles of titanium	NA	NA	NA	3,857	4,526
Total[2]	9,008	9,640	11,041	13,342	15,816
Imports:[1]					
Sponge	1,475	924	1,364	903	1,093
Scrap	2,155	2,218	4,235	5,308	3,037
Ingot and billet	96	68	237	190	162
Other unwrought	NA	NA	NA	119	213
Other wrought (mill products)	986	892	822	1,049	988
Other articles of titanium	NA	NA	NA	200	279
Total[2]	4,712	4,101	6,658	7,770	5,772
Stocks, yearend:					
Government: Sponge (total inventory)	33,413	33,413	33,413	33,413	33,413
Industry:					
Sponge	2,885	2,272	2,439	2,114	3,267
Scrap	10,485	9,212	8,596	8,028	8,535
Ingot	3,719	4,044	3,933	3,548	3,725
Other	30	14	8	7	3
Total industry[2]	17,119	15,542	14,977	13,697	15,530
Reported consumption:					
Sponge	17,680	17,973	21,003	24,927	23,207
Scrap	14,957	16,363	18,058	r17,596	14,973
Ingot	30,664	32,260	35,556	31,396	35,320
Mill products (net shipments):	18,908	20,218	22,558	24,997	23,923
Forging and extrusion billet	9,637	10,968	10,694	11,742	10,729
Rod and bar	2,732	2,932	3,528	3,566	3,499
Other[3]	6,539	6,318	8,336	9,689	9,695
Castings (shipments)	385	431	473	485	482

rRevised. NA Not available.

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export categories for 1989 and 1990 are not necessarily comparable with those in previous years.

[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.

Consumption and Uses

Concentrates.—Total U.S. consumption of TiO_2 in concentrates decreased about 2% from the 1989 level. This decline mainly was attributed to a slowing economy. Both ilmenite and rutile consumption increased slightly, while slag consumption dropped by about 6%. Distribution of total consumption by end use was pigments, 93%; metal, 4%; and other uses, 3%.

Ferrotitanium.—Consumption of titanium in the form of ferrotitanium and scrap in steel and other alloys rose about 10% in 1990.

Metal.—Net shipments of mill products fell by about 4%, and sponge production also decreased by about 2%. Consumption of scrap for remelting continued to drop and supplied a calculated 40.7% of ingot feedstock compared with 42.5% in 1989. Castings shipments were about the same.

Mill product shipments by product type were forging and extrusion billet, 45%; sheet, strip, plate, extrusions, and other, 40%; and rod and bar, 15%.

TABLE 9

CAPACITIES OF U.S. TITANIUM DIOXIDE PIGMENT PLANTS ON DECEMBER 31, 1990[1]

Company and plant location	Pigment capacity (metric tons per year)	
	Sulfate process	Chloride process
E.I. du Pont de Nemours & Co. Inc.:		
Antioch, CA	—	36,000
De Lisle, MS	—	160,000
Edge Moor, DE	—	129,000
New Johnsonville, TN	—	297,000
Kemira Inc., Savannah, GA	54,000	91,000
Kerr-McGee Chemical Corp., Hamilton, MS	—	96,000
SCM Chemicals Inc., Hanson Industries U.S.A.:		
Ashtabula, OH	—	111,000
Baltimore, MD	63,000	49,000
Total	117,000	969,000

[1]The table does not include Hitox Corp.'s Corpus Christi, TX, production capacity of about 18,000 tons per year of buff TiO_2, which is made by refining and fine-grinding of synthetic rutile.

Estimated U.S. mill product usage by application was as follows: commercial aircraft, 41%; military aerospace, 37%; chemical industry, including pulp and paper, 10%; powerplant condensers, 4%; naval and other marine uses, 3%; medical implants, 1%; and other uses, mainly oil drilling, flue gas desulfurization, and automotive, 4%.

Current use of titanium in large commercial aircraft represents about 6% of aircraft empty weight. Titanium is utilized where high-strength toughness, heat resistance, and high structural efficiency are required. Typical aircraft uses are for structural forgings, such as the landing gear beam in the Boeing 757; wing skins for the F-14 and F-15 fighter aircraft; rotor parts for helicopter systems; B-1B fracture-critical forgings and wing support sections; and rotor discs and compressor blades on various engines. Major nonaerospace industrial uses are mainly those requiring superior resistance to corrosion.

Prospective use of titanium was enhanced by United Airlines' order for 68 Boeing 777 airplanes in October. A Boeing spokesperson said that the company was expected to build a 9%-titanium aircraft in the 1990's, surpassing the 6% titanium in the Boeing 757. Construction of the first 777 was set to begin in 1992. In the meantime, Boeing expected to build 38 aircraft per month, starting in the second half of 1991, compared with 34 per month in 1990.

Pigment.—Apparent domestic consumption of TiO_2 pigments was about 925,000 tons, about 2% less than in 1989, despite full-capacity operation of U.S. TiO_2 pigment plants.

Stocks

The TiO_2 content of inventories of ilmenite and rutile increased by 43% and 11%, respectively, while titanium slag stocks decreased by 14%. Overall TiO_2 content of concentrate stocks rose by 18%. Stocks of TiO_2 pigment decreased slightly to about 62,000 tons, a 20-day supply.

Markets and Prices

Prices of ilmenite and titanium slag rose slightly during the year; rutile prices, however, increased by about 50% in 1990. Titanium dioxide prices decreased about 3 cents per pound in the fourth quarter in response to the easing of the tight supply and demand situation.

Titanium sponge prices averaged about $5.25 per pound in the first half of the year, $5.00 per pound in the third quarter, and $4.75 per pound in the fourth quarter according to industry sources. The decrease in sponge prices was attributed to increased production capacity and

TABLE 10

COMPONENTS OF U.S. TITANIUM DIOXIDE PIGMENT SUPPLY AND DEMAND

(Metric tons unless otherwise specified)

Component	1987		1988		1989		1990	
	Gross weight	TiO_2 content	Gross weight	TiO_2 content	Gross weight	TiO_2 content	Gross weight	TiO_2 content
Production	878,558	820,810	926,746	858,166	1,006,581	935,919	978,659	913,275
Shipments:[1]								
Quantity	1,043,129	977,424	1,097,481	1,020,517	1,126,622	1,046,633	1,116,431	1,045,748
Value thousands	$1,700,644	$1,700,644	$1,954,656	$1,954,656	$2,352,390	$2,352,390	$2,404,282	$2,404,282
Exports	108,889	e99,748	118,422	e107,409	212,197	e193,311	202,288	e189,544
Imports for consumption	174,219	e162,767	185,468	e171,743	166,346	e154,669	147,592	e138,294
Stocks, yearend	47,478	e44,358	49,734	e46,053	63,205	e58,768	61,721	e57,597
Consumption, apparent[2]	966,169	e904,322	991,536	e920,805	947,259	e884,562	925,447	e863,196

eEstimated.
[1]Includes interplant transfers.
[2]Production plus imports minus exports plus stock decrease or minus stock increase.

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

TABLE 11

U.S. CONSUMPTION OF TITANIUM CONCENTRATES

(Metric tons)

Year	Ilmenite[1]		Titanium slag		Rutile (natural and synthetic)[2]	
	Gross weight	TiO_2 content[e]	Gross weight	TiO_2 content[e]	Gross weight	TiO_2 content[e]
1986	731,436	465,136	250,677	201,358	298,601	280,669
1987	744,266	463,072	251,423	202,688	320,505	301,534
1988	679,008	429,736	300,013	242,594	352,356	331,376
1989:						
Alloys and carbide	(3)	(3)	(4)	(4)	—	—
Pigments	659,048	419,329	414,830	335,395	286,558	271,208
Welding-rod coatings and fluxes	(3)	(3)	—	—	3,807	3,603
Miscellaneous[5]	536	414	(4)	(4)	75,778	71,178
Total	659,584	419,743	414,830	335,395	366,143	345,989
1990:						
Alloys and carbide	(3)	(3)	(4)	(4)	—	—
Pigments	687,901	445,502	390,537	313,648	288,734	271,637
Welding-rod coatings and fluxes	(3)	(3)	—	—	4,295	4,047
Miscellaneous[5]	1,047	726	(4)	(4)	76,425	71,373
Total	688,948	446,228	390,537	313,648	369,454	347,057

[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.

somewhat lower requirements for ingot production. Prices of mill products rose about 5% early in the year in response to high demand and increased costs. Scrap metal prices remained low throughout the year, probably because of the relative abundance of sponge and increased availability of scrap in Europe from the U.S.S.R.

Foreign Trade

Imports of titanium raw materials decreased by 28% from those in 1989, with sharp declines in ilmenite and slag imports. On the basis of TiO_2 content, principal import sources for raw materials were Australia, 45%; the Republic of South Africa, 35%; Canada, 11%, and Sierra Leone, 8%.

TABLE 12

U.S. DISTRIBUTION OF DOMESTIC TITANIUM PIGMENT SHIPMENTS, TITANIUM DIOXIDE CONTENT, BY INDUSTRY

(Percentage)

Industry	1986	1987	1988	1989	1990
Ceramics	W	W	0.4	0.4	W
Coated fabrics and textiles	0.4	0.3	W	.4	0.2
Floor coverings	.9	1.2	1.2	1.1	1.0
Paint, varnish, lacquer	52.6	49.5	48.1	50.0	48.9
Paper	20.7	24.3	24.2	25.8	26.5
Plastics	15.8	17.0	17.0	16.3	16.6
Printing ink	1.4	1.2	1.7	.8	1.6
Roofing granules	.4	.4	.4	.3	.4
Rubber	2.0	1.8	1.7	1.4	1.5
Other	5.8	4.3	5.3	3.5	3.3
Total	100.0	100.0	100.0	100.0	100.0

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

World Review

Capacity.—The data in table 20 are rated capacities for mines and beneficiation plants, sponge metal facilities, and TiO_2 pigment plants as of December 31, 1990. 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 a 365-day-per-year operation, 3 shifts per day. Capacity figures are based on information obtained from the producing companies, from news items, and

from U.S. Bureau of Mines estimates.

Reserves.—U.S. and world reserves and reserve base data for titanium are shown in tables 21 and 22. U.S. reserves of 7.8 million tons of TiO_2 in ilmenite and 300,000 tons of TiO_2 in rutile occur mainly in ancient beach sand deposits in Florida. Ilmenite concentrates from the U.S. sand deposits contain about 60% to 65% TiO_2, while those from rock deposits contain 45% to 50% TiO_2. The U.S. reserve base of 34.7 million tons of TiO_2 occurs as 23.5 million tons in ilmenite, 9.8 million tons in perovskite ($CaTiO_3$), and 1.4 million tons in rutile.

TABLE 13

U.S. CONSUMPTION OF TITANIUM PRODUCTS[1] IN STEEL AND OTHER ALLOYS

(Metric tons)

	1986	1987	1988	1989	1990
Carbon steel	664	711	877	W	1,687
Stainless and heat-resisting steel	1,982	2,229	2,742	2,647	2,722
Other alloy steel (includes HSLA)	269	325	249	149	173
Tool steel	W	W	W	W	W
Total steel[2]	2,916	3,265	3,868	2,796	4,582
Cast irons	59	W	W	W	W
Superalloys	572	625	642	800	921
Alloys, other than above	292	290	1,552	873	1,071
Miscellaneous and unspecified	32	41	54	1,600	74
Total consumption[2]	3,871	4,221	6,116	6,069	6,648

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1]Includes ferrotitanium containing 20% to 70% titanium and titanium metal scrap.
[2]Data may not add to totals shown because of independent rounding.

TABLE 14

U.S. STOCKS OF TITANIUM CONCENTRATES AND PIGMENT, DECEMBER 31

(Metric tons)

	Gross weight	TiO_2 content
Ilmenite:[1]		
1988	173,372	98,772
1989	236,679	137,643
1990	341,891	196,645
Titanium slag:[1]		
1988	129,537	105,429
1989	96,067	78,078
1990	85,960	68,605
Rutile:[1]		
1988	117,751	108,339
1989	155,024	144,618
1990	171,085	161,026
Titanium pigment:[2]		
1988	49,734	e46,053
1989	63,205	r e58,768
1990	61,721	e57,597

eEstimated. rRevised.
[1]Producer, consumer, and dealer stocks.
[2]Bureau of the Census. Producer stocks only.

TABLE 15

PUBLISHED PRICES OF TITANIUM CONCENTRATES AND PRODUCTS[1]

		1989	1990
Concentrates:			
Ilmenite, f.o.b. eastern U.S. ports	per metric ton	(2)	(2)
Ilmenite, f.o.b. Australian ports	do.	$67.00-$75.00	$69.00-$77.00
Ilmenite, large lots, bulk, f.o.b. U.S. east coast	do.	NA	NA
Rutile, bagged, f.o.b. Australian ports	do.	553.00-632.00	693.00-770.00
Rutile, bulk, f.o.b. Australian ports	do.	514.00-553.00	732.00-847.00
Rutile, large lots, bulk, f.o.b. U.S. east coast	do.	540.00-550.00	550.00-580.00
Synthetic rutile, f.o.b. Mobile, AL	do.	NA	NA
Titanium slag, 80% TiO_2, f.o.b. Sorel, Quebec[e]	do.	260.00-280.00	270.00-290.00
Titanium slag, 85% TiO_2, f.o.b. Richards Bay, Republic of South Africa[e]	do.	275.00-300.00	285.00-310.00
Metal:			
Sponge, reported sales	per pound	4.80- 5.30	4.50- 5.00
Sponge, Japanese, under contract, c.i.f. U.S. ports, including import duty	do.	No quotation	No quotation
Mill products:			
Bar	do.	12.56- 16.54	11.50- 13.24
Billet	do.	8.87- 12.96	7.80- 9.59
Plate	do.	13.07- 15.20	12.80- 13.75
Sheet	do.	10.50- 11.03	9.60- 11.60
Strip	do.	10.50- 11.32	10.70- 12.57
Scrap:			
Cuttings, commercially pure	do.	4.50- 4.66	NA
Turnings, commercially pure	do.	4.02- 4.18	NA
Turnings, unprocessed	do.	2.73- 3.05	1.05- 1.15

See footnotes at end of table.

TABLE 15—Continued

PUBLISHED PRICES OF TITANIUM CONCENTRATES AND PRODUCTS[1]

		1989	1990
Pigment:			
Titanium dioxide pigment, f.o.b. U.S. plants, anatase	per pound	$1.01- $1.02	$0.99
Titanium dioxide pigment, f.o.b. U.S. plants, rutile	do.	1.04- 1.05	1.01

[e]Estimated. NA Not available.
[1]Yearend.
[2]List price suspended effective Jan. 1, 1985.

Sources: American Metal Market, American Paint and Coatings Journal, Chemical Marketing Reporter, Industrial Minerals (London), Metal Bulletin, Metals Week, and industry contacts.

TABLE 16

U.S. EXPORTS OF TITANIUM PRODUCTS, BY CLASS[1]

Class	1988		1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Metal:						
Sponge	80	$574	136	$910	331	$2,073
Scrap	5,989	23,374	5,474	22,909	5,487	22,443
Ingots, billets, slabs, etc.	2,083	33,312	NA	NA	NA	NA
Other unwrought	210	1,480	NA	NA	NA	NA
Billet	NA	NA	1,128	21,765	969	17,890
Blooms and sheet bars	NA	NA	1,240	27,630	887	23,417
Ingot	NA	NA	334	5,471	514	7,426
Other	NA	NA	1,173	8,906	3,102	20,502
Wrought	2,679	71,958	NA	NA	NA	NA
Bars and rods	NA	NA	1,848	49,969	1,697	54,244
Other	NA	NA	2,009	60,542	2,829	94,046
Total[2]	11,041	130,698	13,342	198,102	15,816	242,040
Ores and concentrates	9,368	3,729	19,832	5,900	18,765	7,398
Pigments, oxides, and compounds:						
Titanium dioxide pigments	118,422	219,237	68,485	141,359	153,361	327,009
Titanium oxides	NA	NA	143,712	296,286	48,927	107,551
Titanium compounds, except pigment-grade	4,478	14,885	NA	NA	NA	NA
Total	122,900	234,122	212,197	437,645	202,288	434,560

NA Not available.
[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, export categories for 1989 and 1990 are not necessarily comparable with those in prior years.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

Other U.S. resources include additional rock deposits of ilmenite in California, Minnesota, New York, Wyoming, and sand deposits of ilmenite and/or rutile in Georgia, Idaho, New Jersey, North Carolina, Oregon, and South Carolina, as well as large quantities of accessory rutile in porphyry copper ores and mill tailings.

The U.S. Bureau of Mines is compiling a computerized file of worldwide mineral deposit data called the Minerals Availability System (MAS). When fully developed, MAS will provide a means of analyzing supply positions relative to available reserves, mineral-related land use issues, environmental issues, and a variety of problems associated with the mining, processing, and transporting of titanium and other commodities. Most of the resource data in tables 21 and 22 were derived from MAS reports.

Major titanium reserves in the United States are owned by Du Pont and AMU in Florida. Reserves in Australia are held mainly by Associated Minerals Consolidated Ltd. (AMC), a subsidiary of RGC, Consolidated Rutile Ltd.; Westralian Sands Ltd.; and Cable Sands Ltd. Reserves at Allard Lake, Quebec, Canada, are held by QIT-Fer et Titane Inc. (QIT), now a subsidiary of RTZ Corp. PLC. QIT also has a 50% interest in Richards Bay mineral sands deposits in the Republic of South Africa. Major deposits in Brazil, India, and Sri Lanka are held by the respective Governments.

TABLE 17

U.S. IMPORTS FOR CONSUMPTION OF TITANIUM CONCENTRATES, BY COUNTRY[1]

Concentrate and country	1988		1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ilmenite:						
Australia	348,364	$16,657	317,835	$20,335	326,186	$22,206
Ghana[2]	3,291	178	—	—	—	—
India	—	—	—	—	19	36
Sierra Leone	21,516	1,625	52,261	2,895	19,701	720
Sri Lanka	21,000	1,029	30,400	1,672	—	—
St. Pierre and Miquelon[2]	—	—	11,255	598	—	—
Total[3]	394,170	19,489	411,751	25,500	345,907	22,962
Titanium slag:						
Canada	222,626	48,597	117,609	25,260	99,510	22,434
Norway	—	—	—	—	5,581	1,271
South Africa, Republic of	212,015	44,292	268,537	59,851	268,531	65,745
Total[3]	434,641	92,889	386,146	85,111	373,623	89,450
Rutile, natural:						
Australia	99,934	44,546	108,380	54,213	120,686	68,885
Canada	—	—	82	28	379	22
Mexico	—	—	1,050	35	—	—
Netherlands	—	—	—	—	1,943	1,493
Sierra Leone	36,165	16,163	32,793	17,294	52,776	24,467
South Africa, Republic of	18,051	6,167	46,252	19,591	42,234	16,626
Other	198	23	68	554	9	133
Total[3]	154,348	66,899	188,625	91,715	218,026	111,627
Rutile, synthetic:						
Australia	62,281	20,462	64,190	22,517	52,578	13,632
Brazil	—	—	—	—	2	5
China	32	13	—	—	—	—
India	8,007	3,203	9,101	4,179	4,000	2,400
Japan	6,456	3,372	2,979	1,515	—	—
Netherlands	—	—	(4)	2	—	—
Total[3]	76,776	27,050	76,270	28,213	56,579	16,037
Titaniferous iron ore:[5]						
Canada	24,802	1,534	37,922	1,876	28,818	2,169

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 and 1990 are not necessarily comparable with those in prior years.
[2]Country of transshipment rather than country of origin.
[3]Data may not add to totals shown because of independent rounding.
[4]Less than 1/2 unit.
[5]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.

NL Industries controls Titania A/S, owner of the large hard-rock deposit at Tellnes, Norway.

U.S. reported consumption of titanium dioxide in concentrates in 1990 was 1,107,000 tons. At this annual consumption rate, U.S. reserves of 8,100,000 tons would be sufficient for only about 7 years, without imports. However, with the current level of import reliance, 62% of reported consumption, these reserves would provide almost a 20-year supply of titanium. The U.S. reserve base of 35 million tons TiO_2 content is equivalent to almost 32 times the 1990 domestic consumption level.

World production of TiO_2 in concentrates decreased in 1990, in line with the slight decrease in world demand. Production capacity for TiO_2 in concentrates increased by about 1%, and TiO_2 pigment production capacity increased by about 2% in 1990. These capacity increases along with the slight decrease in demand helped alleviate the tight supply-demand relationship that has affected TiO_2 pigments in the past few years. Because of increased environmental regulations, particularly in Europe, regarding disposal of waste acid from sulfate-process TiO_2 plants, several producers have invested in additional acid recycling equipment to reduce or eliminate acid disposal.

Australia.—In May, the Cooljarloo, Western Australia, joint venture between Kerr McGee and Minproc Holdings was named TiWest, and production of ilmenite and rutile began in mid-1990. The second stage of the project, production of synthetic rutile, was expected to begin in early 1991, providing concentrate for sale as well as feed material for TiWest's TiO_2 pigment plant, to be completed by mid-1991. Total annual production capacities at the various facilities when completed were expected to be ilmenite, 400,000 tons; rutile, 35,000 tons; leucoxene, 9,000 tons; synthetic rutile, 68,000 tons; and TiO_2 pigment, 54,000 tons.

Although commissioned in 1989, start-up of Australmin Holdings Ltd.'s mineral sands operations at Newrybar, New South Wales, was delayed until the first quarter of 1990 by an appeal to the Land and Environment Court of New South Wales. Conditional approvals for mining and processing were suspended until the appeal was dismissed in November 1989. The proposed plan was to recover about 12,000 tons of rutile and 10,000 tons of zircon annually from mineral sands mined at Newrybar and a processing plant at Woodburn.

Wimmera Industrial Minerals Pty. Ltd. (WIM), a subsidiary of CRA Ltd., announced an upgrading of reserves for its main mineral sands deposit near Horsham, Victoria. The company revised its grade of heavy minerals from 3.2% to 4.0% by excluding some of the low-grade material overlaying the main ore body. WIM also detailed four additional mineral sands resources in the same area, grading from 3.5% to 7.2% heavy minerals. Because of the fine grain size of the minerals, WIM was operating a pilot plant to develop techniques to separate

TABLE 18

U.S. IMPORTS FOR CONSUMPTION OF TITANIUM PIGMENTS, BY COUNTRY

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
80% or more titanium dioxide:				
Australia	1,281	$2,281	—	—
Belgium	7,663	12,047	5,046	$8,542
Canada	25,608	38,081	37,235	60,481
China	1,434	1,867	1,027	1,128
Finland	2,432	4,536	2,301	4,450
France	3,015	6,108	1,755	3,611
Germany, Federal Republic of	20,555	35,109	17,165	32,033
Japan	3,932	7,731	3,847	7,822
Mexico	—	—	3,632	6,768
Netherlands	1,611	3,002	—	—
Norway	744	1,044	4,399	7,466
Singapore	4,323	6,241	3,536	6,340
United Kingdom	956	1,883	185	364
Other	435	863	115	127
Total	73,989	120,793	80,243	139,132
Other titanium dioxide:				
Belgium	1,601	2,618	399	706
Canada	3,629	5,904	4,409	7,776
France	15,352	21,365	12,880	22,934
Germany, Federal Republic of	5,220	11,885	2,898	7,493
Italy	6,075	10,717	1,789	3,161
Norway	2,802	3,420	675	1,065
South Africa, Republic of	906	1,522	148	254
Spain	16,020	27,673	9,181	15,838
United Kingdom	7,125	12,489	12,196	21,226
Other	327	825	362	1,076
Total	59,057	98,418	44,937	81,529
Titanium oxide:				
Australia	225	409	—	409
Belgium	100	249	113	249
Canada	15,752	24,777	5,266	24,777
China	553	908	139	908
Finland	860	1,546	150	1,546
France	5,058	9,056	4,469	9,056
Germany, Federal Republic of	121	993	2,198	993
Japan	709	1,781	94	1,781
Mexico	671	1,789	159	1,789
Norway	—	—	468	771
United Kingdom	8,770	15,237	9,301	16,497
Yugoslavia	274	711	—	—
Other	207	473	55	165
Total	33,300	57,929	22,412	58,941
Grand total	166,346	277,140	147,592	279,602

Source: Bureau of the Census.

and concentrate the various minerals.

Nissho Iwai, a Japanese trading group, purchased the Australian mineral sands operations from Pioneer International Ltd. for $193 million in January. The two operations included in the sale were RZ Mines Pty. Ltd., which has operations in New South Wales and holdings in Queensland, and Cable Sands, with operations in Western Australia.

Brazil.—In February, Compania Vale do Rio Doce began operation of a 50-ton-per-year pilot plant to produce titanium sponge in Minas Gerais. The company planned to spend 2 years testing the sponge for quality and another 3 years gearing up to produce sponge on an industrial scale of 5,000 to 10,000 tons per year.[6]

A $400 million consortium of Brazilian and Japanese companies was formed to develop the ilmenite and zircon reserves along the coast of the State of Bahia. The companies in the consortium were the Bahia State Prospecting Co., Multiquartz Mining Co., both of Brazil, and Sumitomo Corp. and Kawatetsu Co. of Japan. Bahia State Prospecting conducted exploration and located the deposit, estimated to contain 3 million tons of ore, Sumitomo planned to provide titanium technology, and Kawatetsu planned to provide the zircon technology. Total cost of the project, up to the point of bringing the mine on-stream, was estimated to be $16 million. The concentration plant was expected to upgrade the crude ore from 4% to 55% ilmenite, with an estimated production rate of 200,000 tons per year. Initial production was scheduled for 1996.

China.—Marubeni Corp. of Japan announced that it had set up a joint venture with Malaysia Mining Corp. to mine ilmenite on Hainan Island in the South China Sea. The companies expected to recover 50,000 tons per year of ilmenite by late 1992. Sixty percent of the ilmenite was destined for export to Japan, and the remaining 40% would be used to produce 10,000 tons per year of TiO_2 on Hainan Island.

Finland.—Kemira planned to invest $25 million in acid waste recycling equipment at its sulfate-process TiO_2 plant in Pori. By the beginning of 1992, Kemira expected to increase the concentration of the waste acid from 70% to 80% so that the company could use all the recycled

TABLE 19

U.S. IMPORTS FOR CONSUMPTION OF TITANIUM METAL, BY CLASS AND COUNTRY[1]

Class and country	1988		1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Unwrought:						
Sponge:						
China	390	$2,656	225	$1,709	116	$842
Japan	949	7,668	649	6,203	934	9,057
United Kingdom	23	172	9	109	26	367
Other	3	27	20	160	17	133
Total[2]	1,364	10,523	903	8,181	1,093	10,398
Waste and scrap:						
Austria	433	1,597	142	1,209	72	402
Belgium	63	175	8	50	18	73
Canada	345	1,539	480	3,517	228	791
China	145	981	173	1,225	268	1,528
El Salvador	—	—	111	736	—	—
France	180	1,157	216	1,451	283	1,448
Germany, Federal Republic of	406	2,609	303	2,719	52	282
Japan	1,903	10,181	2,121	15,482	1,004	5,799
Sweden	—	—	87	587	77	665
U.S.S.R.	—	—	524	4,007	397	2,680
United Kingdom	557	3,619	919	9,204	521	3,230
Other	204	1,005	224	1,711	117	653
Total[2]	4,235	22,863	5,308	41,898	3,037	17,550
Ingot and billets:						
Germany, Federal Republic of	17	629	—	—	—	—
Hong Kong	—	—	86	713	—	—
Israel	11	342	—	—	—	—
Japan	61	740	36	527	162	47
United Kingdom	137	1,300	68	862	—	—
Other	11	152	—	—	—	—
Total	237	r3,163	190	2,102	162	47
Powder:						
Israel	NA	NA	31	887	18	431
Other	NA	NA	6	374	2	95
Total	NA	NA	37	1,261	20	526
Other:[3]						
China	NA	NA	35	95	—	—
Japan	NA	NA	—	—	24	519
United Kingdom	NA	NA	33	433	139	1,686
Other	NA	NA	14	4,445	29	153
Total[2]	NA	NA	82	4,973	193	2,359
Wrought titanium:[4]						
Canada	298	5,548	638	14,693	755	17,802
France	—	—	17	516	17	548
Germany, Federal Republic of	78	1,012	25	792	20	379
Japan	355	6,117	474	11,671	352	9,858
Sweden	—	—	16	3,165	6	429
United Kingdom	65	1,884	56	1,584	95	5,173

See footnotes at end of table.

TABLE 19—Continued

U.S. IMPORTS FOR CONSUMPTION OF TITANIUM METAL, BY CLASS AND COUNTRY[1]

Class and country	1988		1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Other	26	$1,178	24	$1,664	22	$1,557
Total[2]	822	r15,739	1,250	34,085	1,266	35,746

rRevised. NA Not available.

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 and 1990 are not necessarily comparable with those in prior years.

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

[3]Includes blooms, sheet, bars, slabs, and other unwrought.

[4]Includes bars, castings, foil, pipes, plates, profiles, rods, sheet, strip, tubes, wire, and other.

Source: Bureau of the Census.

acid in its TiO_2 production process. Kemira also was investigating pilot-plant-scale purification technology for dilute waste acid streams, for which recycling was not economical. The long-term goal for Kemira was to eliminate all discharges to the sea.

Germany, Federal Republic of.—Sachtleben Chemie GmbH announced the startup of a waste acid recycling plant early in 1990 near the company's operations in Duisberg. The new plant will serve Sachtleben Chemie's plant and Kronos Titan GmbH's plant in Leverkusan. The new acid plant will concentrate waste acid to form reusable sulfuric acid and was expected to end the dumping of acid into the North Sea.[7]

India.—The Indian Government reportedly approved the construction of a 1,000-ton-per-year titanium sponge plant to meet the country's domestic needs. Feed for the plant was expected to come from domestic ilmenite and rutile reserves in the State of Kerala. No timetable for construction was established.

Italy.—Tioxide announced that it would construct an ultrafine TiO_2 production plant at its Tioxide Italia SpA operation in Scarlino. Using the company's patented technology, Tioxide planned to have the plant on-stream in 1991, with an initial production capacity of 400 tons per year and potential for expansion at a later date. Ultrafine TiO_2 is less than 0.2 micrometer in size and was expected to be used as a barrier against ultraviolet radiation in products such as plastics and food packaging.

Japan.—Estimated production of titanium sponge in Japan was 26,000 tons, a 22% increase from the 1989 level of 21,341 tons. Annual sponge production capacity by the three Japanese producers was as follow: Osaka, 13,200 tons; Toho, 10,000 tons; and Showa, 3,000 tons. Osaka began a $19 million expansion program to increase its annual sponge capacity to 15,000 tons by April 1991.

The Japanese sponge producers reportedly began a 5-year plan to develop a new sponge production process that would allow continuous output at lower costs. The producers planned to conduct laboratory tests in 1990 and build a 1,000-ton-per-year pilot plant by 1992. The new process involved mixing gaseous $TiCl_4$ with magnesium vapor at a high temperature and suitable pressure to produce titanium metal.

Korea, Republic of.—After a 4-year delay because of environmental concerns, the Republic of Korea approved a proposed $97 million, 60,000-ton-per-year TiO_2 plant. The plant will be 80% controlled by Du Pont, which invested $77.6 million, and the remaining 20% was invested by a local firm, Hanyang Chemical Corp. Plant completion was scheduled for late 1993 or early 1994.

SCM and Lucky Metals Corp. announced that they would construct a 40,000-ton-per-year TiO_2 pigment plant near Ulsan by the end of 1991. The plant would use SCM's chloride-process technology, and SCM would supply the raw materials to the Ulsan plant. Lucky Metals would then process the TiO_2 into various grades for the coatings, plastics, and other industries.

Malaysia.—U.S.-based Hitox Corp. completed construction of a 50,000-ton-per-year synthetic rutile plant. The synthetic rutile will provide a captive source of feed material for Hitox's buff TiO_2 plant in Corpus Christi, TX.

Because of its allegedly high radioactivity level, Japan reportedly suspended imports of Malaysian ilmenite. The ilmenite, a byproduct of tin mining in Malaysia, supplied about one-half of Japan's ilmenite requirements.[8]

Mozambique.—Kenmare Resources PLC of Ireland suffered a setback in its plans to develop the Congolone mineral sands deposit near Angoche. In November, Johannesburg Consolidated Investment Corp. (JCIC) withdrew from negotiations to joint venture the project. JCIC was expected to take a 51% option on the project, but failed to gain the support of the Credit Insurance Guarantee Corp. of the Republic of South Africa.

Netherlands.—In June, TDF Tiofine BV began operation of a new 45,000-ton-per-year chloride-process TiO_2 plant at Rosenberg that replaced its sulfate-process plant at the same location.

Saudi Arabia.—Crystal Pigment Co. expected to complete a 50,000-ton-per-year chloride-process TiO_2 plant at Yanbu by mid-1991. Crystal Pigment is owned 25% by Kerr McGee, 25% by Shairco of Saudi Arabia, and the remainder by other investors.

Spain.—Tioxide planned to invest $31 million in an acid recycling plant at its subsidiary Tioxide Espana SA plant at Huelva. The new recycling facility will be based on a pilot plant that used technology developed jointly by Lurgi and Tioxide Espana.

TABLE 20

WORLD TITANIUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990

(Thousand metric tons of TiO_2 content of concentrates, gross weight of sponge (more than 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	—	—	—	74	38	112
Mexico	—	—	—	—	—	79	79
United States	217	30	100	30	117	969	1,086
Total	1,097	30	100	30	191	1,086	1,277
South America: Brazil	83	[4]15	—	—	55	—	55
Europe:							
Belgium	—	—	—	—	70	—	70
Czechoslovakia	—	—	—	—	22	—	22
Finland	—	—	—	—	80	—	80
France	—	—	—	—	225	—	225
Germany, Federal Republic of	—	—	—	—	240	80	320
Italy	—	—	—	—	75	—	75
Netherlands	—	—	—	—	—	45	45
Norway	450	—	—	—	27	—	27
Poland	—	—	—	—	36	—	36
Spain	—	—	—	—	65	—	65
U.S.S.R.	250	10	—	52	100	—	100
United Kingdom	—	—	—	5	136	158	294
Yugoslavia	—	—	—	—	28	—	28
Total	700	10	—	57	1,104	283	1,387
Africa:							
Sierra Leone	35	120	—	—	—	—	—
South Africa, Republic of	[5]640	94	—	—	35	—	35
Total	675	214	—	—	35	—	35
Asia:							
China	90	—	—	3	25	—	25
India	200	19	138	—	12	22	34
Japan	—	—	46	27	274	54	328
Korea, Republic of	—	—	—	—	18	—	18
Malaysia	275	—	96	—	—	—	—
Singapore	—	—	—	—	—	36	36
Sri Lanka	80	13	—	—	—	—	—
Taiwan	—	—	—	—	10	—	10
Thailand	16	—	—	—	—	—	—
Total	661	32	280	30	339	112	451
Oceania: Australia	1,100	260	250	—	35	70	105
World total (may be rounded)	4,320	560	630	117	1,760	1,550	3,310

[1]Sulfate process.
[2]Chloride process.
[3]Contained in 80% TiO_2 slag made from ilmenite.
[4]Mainly anatase.
[5]Contained in 85% TiO_2 slag made from ilmenite.

Sources: Technical publications, especially Industrial Minerals; industry contacts; and U.S. Bureau of Mines estimates.

South Africa, Republic of.—Completion of a new dry mill by Richards Bay Minerals substantially increased rutile production capacity to about 100,000 tons per year. The new mill also will provide ilmenite for increased production of RB slag beginning in 1991. Installation of a fourth ilmenite smelting furnace in the second half of 1991 will increase production capacity of RB slag to 1 million tons per year.

Taiwan.—ISK Taiwan, a subsidiary of Japan's ISK, began operating an 18,000-ton-per-year rutile finishing plant in Kaohsing in July. Raw materials for the plant will be supplied from ISK's Yokkaichi, Japan, plant, and the wastes from the Taiwanese plant also will be treated there.

Du Pont received Government approval for

TABLE 21

U.S. TITANIUM RESERVES AND RESERVE BASE IN 1990

(Thousand metric tons of TiO_2 content)

State	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.

its new 60,000-ton-per-year TiO_2 plant in Taiwan, but still is awaiting a construction permit from local authorities. Completion of this plant was scheduled for 1992.

United Kingdom.—In December, IMI PLC acquired TiLine Inc., an Albany, OR, manufacturer of titanium investment castings, for about $6 million. IMI said that the acquisition would complement the line of castings made by TiTech International Inc., Pomona, CA, which IMI acquired in June 1989.

SCM Chemicals Ltd. announced that it would invest in technology to reduce wastes from its chloride-process TiO_2 plant at Stallingborough. A new plant would convert the acid wastes into hydrochloric acid and metal oxides, reduce solids, and dilute acid discharge. If the plant proves successful, SCM will evaluate the feasibility of using the technology at its other chloride-process plant locations.

Current Research

Scientists at the National Aeronautics and Space Administration (NASA) and Boeing Co. developed a new aircraft wing design that could cut jet fuel consumption by an estimated 10%. In the new design, a titanium surface that contains about 19 million tiny laser-drilled holes was added to the leading surface of the wing. These holes suck in air to reduce turbulence across the wing surface. Boeing successfully flew a 757 jet with a 22-foot wing section retrofitted with the new design.[9]

Research continued on titanium aluminide (Ti_3Al) primarily for aircraft components. Texas Instruments Inc. reportedly was supplying Ti_3Al foil to several military aerospace contractors for use in jet engine parts and advanced aircraft structures, such as fuselage and wing panels. By using clad-metal rolling and bonding technology, Texas Instruments developed cold-rolling and annealing processes that make alpha-2 Ti_3Al commercially feasible. According to the company, the greatest demand for these Ti_3Al foils was in metal-matrix composite applications, but the alpha-2 material also can be used for actively cooled structures.[10]

Investigators at Southwest Research Institute demonstrated that additions of columbium to Ti_3Al act as phase stabilizers and enhance the fracture toughness of the alloys. Unalloyed, Ti_3Al is brittle, but at ambient temperature, additions of columbium increase the fracture toughness by a factor of four. Columbium also increases the resistance of Ti_3Al to crack extension, consequently propagation of cracks in the material is reduced, even at higher temperatures.

Shape-memory alloys are materials that when deformed can return to their original shape when heated. One of the commercially feasible shape-memory alloys is nickel-titanium. Joint development between Raychem Corp. and Mercedes-Benz AG led to the installation of nickel-titanium shape-memory alloy springs in engines in some Mercedes-Benz automobiles. When the engine temperature is low, the shape-memory valve spring is soft, which allows a steel spring to move a piston. At high temperatures, the shape-memory spring becomes stronger than the steel spring, pushing the piston in the opposite direction. These piston movements help to optimize shifting pressure.[11]

At the University of Tokyo, a professor developed a method to produce titanium by deoxidation. In the process, TiO_2 is melted in an argon atmosphere by high-frequency heating; it is then combined with aluminum and a small quantity of calcium fluoride. Aluminum reacts with the oxygen in the TiO_2 to produce alumina. The alumina is then absorbed by the calcium fluoride. After remelting, a titanium ingot containing less than 0.6% oxygen was produced. According to the researcher, the new process is estimated to consume less than 2,500 kilowatt-hours of electricity per ton of titanium ingot, compared with 16,000 kilowatt-hours for the present process.[12]

OUTLOOK

U.S. demand for titanium mill products in 1990 declined about 2%, despite the continued high level of orders for commercial aircraft. Industry sources indicated that some inventory buildup by customers had occurred, and the shipments in the next few years would therefore be somewhat lower than those in 1990. Defense needs, however, tend to offset effects of previous inventory building and economic slowdown. It was expected that recently completed and future planned expansions of U.S. titanium sponge capacity will provide an adequate supply of titanium for the next several years.

World TiO_2 pigment production capacity in 1990 was estimated at about 3.3 million tons per year and demand at a little less than 3 million tons. An industry forecast of annual growth in demand was lowered from 3% in 1989 to 2%, or about 60,000 tons per year, because of the effect of inventory reduction and the potential effect of higher oil prices on the world economy. Planned net annual capacity increases were about 240,000 tons in 1991 and 230,000 tons between 1992 and 1995. With these increases, it is likely that a moderate capacity surplus will exist, at least through 1995, even if some of the planned expansions are postponed or cut back.

If plans for all of the announced pro-

TABLE 22

WORLD TITANIUM RESERVES AND RESERVE BASE IN 1990

(Thousand metric tons of TiO_2 content[1])

	Reserves			Reserve base[2]		
	Ilmenite	Rutile and anatase[3]	Total	Ilmenite and perovskite[4]	Rutile and anatase[3]	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	35,000	300	35,000	106,000	1,400	108,000
South America:						
Brazil	1,600	66,000	68,000	1,600	86,000	88,000
Europe:						
Finland	1,400	—	1,400	1,400	—	1,400
Italy	—	—	—	9,000	21,000	30,000
Norway	32,000	—	32,000	90,000	—	90,000
U.S.S.R.	5,900	2,500	8,400	13,000	2,500	15,500
Total	39,000	2,500	42,000	113,000	24,000	137,000
Africa:						
Egypt	—	—	—	1,400	—	1,400
Madagascar	—	—	—	15,000	—	15,000
Mozambique	2,300	100	2,400	2,300	100	2,400
Sierra Leone	1,000	2,000	3,000	1,000	2,000	3,000
South Africa, Republic of	36,000	3,600	39,600	45,000	4,500	49,500
Total	39,000	5,700	45,000	65,000	6,600	71,000
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	65,000	5,200	70,000	77,000	5,200	82,000
Oceania:						
Australia	24,000	5,300	29,000	66,000	42,000	108,000
World total	204,000	85,000	289,000	429,000	165,000	594,000

[1]Data may not add to totals shown because of independent rounding.
[2]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).
[3]Mainly anatase in Brazil; rutile elsewhere.
[4]Ilmenite except for 9.8 million tons in Colorado perovskite.

jects for development of titanium raw materials are implemented, an additional 1.4 million tons per year or more of TiO_2 in concentrates could be produced by 1995. At the projected 60,000-ton-per-year growth rate for TiO_2 pigment demand and little if any projected growth in titanium metal demand in the next few years, the world supply of TiO_2 in concentrates should be more than adequate through 1995.

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[3]Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing. Phase 5—Energy Data and Flow Sheets, Intermediate Priority Commodities. Sept. 16, 1975, pp. 172-202, Natl. Tech. Inf. Service, Springfield, VA, PB 246-357.

[4]Federal Register. Titanium Sponge From Japan; Final Results of Antidumping Duty Administrative Review (Int. Trade Administration, Dep. Commerce). V. 55, No. 202, Oct. 18, 1990, pp. 42227-42230.

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TABLE 23

TITANIUM: WORLD PRODUCTION OF CONCENTRATES (ILMENITE, LEUCOXENE, RUTILE, AND TITANIFEROUS SLAG), BY COUNTRY[1]

(Metric tons)

Concentrate type and country	1986	1987	1988	1989[p]	1990[e]
Ilmenite and leucoxene:[2]					
Australia:					
Ilmenite	1,237,694	1,498,087	1,610,175	[r]1,696,000	[3]1,600,000
Leucoxene	14,143	11,290	11,742	[r]18,000	[3]19,000
Brazil	75,472	[r]169,627	[r]143,681	[r]146,800	150,000
China[e]	140,000	140,000	150,000	150,000	150,000
India[e]	140,000	140,000	140,000	160,000	160,000
Malaysia	414,941	509,202	486,305	[r]520,787	[3]501,585
Norway	803,622	852,322	[r]898,035	[r]929,830	900,000
Portugal	232	141	59	[r]111	45
Sierra Leone	—	5,600	42,118	62,310	[3]54,639
Sri Lanka	129,907	128,500	74,305	[e]75,000	75,000
Thailand	[r]14,295	27,078	18,254	[r]16,985	[3]10,674
U.S.S.R.[e]	450,000	455,000	460,000	460,000	430,000
United States	W	W	W	W	W
Total	[r]3,420,306	[r]3,936,847	[r]4,034,674	[r]4,235,823	4,050,943
Rutile:					
Australia	215,774	246,263	230,637	[r]243,000	[3]226,000
Brazil	495	[r]324	[r]1,514	[r]2,600	2,600
India[e]	7,000	7,000	5,000	5,000	5,000
Sierra Leone	97,100	113,300	126,358	128,340	[3]144,284
South Africa, Republic of[e]	55,000	55,000	55,000	60,000	60,000
Sri Lanka	8,443	7,200	5,255	[e]5,200	5,000
Thailand	48	92	128	([4])	—
U.S.S.R.[e]	10,000	10,000	10,000	10,000	9,500
United States	W	W	W	W	W
Total	393,860	[r]439,179	[r]433,892	[r]454,140	452,384
Titaniferous slag:					
Canada[e 5]	850,000	925,000	1,025,000	1,040,000	760,000
South Africa, Republic of[e 6]	435,000	650,000	700,000	725,000	725,000
Total	1,285,000	1,575,000	1,725,000	1,765,000	1,485,000

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."
[1]Table excludes production of unbeneficiated anatase ore in Brazil, in metric tons, as follows: 1986—2,772,082; 1987—3,344,318; 1988—3,400,000; 1989—3,500,000 (estimated); and 1990—3,500,000 (estimated). This material reportedly contains 20% TiO_2. Table contains data available through June 14, 1991.
[2]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.
[3]Reported figure.
[4]Revised to zero.
[5]Contains 80% TiO_2.
[6]Contains 85% TiO_2.

TUNGSTEN

By Gerald R. Smith

Mr. Smith, a physical scientist with 27 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 Jackson, mineral data assistant; the world production table was prepared by Virginia Woodson, international data coordinator; and the outlook data were prepared by Barry Klein, Economist.

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 are used advantageously in the production of numerous end-use items for domestic and military applications.

Total domestic consumption of tungsten in primary end-use categories increased about 6% in 1990 compared with that of 1989. Demand for products other than carbides, such as steels, superalloys, and mill products, was moderately strong and accounted for approximately 4% of the increase.

Most U.S. tungsten mines remained closed because of the persistently low prices for tungsten concentrate. Average prices for wolframite and scheelite concentrate decreased by 18% and 4%, respectively, in 1990, according to quotations published in Metal Bulletin (London).

Based on a revised assessment of military requirements, the goal for the tungsten family group in the National Defense Stockpile was raised to a level essentially equal to the present inventory in the stockpile.

A summary of the important U.S. and international statistics for 1990 and the previous 4 years are shown in table 1.

TABLE 1

SALIENT TUNGSTEN STATISTICS

(Metric tons of tungsten content unless otherwise specified)

		1986	1987	1988	1989	1990
United States:						
Concentrate:						
Mine production		780	34	W	W	W
Mine shipments		817	34	W	W	W
Value	thousands	$5,774	$216	W	W	W
Consumption		4,804	5,506	7,832	7,725	[1]5,878
Shipments from Government stocks		301	708	524	466	—
Exports		34	2	172	203	139
Imports for consumption		2,522	4,414	8,045	7,896	e6,420
Stocks, Dec. 31:						
Producer		21	21	21	10	7
Consumer		502	329	499	1,261	1,077
Ammonium paratungstate:						
Production		5,604	5,336	8,357	7,831	[1]6,142
Consumption		6,475	6,363	8,014	8,493	8,787
Stocks, Dec. 31: Producer and consumer		468	292	1,016	915	896
Primary products:						
Production		6,408	7,424	8,068	8,749	[2]4,677
Consumption		7,214	7,228	8,298	7,990	8,496
Stocks, Dec. 31:						
Producer		1,484	1,646	1,890	1,562	[3]1,459
Consumer		860	787	930	761	782
World: Concentrate:						
Production		r43,480	r42,474	r42,202	r42,099	e40,350
Consumption		44,406	r43,853	r44,565	r44,125	e40,393

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.
[1]Excludes 2 months of "withheld" data.
[2]Includes only hydrogen-reduced metal powder and chemicals.
[3]Excludes tungsten carbide-cast and crystalline.

DOMESTIC DATA COVERAGE

Domestic production data for tungsten are developed by the U.S. Bureau of Mines by means of three separate, voluntary surveys. These surveys are "Tungsten Ore and Concentrate," "Tungsten Concentrate and Tungsten Products," and "Tungsten Concentrate." Of the 51 known mining and processing operations to which survey requests were sent, 94% responded and are represented in the production totals shown in table 1.

BACKGROUND

Definitions

Tungsten, a silvery gray metal, has an atomic number of 74 and an atomic

weight of 183.92. Its most outstanding physical property is its high melting point of 3,410° C, the highest of all metals. Tungsten is one of the heaviest of elements, with a density of 19.3 grams per cubic centimeter at 20° C. It has good corrosion resistance, good thermal and electrical conductivity, and a low coefficient of expansion. At temperatures above 1,650° C, tungsten has the highest tensile strength of all metals.

Tungsten concentrate is sold in units of tungsten trioxide (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: ammonium paratungstate (APT), tungstic acid, sodium tungstate, tungsten metal powder, and tungsten carbide powder. Most of the APT is reduced to tungsten metal powder, which then is processed into tungsten carbide powder.

Tungsten alloys and tungsten mill products such as rod, wire, and sheet are produced from hydrogen-reduced tungsten metal powder. The tungsten carbide produced from powder is cemented, usually with cobalt, to form various cutting and wear-resistant tools and parts.

Tungsten chemicals (APT, tungstic acid, and sodium tungstate) are produced as coproducts at some tungsten processing plants and as primary products at others. When not processed further into metal powder, they generally are used in the chemical industry.

Products for Trade and Industry

Tungsten materials can be divided into four major classes, depending on use: (1) a carbide in cutting and wear-resistant materials and welding and hard-facing rods; (2) mill products made from essentially pure metal; (3) an alloy constituent in high-speed and tool and die steels, superalloys, and nonferrous alloys; and (4) various chemicals and compounds for nonmetallurgical applications.

The extreme hardness of tungsten carbide at temperatures exceeding 1,000° C makes it a preferred metalworking material for cutting edges of machine tools subject to intense wear or abrasion and for metal surfaces in forming and shaping dies. The mining and petroleum industries use tungsten carbide in drill bits, in the cutting edges of earth-moving equipment, and in crushing machinery. Tungsten carbide is used widely in wear parts of transportation and electrical equipment.

In most applications, tungsten carbide generally is cemented with a powdered cobalt metal binder by compaction and sintering. The cobalt content can range from about 3 to 25 weight percent, with the higher content providing greater shock resistance at a sacrifice in hardness. Tantalum and/or titanium carbides are used in conjunction with tungsten carbide in certain cutting and chipping tools. Also, coatings such as titanium carbide, titanium nitride, and aluminum oxide on tungsten carbide are used extensively to increase the life of inserts for machining applications.

Mill products made from pure or substantially pure tungsten metal powder are used in significant quantities by the electrical and electronic industries. Tungsten wire is used as the filament in electric lamps and as cathodes for electronic tubes. Disks produced from tungsten rods or sheet are used in automotive distributor points, although this end use is declining as the number of automobiles with electronic ignition systems increases. They are also used as contact points in numerous manufactured products. Tungsten metal is employed as heat and radiation shielding, as electrodes for inert-gas welding, as components of X-ray and cathode-ray tubes, and as heating elements in high-temperature resistance furnaces. Tungsten metal is used by the aerospace industry because it retains its strength at elevated temperature in reducing or inert atmospheres. The use of tungsten as a heavy metal for counterweights and balances, especially by the aircraft industry, has been replaced, to a significant extent, by depleted uranium, which approaches the density of tungsten.

Cast tungsten carbide is used principally as a hard-facing material. In this application, carbide particles are applied by a welding process to provide an abrasion-resisting surface layer on the surface to be coated. The carbide may be initially in the form of rod or loose grains in a tube.

As an alloy constituent, tungsten is used primarily in the production of high-speed steels and tool and die steels. Hardness and oxidation resistance at elevated temperatures are the most important properties possessed by these steels, which are used for machinery and equipment in the metalworking, construction, and mining industries. Certain grades of stainless and other alloy steels contain tungsten to improve wear and abrasion resistance, shock resistance, corrosion resistance, and/or strength at high temperatures.

Tungsten is an important constituent in a wide variety of superalloys and nonferrous alloys. Tungsten-containing superalloys are being utilized increasingly in high-temperature applications for their high-temperature strength and oxidation resistance. Tungsten alloyed with copper or silver is used for electrical contacts to provide wear resistance with adequate electrical conductivity.

Nonmetallurgical applications of tungsten include chemicals used in textile dyes, paints, enamels, toners, and coloring glass. Certain tungsten compounds are luminescent and used as phosphors in pigments, X-ray screens, television picture tubes, and fluorescent lighting. Sodium tungstate is employed as a corrosion inhibitor and a fireproofing agent in textiles. APT is used in making catalysts for the refining of petroleum. Among other chemical applications, tungsten compounds are used in chemical-vapor deposition, as catalysts in other chemical processing, and as laboratory reagents.

The chief nonindustrial use of tungsten is in armor-piercing ordnance, but this has been replaced, in part, by depleted uranium.

ANNUAL REVIEW

Legislation and Government Programs

The National Defense Authorization Act for Fiscal Years 1990 and 1991 included no authority for disposal of tungsten from the National Defense Stockpile during 1990. This was the first time since 1961 that no tungsten was shipped from the defense stockpile.

Goals for the tungsten family group in the National Defense Stockpile were increased based on a revised assessment of military requirements. On June 26, 1990, requirements were raised by 9,178 metric tons (20,234,000 pounds) of tungsten content and established at 32,160 metric tons (70,900,000 pounds) of tungsten content. As a result, the new goal essentially equaled the existing inventory level for the tungsten family group as shown in table 2. The preceding action was taken under authority vested in the Assistant Secretary of Defense and in compliance with the National Defense Authorization Act for Fiscal Years 1990 and 1991.

On August 3, 1990, the Environmental Protection Agency (EPA) published the final regulations under the Clean Water Act affecting nonferrous manufacturing (55 FR 31692). The regulations limited effluent discharges to waters of the United States and the introduction of pollutants into publicly owned treatment works by existing and new sources that conduct metal manufacturing operations in the metallurgical acid plants subcategory. Issued for the purposes of judicial review on August 17, 1990, the regulations became effective on September 17, 1990, and covered the secondary tungsten and cobalt subcategory along with five other subcategories. Amendments included in these final regulations were in response to settlement agreements with six petitioners, published October 30, 1989, (54 FR 45299), regarding regulations in 40 CFR 421 promulgated September 20, 1985, (50 FR 38276). The regulations for the secondary tungsten and cobalt subcategory (40 CFR 421.310-40 CFR 421.317) affected only cobalt effluents, but were directed toward processing methods integrally involved with the secondary recovery of cemented tungsten carbide components.

Regulations regarding "best available technology" and "pretreatment standards for existing sources" were to be complied with on EPA's effective date. The compliance date for "new source performance standards" and "pretreatment standards for new sources" will be the date the new source begins operation.

A bill introduced in the House of Representatives to extend the temporary suspension of duties on tungsten ore concentrates to December 31, 1993, did not proceed beyond the Committee on Ways and Means. As a result, the duty of 37.5 cents per kilogram (17 cents per pound) of tungsten content on imports from countries with most-favored-nation status was reinstated on January 1, 1991. The suspension had been in effect since October 1, 1988.

TABLE 2

U.S. GOVERNMENT TUNGSTEN STOCKPILE MATERIAL INVENTORIES AND GOALS

(Metric tons of tungsten content)

Material	Goals	Inventory by program, Dec. 31, 1990		
		National stockpile	DPA[1] inventory	Total
Tungsten concentrate:				
Stockpile grade	35,938	r24,504	72	24,576
Nonstockpile grade	—	10,055	5	10,060
Total[2]	35,938	34,559	77	34,636
Ferrotungsten:				
Stockpile grade	—	385	—	385
Nonstockpile grade	—	533	—	533
Total	—	918	—	918
Tungsten metal powder:				
Stockpile grade	726	711	—	711
Nonstockpile grade	—	150	—	150
Total	726	861	—	861
Tungsten carbide powder:				
Stockpile grade	907	871	—	871
Nonstockpile grade	—	51	—	51
Total	907	922	—	922

rRevised.
[1]Defense Production Act (DPA) of 1950.
[2]Apply the multiplication factor 0.851 to obtain the tungsten metal equivalent used in calculating the total recoverable metal in the tungsten family group.

Strategic Considerations

Tungsten is an important strategic material necessary for defense purposes. Currently, the heavy-metal alloys of tungsten, containing 3% to 10% nickel and small quantities of iron or copper, are used in several of the smaller diameter projectiles for penetrating armorplate. Cemented tungsten carbide parts, which exhibit excellent cutting and wear-resistant properties, are vital to the U.S. metalworking, machining, construction, transportation, mining, and oil and gas drilling industries. Tungsten mill products and powders are essential to the lamp and lighting industry as filaments and electrodes; to the electrical and electronic industries as wear-resistant, electrically conductive contact surfaces; and to the superalloy and steel industries as alloying components. The U.S. Department of Defense relies heavily on the maintenance of a broad domestic production base to cover mobilization contingencies. The entire tungsten industry, from mined ore to manufactured products, thus represents an important component of the U.S. defense policy. The Department of Defense continually assesses the U.S. ability to produce tungsten to ensure that this and other sources of supply are sufficient to meet current and projected levels of demand necessary to preserve the national defense. To that end, the quantity of tungsten in the National Defense Stockpile was increased to a level approximating that of the existing inventory in the stockpile.

Issues

During 1990, China continued to be the dominant supplier of tungsten products to the world market. Concentrate, APT, and ferrotungsten prices generally remained low, while market opportunities were limited by a supply-demand imbalance. Many Western World producers

believed that much of the problem rested with China's failure to place adequate controls on its production, distribution, and pricing policies. As a result of the depressed market, most tungsten mines in the United States and other Western nations remained closed or were operated at reduced capacity during the year. Also, two other mines, one in Australia and one in Brazil, were added to the list of closed mines during the year. Market conditions generally offered little or no economic incentive for producers to explore or develop other tungsten resources. One U.S. company, however, began an effort during the final quarter of the year to request U.S. Government action that would adjust the apparent inequities in the concentrate market. U.S. Tungsten Corp., a subsidiary of Strategic Metals Corp., Danbury, CT, and the operator of the Pine Creek tungsten mine and mill, Bishop, CA, initiated plans to file an antidumping suit against imports of Chinese tungsten ore concentrate.

Some indication of changes in China's tungsten production policies were reported near the end of 1990. Senior officials from China National Minerals and Metals Import and Export Corp. directed that all Government subsidies be removed from tungsten production operations effective January 1, 1991. Essentially, only economically sound operations would be able to continue under this new policy. A few industry officials viewed the Chinese action as an encouraging step toward achieving a more balanced supply-demand condition.

Production

Tungsten mining activity in 1990 was limited because prices for concentrate remained low. Recent statistics on domestic mining as well as a list of major concentrate producers and those processing the various stages of intermediate tungsten materials are shown in tables 3 and 4, respectively. Net production statistics for tungsten metal powders, carbides, and chemicals are shown in table 5.

Curtis Tungsten Inc., Upland, CA, announced a shipment of 24 metric tons of scheelite concentrate in February 1990. This was the first concentrate delivered from Curtis's Andrew tungsten mine, in the San Gabriel Mountains north of Los Angeles, since being operated intermittently during a 10-year period prior to 1985. The company reportedly was recovering its material from relatively rich

TABLE 3

TUNGSTEN CONCENTRATE SHIPPED FROM MINES IN THE UNITED STATES

Year	Quantity		Reported value, f.o.b. mine[1]		
	Metric ton units[2] of WO_3	Tungsten content (metric tons)	Total (thousands)	Average per unit of WO_3	Average per kilogram of tungsten
1986	103,053	817	5,774	56.04	7.07
1987	4,228	34	216	[3]50.34	6.35
1988	W	—	W	—	—
1989	W	—	W	—	—
1990	W	—	W	—	—

W Withheld to avoid disclosing company proprietary data.
[1]Values apply to finished concentrate and are in some instances f.o.b. custom mill.
[2]A metric ton unit equals 10 kilograms of tungsten trioxide (WO_3) and contains 7.93 kilograms of tungsten.
[3]Metals Week, U.S. spot quotations—annual average.

TABLE 4

MAJOR PRODUCERS OF TUNGSTEN CONCENTRATE AND PRINCIPAL TUNGSTEN PROCESSORS IN THE UNITED STATES IN 1990

Company	Location of mine, mill, or processing plant
Producers of tungsten concentrate:	
Curtis Tungsten Inc.	Upland, CA.
U.S. Tungsten Corp., a division of Strategic Minerals Corp.	Bishop, CA.
Processors of tungsten:	
Buffalo Tungsten Inc.	Depew, NY.
Canada Tungsten Mining Corp. Ltd.	Fort Madison, IA.
General Electric Co.	Euclid, OH.
GTE Products Corp.	Towanda, PA.
Kennametal Inc.	Latrobe, PA, and Fallon, NV.
Teledyne Firth Sterling	La Vergne, TN.
Teledyne Wah Chang Huntsville	Huntsville, AL.
U.S. Tungsten Corp., a division of Strategic Minerals Corp.	Bishop, CA.

TABLE 5

PRODUCTION, DISPOSITION, AND STOCKS OF TUNGSTEN PRODUCTS IN THE UNITED STATES IN 1990

(Metric tons of tungsten content)

	Tungsten carbide powder				
	Hydrogen-reduced metal powder	Made from metal powder	Cast and crystalline	Chemicals	Total[1]
Gross production during year	8,353	4,151	W	W	12,504
Used to make other products listed here	4,129	W	W	W	4,129
Net production	4,224	W	W	453	4,677
Producer stocks, Dec. 31	778	503	W	178	1,459

W Withheld to avoid disclosing company proprietary data.
[1]Excludes "withheld" data.

veins containing in excess of 1% WO_3. Efforts to produce additional concentrate were hampered by a severe drought that struck southern California for most of the year. Curtis reported in mid-June that it would attempt to increase its assets by entering into an agreement with Gartung Industries Inc., owner of the Strawberry tungsten mine, mill, and 90-man camp in Madera County, CA. These facilities, formerly owned by Teledyne Tungsten, a subsidiary of Teledyne Inc., were operated from July 1978 through December 1986.

U.S. Tungsten Corp., Bishop, CA, continued as the only other company producing tungsten concentrate. The Pine Creek Mine and mill again was operated on an intermittent basis at levels below capacity to provide supplemental feedstock to the company's APT conversion facility. Imported concentrate was the primary source of raw material.

Canada Tungsten Mining Corp. Ltd. suspended operations at its Fort Madison, IA, APT conversion facility at the end of March and did not produce additional APT the remainder of the year. The closure was described as an inventory control measure. The company continued during the year to supply its customers with APT and other upgraded products from its inventories.

Consumption and Uses

Total domestic consumption of tungsten in primary end-use categories (table 6) increased by about 6% in 1990 compared with that of 1989. Demand for cemented carbides in the combined cutting tool, mining tool, oil drilling equipment, and wear-resistant component industries remained strong during the year, ending with an increase of about 2% compared with that of 1989. Demand for other tungsten products, including specialty steels, superalloys, chemicals, and mill products made from metal powder, was moderately strong during the year, accounting for the remaining 4% increase in demand for tungsten products.

Strength in the cemented carbide end-use sector was due, in part, to an increase in oil drilling activity in the final months of the year. As a result of the Iraqi invasion of Kuwait and the subsequent increase in the price of crude oil, the number of operating oil rigs in the United States rose notably. Figures reported by the International Association of Drilling Contractors and Baker Hughes Inc. showed a drill rig count of 1,179 by mid-December 1990 compared with a count of 966 on August 6, immediately after the invasion.

Markets and Prices

Average prices for wolframite and scheelite concentrate decreased by 18% and 4%, respectively, in 1990, according to quotations published in Metal Bulletin (table 7). Wolframite prices generally declined as the year progressed, showing only minor recovery in the second quarter of the year. Scheelite prices were considerably more stable, but also exhibited a declining trend throughout the year.

Domestic APT prices decreased about 4% during the year from a range of $66.69 to $67.79 per mtu in January 1990 to a range of $63.93 to $65.59 per mtu by the end of December. Prices for tungsten metal powder and tungsten carbide powder remained virtually unchanged during the year, quoted at $22.00 and $21.65 per kilogram, respectively.

Wolframite and scheelite prices published by Metal Bulletin are a standard

TABLE 6

CONSUMPTION AND STOCKS OF TUNGSTEN PRODUCTS IN THE UNITED STATES IN 1990, BY END USE

(Metric tons of tungsten content)

End use	Ferrotungsten	Tungsten metal powder	Tungsten carbide powder	Scheelite (natural-synthetic)	Tungsten scrap[1]	Other tungsten materials[2]	Total[3]
Steel:							
Stainless and heat-resisting	64	—	—	W	W	W	64
Alloy	66	—	—	8	—	—	74
Tool	342	—	—	W	W	—	342
Superalloys	5	19	W	7	295	W	325
Alloys (excludes steels and superalloys):							
Cutting and wear-resistant materials	—	86	4,900	—	W	W	4,985
Other alloys[4]	W	8	1	—	W	—	9
Mill products made from metal powder	—	2,181	W	—	—	W	2,181
Chemical and ceramic uses	—	—	—	—	—	50	50
Miscellaneous and unspecified	10	([5])	53	78	167	155	464
Total[3]	488	2,294	[6]4,954	93	462	205	8,496
Consumer stocks, Dec. 31, 1990	33	20	[6]621	11	74	34	793

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1]Does not include that used in making primary tungsten products.
[2]Includes tungsten chemicals and others.
[3]Data may not add to totals shown because of independent rounding.
[4]Includes welding and hard-facing rods and materials and nonferrous alloys.
[5]Less than 1/2 unit.
[6]Based on reported consumption plus information from secondary sources on companies not canvassed; includes estimates.

TABLE 7

MONTHLY PRICE QUOTATIONS OF TUNGSTEN CONCENTRATE IN 1990

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]				International Tungsten Indicator, weighted average price,[4] 60% to 79% WO_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	Dollars per metric ton unit	Dollars per short ton unit
January	56.00	72.00	64.00	58.06	41.00	61.00	50.75	46.04	35.00	44.00	39.67	43.73	57.29	52.41
February	56.00	72.00	64.00	58.06	39.00	58.00	48.57	44.06	34.00	42.00	38.00	41.89	60.14	54.56
March	54.00	72.00	63.33	57.45	39.00	57.00	47.83	43.39	36.00	44.00	39.50	43.54	60.07	54.49
April	54.00	70.00	62.00	56.25	39.00	60.00	48.25	43.77	38.00	46.00	42.25	46.57	57.27	51.96
May	54.00	71.00	62.06	56.30	40.00	60.00	50.00	45.36	36.00	45.00	40.88	45.06	53.27	48.19
June	54.00	72.00	63.00	57.15	40.00	57.00	48.44	43.94	35.00	44.00	39.75	43.82	51.08	46.34
July	54.00	72.00	63.00	57.15	37.00	54.00	46.28	41.98	33.00	42.00	37.50	41.34	59.06	53.57
August	54.00	72.00	63.00	57.15	37.00	53.00	45.00	40.82	33.00	42.00	37.50	41.34	52.91	48.00
September	52.00	72.00	62.44	56.64	37.00	51.00	43.81	39.74	31.00	40.00	35.17	38.77	48.92	44.38
October	52.00	71.00	61.50	55.79	35.00	50.00	42.56	38.61	31.00	39.00	35.00	38.58	54.56	49.50
November	52.00	71.00	61.50	55.79	35.00	49.00	42.50	38.56	31.00	39.00	35.00	38.58	45.04	40.86
December	52.00	71.00	61.50	55.79	37.00	49.00	43.00	39.01	32.00	39.00	35.50	39.13	51.66	46.87

[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 $62.61 for 1990. The average equivalent price per short ton unit of WO_3 was $56.80 for 1990.

[2]Low and high prices are reported semiweekly. Monthly averages are arithmetic averages for 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 $46.42 for 1990. The average equivalent price per short ton unit of WO_3 was $42.11 for 1990.

[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 $37.98 for 1990. The average equivalent price per metric ton unit of WO_3 was $41.87 for 1990.

[4]Weighted average price per metric ton unit of WO_3 was $54.27 for 1990. The equivalent weighted average price per short ton unit of WO_3 was $49.23 for 1990.

for the industry. Discussions regarding the magazine's tungsten pricing methods were held at the International Tungsten Industry Association's (ITIA) Fifth International Tungsten Symposium in Budapest, Hungary, December 1990. Responses to a questionnaire on pricing, sent to many tungsten industry representatives by Metal Bulletin, served as the basis for most of the discussion. In general, most respondents felt that the published prices were a fair reflection of the market, especially over an extended period of time and given the parameters within which they were formulated. There were some broad criticisms that the prices were influenced to a large degree by merchants, in spite of the fact that only confirmed purchases by consumers are taken into account when formulating the published quotation. Confirmation of consumer transactions is carried out to the best extent possible by contacting the seller in the transaction and/or requesting copies of the sales contract. An additional broad criticism centered on the fact the published quotations did not include also the quantity of transacted material. Although this is true, Metal Bulletin does provide an indication of the quantity transacted by publishing, twice monthly, the tonnages represented in the International Tungsten Indicator price statistics. Furthermore, in situations where there is significant movement in price, there is usually an accompanying article in Metal Bulletin explaining such change that includes some information on the sales quantities involved.

On the matter of the adequacy of the concentrate specifications used to formulate the wolframite price, most respondents were satisfied with the minimum 65% WO_3 limit, but suggested that tin, arsenic, and phosphorus limits be lowered and calcium and antimony limits be added. With respect to the effectiveness with which the quotations reflect the wide range of wolframite grades transacted, most respondents were opposed to splitting the quotation into separate grades or separate origins. This would only serve to reduce further the reportable quantities used in formulating the quotations.

Little change was recommended in the manner in which the present scheelite concentrate prices were quoted. There were, however, some suggestions that the maximum molybdenum content be specified and that artificial scheelite be excluded since it is not, strictly speaking, a concentrate, but rather a chemical product.

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 8 through 16. Import tariff rates for the various materials are shown in table 17.

Total U.S. imports of tungsten materials decreased about 13% in 1990 compared with that of 1989. China continued

TABLE 8

U.S. EXPORTS OF TUNGSTEN ORE AND CONCENTRATE, BY COUNTRY

Country	1989		1990	
	Tungsten content[1] (metric tons)	Value (thousands)	Tungsten content[2] (metric tons)	Value (thousands)
Austria	42	$320	60	$334
Belgium	—	—	10	56
Canada	8	62	—	—
Germany, Federal Republic of	31	231	9	47
Hong Kong	—	—	1	6
Japan	29	221	—	—
Mexico	(3)	4	6	31
Peru	—	—	10	57
Singapore	86	648	42	234
South Africa, Republic of	(3)	4	—	—
Turkey	6	49	—	—
Total[4]	203	1,539	139	765

[1]Calculated based upon an estimated value of $60 per metric ton unit WO_3.
[2]Calculated based upon an estimated value of $44 per metric ton unit WO_3.
[3]Less than 1/2 unit.
[4]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9

U.S. EXPORTS OF AMMONIUM PARATUNGSTATE, BY COUNTRY

Country	1989		1990	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Denmark	—	—	1	$10
France	—	—	48	270
Germany, Federal Republic of	r6	$71	—	—
Hungary	r10	83	10	73
Japan	r50	376	159	1,047
Mexico	r14	121	—	—
Netherlands	r14	123	—	—
South Africa, Republic of	1	10	—	—
Sweden	r14	123	—	—
United Kingdom	r69	595	138	1,056
Total[1]	178	1,503	356	2,456

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

Source: Bureau of the Census.

to be the dominant supplier, providing about 50% of all imported tungsten materials, although its share of the import market declined by 11 percentage points from that of 1989. Restrictions on the imports of APT and tungstic acid from China continued through 1990 in accordance with the 1987 Orderly Marketing Agreement (OMA). Of the aggregate APT and tungstic acid import quota of 757.8 metric tons (1,670,687 pounds) tungsten content designated for 1990, approximately 413 metric tons (910,508 pounds) was actually imported. Concentrates, oxides, ferrotungsten, and sodium tungstate continued to represent a significantly greater post-OMA share of tungsten materials imported from China. In 1990, these four types of materials constituted about 90% of all Chinese imports, whereas in 1987 they made up only about 50% of the Chinese imports.

In view of the fact that the present OMA will expire on September 30, 1991, U.S. processors of tungsten began discussions to consider future options to this trade agreement. Among the options reportedly mentioned were an extension of the present OMA for an additional 3 years, an increase in the OMA's scope to include other upgraded tungsten products, and an initiation of other trade actions, such as dumping or countervailing suits.

World Review

Capacity.—The data in table 18 are rated capacity for mines and mills as of December 31, 1989. 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.

United Nations Conference on Trade and Development (UNCTAD).—The UNCTAD Committee on Tungsten convened its 22d session in Geneva, Switzerland, in December 1990. A Secretariat paper and national statements presented to the Sessional Working Group provided a review of current market conditions. The Secretariat presented a pessimistic outlook for the industry. The present trend of declining prices for tungsten concentrates was expected to continue into

TABLE 10

U.S. EXPORTS OF TUNGSTEN CARBIDE POWDER, BY COUNTRY

Country	1989		1990	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Argentina	(1)	$16	(1)	$9
Australia	27	576	90	570
Austria	84	1,202	52	919
Belgium	21	784	9	276
Brazil	17	530	6	178
Canada	253	4,448	221	4,134
Chile	1	29	(1)	3
China	—	—	2	59
Denmark	29	599	39	454
Finland	4	97	3	74
France	82	1,866	33	1,150
Germany, Federal Republic of	196	4,699	150	3,573
Hong Kong	2	56	1	20
India	(1)	19	(1)	6
Ireland	(1)	6	(1)	29
Israel	(1)	5	—	—
Italy	146	4,345	118	3,240
Japan	88	1,291	47	817
Korea, Republic of	8	410	1	67
Luxembourg	5	159	11	244
Malaysia	—	—	(1)	3
Mexico	34	626	22	768
Netherlands	32	889	18	707
Singapore	(1)	12	2	86
South Africa, Republic of	45	573	—	—
Spain	(1)	10	50	772
Sweden	80	1,101	75	1,197
Switzerland	29	621	49	1,071
Taiwan	5	116	5	116
United Kingdom	169	2,087	67	1,295
Venezuela	(1)	4	1	39
Other	3	33	2	69
Total[2]	1,360	27,209	1,074	21,946

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

1991, given the persistent oversupply of material and the weakening demand due to the slowdown in the world economy. The chairman of the session indicated that longer term prospects for the tungsten economy will be influenced by developments in Eastern Europe and Asia as well as by disarmament decisions and environmental considerations. The invasion of Kuwait by Iraq in August 1990 contributed to some uncertainty in the future defense-related demand for tungsten.

Comments from delegates at the meeting indicated that the low prices and large overhang of stocks had led not only to extensive mine closures but also to price-cutting competition among suppliers, especially for concentrates and intermediate materials. In addition, it had led to increased protectionism as evidenced by the recent trade actions against China. Moreover, low price levels had led to the termination of certain bilateral trading arrangements between major consumers and the major producer, but the effects of such changes on the tungsten market remained unclear.

The delegation from China noted that the main cause for the deterioration in the tungsten market since August 1989 was not the increase in world production, but rather the stagnation or steady decline in the domestic demand of the major consumers. They indicated that world tungsten output had not increased substantially, as had been alleged, and that the report of a rise in China's output, specifically, also was incorrect. They explained that the declining activity in the automobile, steel, machine building, and construction industries of the major consuming countries; new technological developments; increased recovery of scrap tungsten; and the growth of substitutes had all contributed to a steady decrease in demand. After stating that they had made efforts to improve the health of the tungsten market, the Chinese proposed that the appropriate form of action by the Committee on Tungsten was one directed toward reaching an agreement among the producers and consumers on measures to stabilize the tungsten market.

The Committee on Tungsten agreed to seek designation as an International Commodity Body (ICB) for the purpose of obtaining access to the account for developmental activities within the Common Fund for Commodities under UNCTAD. A separate item was added to the provisional agenda of the 1991 meeting for the purpose of considering project proposals by Governments and industry that could then be submitted for possible financing under this account. The decision to seek designation as an ICB was based on a proposal made by the delegation from Brazil at the 1989 meeting.

European Community (EC).—Subsequent to its investigation into complaints that China was dumping tungsten materials into the EC, the EC Commission's Council of Ministers reached a final

TABLE 11

U.S. EXPORTS OF TUNGSTEN AND TUNGSTEN ALLOY POWDER, BY COUNTRY

Country	1989			1990		
	Gross weight (metric tons)	Tungsten content[1] (metric tons)	Value (thousands)	Gross weight (metric tons)	Tungsten content[1] (metric tons)	Value (thousands)
Australia	35	28	$477	8	7	$124
Austria	85	68	923	48	39	762
Belgium	1	1	18	2	2	87
Brazil	7	6	210	7	5	192
Canada	36	29	790	50	40	1,580
Denmark	1	1	43	—	—	—
Finland	16	13	314	3	3	75
France	15	12	436	6	4	171
Germany, Federal Republic of	135	108	3,214	209	167	5,468
Hong Kong	—	—	—	3	2	23
India	9	7	153	20	16	284
Israel	103	82	1,214	132	105	1,125
Italy	4	3	117	15	12	716
Japan	28	22	695	21	17	531
Korea, Republic of	(2)	(2)	9	1	1	41
Mexico	7	6	173	5	4	162
Netherlands	365	292	4,470	544	435	4,757
Pakistan	(2)	(2)	8	45	36	669
Singapore	20	16	302	1	1	37
South Africa, Republic of	2	1	53	2	2	50
Spain	—	—	—	2	1	50
Sweden	19	15	153	4	3	21
Switzerland	7	6	234	6	5	334
Taiwan	21	17	538	16	13	415
Turkey	2	1	42	2	2	54
United Kingdom	32	26	865	82	66	832
Other	4	2	103	1	(2)	27
Total	954	762	15,554	1,235	988	18,587

[1]Tungsten content estimated by multiplying gross weight by 0.80.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 12

U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Country	1989		1990	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Tungsten and tungsten alloy wire:				
Argentina	(1)	$8	(1)	$12
Belgium	(1)	23	(1)	10
Brazil	4	293	7	486
Canada	9	953	21	1,701
Colombia	(1)	29	—	—

See footnotes at end of table.

TABLE 12—Continued

U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Country	1989		1990	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Tungsten and tungsten alloy wire—Continued				
Costa Rica	(1)	$27	—	—
France	3	249	3	$300
Germany, Federal Republic of	1	316	1	400
Hong Kong	1	63	1	107
India	19	1,158	21	1,270
Italy	7	622	7	706
Japan	10	954	10	1,217
Korea, Republic of	6	589	2	228
Mexico	9	810	4	431
Netherlands	1	127	1	211
Poland	(1)	24	1	57
Switzerland	(1)	38	(1)	71
Taiwan	12	797	5	435
United Kingdom	6	849	1	240
Venezuela	2	474	(1)	5
Other	4	246	5	380
Total	94	8,649	90	8,267
Unwrought tungsten and alloy in crude form, waste, and scrap:				
Australia	3	81	4	67
Austria	(1)	3	9	222
Belgium	—	—	1	36
Canada	30	602	7	184
Chile	7	211	4	112
France	(1)	2	(1)	3
Germany, Federal Republic of	406	8,377	250	4,893
Israel	29	684	34	805
Japan	(1)	16	16	206
Korea, Republic of	1	43	2	91
Sweden	11	122	33	464
Taiwan	12	269	8	205
United Kingdom	12	286	26	401
Other	16	277	24	519
Total	527	10,973	418	8,208
Other tungsten metal:				
Australia	8	217	6	330
Austria	(1)	3	5	247
Belgium	—	—	(1)	10
Brazil	8	631	2	161
Canada	46	2,371	20	1,103
Colombia	(1)	15	—	—
France	9	341	2	139
Germany, Federal Republic of	25	1,056	20	984
Hong Kong	1	81	(1)	29
India	2	99	3	182

See footnotes at end of table.

TABLE 12—Continued

U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Country	1989		1990	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Other tungsten metal—Continued				
Ireland	32	$4,124	38	$5,699
Italy	5	411	8	675
Japan	40	4,081	50	5,077
Korea, Republic of	3	358	11	744
Mexico	10	630	4	426
Netherlands	1	174	1	117
Singapore	2	122	2	141
South Africa, Republic of	1	40	1	60
Spain	2	94	3	214
Sweden	2	161	1	138
Switzerland	9	97	(1)	39
Taiwan	3	219	6	519
Thailand	1	68	1	89
United Kingdom	9	792	42	2,078
Venezuela	(1)	4	1	70
Other	11	408	15	483
Total[2]	230	16,597	242	19,753
Ferrotungsten and ferrosilicon tungsten:				
Canada	—	—	2	25
Indonesia	—	—	4	14
Mexico	33	81	17	45
Venezuela	—	—	2	14
Total	33	81	25	98
Other tungsten compounds:[3]				
Belgium	—	—	(1)	4
Canada	—	—	1	7
France	—	—	1	15
Germany, Federal Republic of	3	15	2	29
Mexico	(1)	3	(1)	3
Singapore	(1)	20	(1)	181
United Kingdom	9	29	15	118
Total[2]	12	67	20	357

[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.

decision on September 24, 1990, on the question of permanent imposition of tariffs on certain tungsten imports from China. In that decision, imports of concentrate, tungstic acid and oxide, and tungsten carbide powder and fused tungsten carbide were made subject to duties of 42.4%, 35%, and 33%, respectively. The duties applied to all exporters to the EC with the exception of China National Nonferrous Metals Import and Export Corp. and China National Minerals and Metals Import and Export Corp. Rather than being subject to the imposed duties, the latter exporters were required to comply with certain undisclosed minimum price standards for their products. According to the Official Journal of the EC, the price standards will have the effect of "increasing the prices of the products concerned, to remove the injury caused to the EC industry. The definitive duties, while substantially lower than the dumping margin, correspond to the minimum price required to ensure that the EC producers receive an adequate return on sales in the case of the concentrates and,

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF TUNGSTEN ORE AND CONCENTRATE, BY COUNTRY

Country	1989		1990	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Austria	47	$346	—	—
Australia	138	1,027	11	$32
Bolivia	753	4,515	1,061	4,613
Burma	29	182	31	148
Canada	—	—	106	1,112
China	5,484	29,573	3,964	18,847
Germany, Federal Republic of	—	—	12	52
Hong Kong	169	1,144	44	284
Japan	32	172	—	—
Mexico	113	834	136	634
Netherlands	—	—	29	138
Peru	666	4,006	744	3,800
Portugal	333	2,580	120	691
Rwanda	—	—	162	950
Sweden	2	5	—	—
Switzerland	11	67	—	—
Thailand	88	476	—	—
Turkey	31	150	—	—
Total	7,896	45,077	6,420	31,301

Source: Bureau of the Census.

TABLE 14

U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM TUNGSTATE, BY COUNTRY

Country	1989		1990	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
China	310	$3,517	413	$3,011
Germany, Federal Republic of	27	388	49	452
Taiwan	30	224	—	—
United Kingdom	64	431	—	—
Total	431	4,560	462	3,463

Source: Bureau of the Census.

in the case of the other products, to remove the injury caused to the EC industry." The provisional duties imposed during the 6 months prior to the final decision were collected at the final duty rates.

International Tungsten Industry Association (ITIA).—The ITIA held its Fifth International Tungsten Symposium in Budapest, Hungary, October 14–18, 1990. At this meeting, 24 papers were presented by speakers from 10 separate nations. Subjects covered included tungsten supply-demand and price trends, pricing methods and specifications, tungsten mine production status in several countries, recent technological advancements in the production of specific

TABLE 15

U.S. IMPORTS FOR CONSUMPTION OF FERROTUNGSTEN, BY COUNTRY

Country	1989		1990	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Australia	—	—	13	$90
Belgium	—	—	9	51
China	359	$1,982	455	2,455
Germany, Federal Republic of	1	4	1	5
Hong Kong	—	—	13	74
United Kingdom	—	—	2	63
Total[1]	360	1,986	493	2,739

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

Source: Bureau of the Census.

TABLE 16

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1989		1990	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Waste and scrap:				
Australia	5	$21	13	$43
Austria	5	37	—	—
Belgium	8	35	—	—
Canada	52	594	30	308
China	192	1,790	99	697
France	—	—	7	29
Germany, Federal Republic of	32	210	15	422
Hong Kong	6	60	1	10
Hungary	5	36	—	—
Israel	114	653	180	1,039
Italy	—	—	8	17
Japan	178	1,085	253	1,205
Korea, Republic of	111	648	25	92
Mexico	10	90	8	73
Netherlands	248	2,216	311	2,585
Singapore	10	102	45	281
South Africa, Republic of	24	143	47	259
Sweden	7	62	7	13
Switzerland	—	—	4	4
United Kingdom	207	1,152	27	304
Other	15	104	—	—
Total	1,229	9,038	1,080	7,381
Unwrought tungsten, except alloys, in lump, grains, and powders:				
Belgium	3	97	5	191

See footnotes at end of table.

TABLE 16—Continued

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1989		1990	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Unwrought tungsten, except alloys, in lump, grains, and powders—Continued				
Canada	8	$190	11	$368
China	—	—	5	117
Germany, Federal Republic of	32	713	25	759
Japan	4	95	10	323
Luxembourg	(1)	4	—	—
Mexico	(1)	3	—	—
Netherlands	—	—	25	194
Sweden	—	—	17	654
Thailand	—	—	14	65
United Kingdom	37	371	58	658
Other	24	174	(1)	9
Total	108	1,647	170	3,338
Unwrought tungsten—ingots, shot, alloys and other:				
Austria	4	134	4	177
Canada	(1)	10	—	—
China	5	95	7	152
Germany, Federal Republic of	1	66	—	—
Other	(1)	27	1	33
Total	[2]11	332	12	362
Wrought tungsten—wire, plate, sheet, strip, foil, and other:[3]				
Austria	17	2,166	15	2,089
Belgium	7	506	3	376
China	(1)	5	(1)	16
France	1	105	(1)	10
Japan	132	13,840	25	4,793
Korea, Republic of	(1)	8	(1)	2
Netherlands	3	315	2	330
United Kingdom	1	45	5	181
Other	4	902	2	498
Total	165	17,892	52	8,295
Tungstic acid: China	68	615	—	—
Calcium tungstate: Germany, Federal Republic of	4	177	4	163
Sodium tungstate:				
China	328	2,139	122	733
Germany, Federal Republic of	(1)	2	(1)	8
Hong Kong	178	1,375	73	476
Japan	4	137	(1)	5
Total	510	3,653	195	1,222
Tungsten carbide:				
Austria	1	8	(1)	1
Canada	47	1,027	22	256
China	44	783	26	484

See footnotes at end of table.

TABLE 16—Continued

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1989		1990	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Tungsten carbide—Continued				
Germany, Federal Republic of	420	$7,602	519	$8,987
Japan	9	36	3	125
Korea, Republic of	38	666	38	642
Luxembourg	29	1,004	24	1,031
Sweden	—	—	26	1,014
United Kingdom	25	518	23	360
Other	24	431	(1)	17
Total	637	12,075	681	12,917
Other tungsten compounds:[4]				
China	r280	3,283	341	2,895
Germany, Federal Republic of	(1)	8	2	19
Japan	(1)	1	—	—
United Kingdom	2	22	(1)	2
Other	—	—	—	—
Total	r282	3,314	343	2,916
Mixtures, organic compounds, chief value in tungsten: Other	(1)	8	—	—

rRevised.
[1]Less than 1/2 unit.
[2]Data do not add to total shown because of independent rounding.
[3]Estimated from reported gross weight.
[4]Includes oxides.

Source: Bureau of the Census.

tungsten end-use items, and environmental issues associated with tungsten processing methods.

Australia.—The Dolphin scheelite mine on King Island, Tasmania, Australia, was offered for sale in August by North Broken Hill Ltd. Company officials stated that continuing depressed tungsten prices and a declining market for the company's gravity-separation grade concentrate were primary reasons for the offer to sell. Although interest in purchasing the mine was shown by at least four investors, the company was unable to attract an immediate buyer. As a result, the mine was closed at the end of November 1990. The King Island closing left the Kara Mine, Tasmania, Australia, as the only operating tungsten mine in Australia. Annual production of tungsten concentrate in Australia was expected to be reduced by about 80%.

Brazil.—Tungsten concentrate production was reduced by about 40% in 1990 compared with that of 1989 as a result of the closure of the Boca de Lage Mine, Currais Novos, Rio Grande do Norte Province. Tungstenio de Brasil Mineirios e Metais Ltd., the operator of the mine, stopped production after its parent company, Anglo American Corp., failed to renew its contract with the present owner. This closure will drop the country's concentrate production level significantly below its estimated consumption level of 670 metric tons of tungsten content per year. Annual concentrate production and consumption statistics for the world are shown in tables 19 and 20, respectively.

A tungsten concentrate upgrading plant was constructed in conjunction with tungsten mining operations near Currais Novos, Rio Grande do Norte. Operation began in late 1990 and was expected to produce 240 and 120 metric tons per year of ferrotungsten and tungsten carbide, respectively. Mineracao Tomas Salustino S.A., owner and operator of the nearby Brejui tungsten mine, holds a partial ownership in this facility.

China.—In addition to the administrative actions to halt Government subsidies to tungsten operations, certain other moves reportedly were initiated near the end of 1990 to gain more control over tungsten sales, exports, and price structure. The moves included terminating the pricing procedure that fixed sales transactions, in many instances, more than 3

TABLE 17

U.S. IMPORT DUTIES ON TUNGSTEN

HTS No.	Item	Rate of duty effective Jan. 1, 1990	
		Most favored nation (MFN)	Non-MFN
2611.00.0000	Tungsten ores and concentrates	$0.37 per kilogram on tungsten content[1]	$1.10 per kilogram on tungsten content.
2825.90.3000	Tungsten oxides	10% ad valorem	45.5% ad valorem.
2825.90.6Q10	Tungstic acid	3.7% ad valorem	25% ad valorem.
2827.39.4000	Chlorides of tungsten	10% ad valorem	45.5% ad valorem.
2841.80.0010	Ammonium tungstates	10% ad valorem	49.5% ad valorem.
2841.80.0020	Calcium tungstate	10% ad valorem	49.5% ad valorem.
2841.80.0050	Other tungstates	10% ad valorem	49.5% ad valorem.
2849.90.3000	Tungsten carbide	10.5%; ad valorem	55.5% ad valorem.
2850.00.1000	Other tungsten compounds	10% ad valorem	45.5% ad valorem.
3823.90.3500	Mixtures of inorganic compounds, chief value tungsten	10% ad valorem	45.5% ad valorem.
7202.80.0000	Ferrotungsten and ferrosilicon tungsten	5.6% ad valorem	35% ad valorem.
8101.10.0000	Tungsten powders	10.5% ad valorem	58% ad valorem.
8101.91.1000	Tungsten waste and scrap	4.2% ad valorem	50% ad valorem.
8101.91.5000	Unwrought tungsten	6.6% ad valorem	60% ad valorem.
8101.92.0000	Wrought tungsten—bar, rod, sheet, etc.	6.5% ad valorem	60% ad valorem.
8101.93.0000	Wrought tungsten—wire	6.5% ad valorem	60% ad valorem.
8101.99.0000	Wrought tungsten—other	5.5% ad valorem	45% ad valorem.

[1]Temporarily suspended through Dec. 31, 1990.

months in advance to one that offered the material on a short-term, spot market basis, generally of 1 to 3 months. Steps were also taken to reduce tungsten concentrate production by 30% to decrease global stocks and strengthen market prices.

India.—Sterling Tungsten, a subsidiary of Sterling Computers, began construction of India's first tungsten metal powder production plant in early 1990. The company is collaborating with Lucky Goldstar International, Republic of South Korea, on the technical aspects of construction and operation. India's State-owned Tamil Nadu Industrial Development Corp. holds a 26% interest, and Sterling, 25%. The remainder will be publicly owned. Production is projected to begin by mid-1991 at this Madras, India, facility.

Japan.—Tokyo Tungsten Co. Ltd. reportedly began a significant expansion project at its Toyana tungsten powder production facility near Tokyo. The project is expected to increase the metal powder output of the plant from the present 840 metric tons per year to 1,200 metric tons per year.

Mongolia.—According to published reports, the trial operations that began at the Tsagaan Davaa tungsten mine in September 1988 were discontinued in early 1990. The mining facility, a joint venture between Mongolia and several Hungarian interests, apparently was unable to be operated economically. At full capacity, the operation was expected to treat 36,000 metric tons of ore annually.

Peru.—Production of tungsten concentrate by Minera Regina at its scheelite and ferberite mine southeast of Lima was increased appreciably in 1990 in spite of the generally depressed tungsten prices. According to a company representative, in addition to the increased production, the company had achieved greater processing efficiency and had improved the quality of its product, although only minimal profit had been achieved at the low 1990 price levels. Total Peruvian production in 1990, of which Minera Regina accounted for 70%, was about 1,200 metric tons tungsten content. Minera Regina's production was increased by approximately 30% compared with that of 1989.

Portugal.—In mid-October 1990, Charter Consolidated Ltd., London, completed the sale of its 75% interest in Portugal's Beralt Tin and Wolfram Ltd., which, through its Portuguese subsidiary, owns 80.55% of the Panasqueira Tungsten Mine near Fundao, Portugal. The purchaser, Minorco SA, an affiliate of Charter Consolidated, has other significant mining interests and additional Portuguese investments. Minorco's plans for the mine were not revealed.

Current Research

Several advancements in tungsten carbide (WC) technology were reported during 1990. Tungsten carbide spray coatings of improved quality were produced with a Super-D-Gun, developed by Union Carbide Coatings Service Corp., which produces higher supersonic speeds than the original D-Gun.[1] A mixture of oxygen and acetylene explodes in the presence of the coating powder in a detonation chamber. The expanding gases reach a temperature of about 4,000° C and accelerate the coating powders to supersonic speeds, thereby improving the bond strength, density, and

TABLE 18

WORLD TUNGSTEN ANNUAL MINE PRODUCTION CAPACITY, DECEMBER 31, 1990

(Metric tons tungsten content)

	Rated capacity[1]
North America:	
Canada	3,000
Mexico	300
United States	3,700
Total	7,000
South America:	
Argentina	40
Bolivia	1,300
Brazil	500
Peru	1,200
Total	3,040
Europe:	
Austria	1,300
Czechoslovakia	50
Portugal	1,400
Spain	100
Sweden	350
U.S.S.R.	9,200
Total	12,400
Africa:	
Rwanda	150
Uganda	10
Zaire	30
Zimbabwe	30
Total	220
Asia:	
Burma	500
China	21,000
India	20
Japan	300
Korea, North	1,000
Korea, Republic of	1,500
Malaysia	10
Mongolia	500
Thailand	500
Turkey	200
Total	25,530
Oceania:	
Australia	2,250
New Zealand	10
Total	2,260
World total	50,450

[1]Includes capacity at operating mines as well as mines on standby basis.

TABLE 19

TUNGSTEN: WORLD CONCENTRATE PRODUCTION, BY COUNTRY[1]

(Metric tons of tungsten content)

Country	1986	1987	1988	1989	1990[e]
Argentina	20	r14	r13	20	16
Australia	1,600	1,150	r1,616	r1,371	900
Austria	1,387	1,250	1,235	e1,245	1,250
Bolivia	1,095	638	900	r1,118	1,200
Brazil	875	r800	r738	r679	2422
Burma	715	493	307	e300	300
Canada	1,959	—	—	—	—
China[e]	15,000	21,000	21,000	21,000	21,000
Czechoslovakia[e]	50	45	50	50	50
France	987	—	—	—	—
India	23	26	r19	r12	13
Japan	579	259	266	r296	250
Korea, North[e]	1,000	500	500	500	1,000
Korea, Republic of	2,455	2,375	2,029	r1,701	21,255
Malaysia	4	—	—	—	—
Mexico	294	213	206	r170	200
Mongolia[e]	1,500	1,500	r1,000	r1,000	500
New Zealand[e]	(2 3)	5	5	5	—
Peru	742	r205	r432	r961	1,200
Portugal	r1,637	1,207	1,382	r1,381	1,405
Rwanda	13	r11	r3	r105	100
Spain	495	81	80	r81	80
Sweden	357	r574	r420	r80	—
Thailand	475	705	651	r603	290
Turkey	r206	r163	r125	re100	100
Uganda[e]	4	4	4	4	4
U.S.S.R.[e]	9,200	9,200	9,200	9,300	8,800
United States	780	34	W	W	W
Zaire	27	21	20	r16	14
Zimbabwe[e]	1	1	1	1	1
Total	r43,480	r42,474	r42,202	r42,099	40,350

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."
[1]Table includes data available through May 8, 1991.
[2]Reported figure.
[3]Less than 1/2 unit.

surface quality of the coating. This wear-resistant coating exhibits compressive residual stress that also improves the fatigue resistance of the coating on substrates such as 4130 steel, 7075 Al, and Ti-6Al-4V.

Either chemical compounds or amorphous mixtures containing tungsten and cobalt were reacted in a gas mixture of controlled carbon concentration to produce a nanophase (ultrafine) WC-cobalt (Co) composite powder.[2] Nanophase WC-23Co powder, after consolidation and formation of a wear-resistant coating by low-pressure plasma (ionized gas) spraying, exhibited good wear resistance and a lower coefficient of friction than conventional WC-Co coatings.

Alloys of WC-6.3Co and WC-6.15Ni implanted with chromium, molybdenum, and titanium ions exhibited lower overall corrosion rates and improved resistance to excessive localized corrosion in accelerated electrochemical corrosion

TABLE 20

TUNGSTEN: WORLD CONCENTRATE CONSUMPTION, BY COUNTRY[1]

(Metric tons of tungsten content)

Country[2]	1986	1987	1988	1989	1990[e]
Argentina	25	65	[e]30	[r]38	30
Australia	94	[e]200	[e]120	[e]130	100
Austria[e]	2,000	2,000	2,100	1,800	1,800
Belgium-Luxembourg	30	[e]50	[e]50	[r]2	—
Brazil	672	867	753	[e]688	670
Bulgaria[e]	100	100	100	100	100
Canada[2]	12	10	10	10	10
China[2 3]	[r]8,500	[r]9,000	[r]9,000	[r]9,000	11,000
Czechoslovakia[e]	1,300	1,300	1,300	1,300	1,300
France	667	269	34	—	—
Germany, Federal Republic of:					
Western states[4]	1,720	1,863	2,144	[r]2,576	500
Eastern states[e]	300	300	300	300	300
Hungary[e]	400	400	500	500	400
India	230	[e]250	[r]87	[r]200	200
Italy[4]	80	86	[r]20	[r]—	—
Japan	2,145	[r]2,119	1,980	1,578	1,500
Korea, North[e]	800	500	500	500	500
Korea, Republic of	1,987	1,950	1,580	[r]2,000	2,000
Mexico	42	64	9	[e]5	5
Netherlands[e]	350	300	330	350	300
Poland[4]	1,264	744	424	[r]—	—
Portugal	40	20	—	—	—
South Africa, Republic of	250	[r]203	[r]242	[r]173	200
Spain[4]	159	[re]20	[re]20	—	—
Sweden	855	567	550	[re]600	550
U.S.S.R.[e]	[r]15,000	[r]15,000	[r]14,500	[r]14,500	13,000
United Kingdom[e]	580	[r]100	[r]50	[r]50	50
United States	4,804	5,506	7,832	7,725	[5]5,878
Total	44,406	[r]43,853	[r]44,565	[r]44,125	40,393

[e]Estimated. [r]Revised.
[1]Source, unless otherwise specified, is Tungsten Statistics, 1989 and 1990, Annual Bulletin of the UNCTAD Committee on Tungsten.
[2]Estimated by the U.S. Bureau of Mines.
[3]Combined internal consumption plus that which was processed to intermediate products and subsequently exported.
[4]Apparent consumption, production plus imports minus exports.
[5]Reported figure; excludes 2 months of "withheld" data.

tests using dilute sulfuric acid and dilute sodium chloride-sodium sulfate solutions.[3] The most promising results were obtained with implanted molybdenum ions.

Composites of Fe-5WC and Fe-20WC exhibiting excellent wear resistance were prepared using hot isostatic pressing (HIP) methods.[4] Dense, pore-free composites were obtained by minimizing the reaction between the iron matrix and the WC particles at pressures from 50 to 200 mega Pascals and a temperature of 800° C. Wear resistance of the composite increased as the HIP pressure was increased.

The wear resistance of plasma-sprayed WC-Co coatings was improved by infiltration with copper alloys.[5] One such alloy consisting of copper, nickel, and phosphorus served as an excellent infiltrant. Hardness of the infiltrated coatings compared favorably with that of conventional cemented WC-Co material.

OUTLOOK

Total apparent consumption of tungsten was correlated with three economic indicators to provide a basis for a statistical projection of tungsten demand through 1995.

Correlation was poor between the consumption data and the Federal Reserve Board (FRB) indexes of Industrial Production-Total and Industrial Production-Metalworking Machinery. Correlation was fair between the consumption data and the FRB index of Industrial Production-Construction and Allied Equipment. On the basis of this indicator, total apparent consumption of tungsten in 1995 was estimated to be about 12,150 metric tons. This corresponds to an average increase of about 2.5% per year over the 1989 level of 10,475 metric tons. Reports by industry spokesmen and studies revealed by independent market analysts apparently share the view that a 3% to 4% average annual increase in total tungsten demand is realistic for the short term. There is expected to be somewhat higher demand for metal powder in the short term due to the anticipated growth in the powder metallurgy market. Demand for tungsten carbide powder, on the other hand, is not expected to increase as rapidly. Growth in the demand for this material will continue to be tempered, particularly in the cemented carbide tool industry, by further competition from substitute materials, including ceramics, ceramic composites, polycrystalline diamond, and cubic boron nitride. Further slowing the rate of demand for these cemented carbide products will be the increased use of ceramic coatings to extend the life of the carbide. In addition, increases in the production of near-net-shape products by techniques such as precision casting, rolling and forging, and powder metallurgy will lessen machining requirements.

Information reported by manufacturers of machine tool equipment indicated that demand for these items could be down as much as 8% in 1991 compared with that of 1990. Such a decline in business activity would likely have a temporary effect on the demand for the cemented carbide tools and cutting inserts

associated with the operation of this machining equipment. A rebound in the demand for machine tool equipment will be expected in 1992. Machine tool requirements in the automotive and aerospace sectors are expected to increase as the economy begins to strengthen in many industrialized countries. Furthermore, solid growth potential reportedly exists in reindustrialized Eastern Europe as well as the United States, where energy exploration and conservation approaches will require new tooling equipment.

Supplies of tungsten concentrate and intermediate materials for U.S. consumption are expected to be sufficient in spite of the continued lack of production at domestic mines in recent years. Actions initiated by the Chinese Government in late 1990 to gain further control over tungsten production, distribution, and pricing will very likely alter the sources of new tungsten supply if implemented for an extended period of time.

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VANADIUM

By Henry E. Hilliard

Mr. Hilliard, a physical scientist with more than 20 years U.S. Bureau of Mines experience, has been the commodity specialist for vanadium since 1986. Domestic survey data were prepared by Lisa Harley, mineral data assistant; international data tables were prepared by William L. Zajac, Chief, International Data Section.

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, 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 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 vanadium that are consistent with international usage, will henceforth report data in kilograms (kg) and metric tons unless otherwise stated.

The year 1990 was a good but not great year for the U.S. vanadium industry, as the data tabulated on the following pages of this report demonstrate. Demand and production were relatively strong when the year began. However, the industry experienced a sharp decrease in production at yearend as demand for vanadium products in many of the major markets weakened appreciably.

Overall, shipments of vanadium products in 1990 were essentially unchanged from 1989 shipments. Production was down by about 20% as some producers shipped from stocks. For the big-volume ferrovanadium (FeV), which is the core of the industry, shipments were down by about 12%. Consumption of FeV in the production of HSLA steel was down by more than 8%, and consumption for full alloy steel decreased by about 9%. Vanadium chemicals reported an increase in shipments for the year.

TABLE 1

SALIENT VANADIUM STATISTICS

(Metric tons of contained vanadium unless otherwise specified)

		1986	1987	1988	1989[p]	1990[e]
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]		2,114	2,275	2,950	2,389	2,308
Consumption		3,908	4,221	4,834	[r]4,646	4,098
Exports:						
Ferrovanadium (gross weight)		465	396	571	493	334
Oxides and hydroxides[4]		—	—	—	1,080	976
Vanadium pentoxide anhydride		1,401	1,311	1,107	2,105	1,461
Other compounds (gross weight)		311	435	887	1,550	1,853
Imports (general):						
Ferrovanadium (gross weight)		678	383	134	650	323
Ore, slag, ash, and residues		1,826	2,054	3,616	3,161	5,123
Vanadium pentoxide, anhydride		402	324	382	133	83
World: Production from ore, concentrate, slag[5]		[r]29,461	[r]28,356	[r]30,480	30,600	31,000

[e]Estimated. [p]Preliminary. [r]Revised. 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; includes metavanadates.

[3]Includes vanadium recovered from fly ash, and spent catalysts.

[4]May include ores and concentrates.

[5]Excludes U.S. 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 1990, there were 83 responses to the consumption survey, representing 81% of the total canvassed. These 83 respondents are estimated to have consumed 95% of total domestic consumption, or about 3,893 metric tons. The estimated consumption of nonrespondents, derived using their past consumption relationships, trends, and data from nonsurvey sources, was about 205 tons. The consumption quantity of 4,098 tons shown in table 1 is the U.S. Bureau of Mines' estimate of total U.S. 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 one-half of the titanium-base alloy market.

Products for Trade and Industry

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.

About 85% of all vanadium consumed is accounted for by use in the steel industry as an alloying agent. Another 10% is used in aerospace titanium alloys, with the remainder for chemical and catalyst preparations. Vanadium is an essential but not totally indispensable alloying metal. Often the addition of small amounts can provide considerable improvement in performance without further processing or a significant increase in cost over standard grades. The small amounts of vanadium combine with carbon or nitrogen or both and precipitate, causing an increase in strength and toughness. In addition, vanadium provides such added benefits as better weldability and heat resistance.

An increasing amount of vanadium has been used in the production of HSLA steels to provide yield points between 36 and 47 kilograms per square millimeter. The addition of small amounts of vanadium, often less than 0.1 weight-percent, to an ordinary carbon steel can significantly increase its strength and improve both its toughness and ductility. HSLA steels with high yield points are attractive for structures such as automobiles, bridges, high-rise buildings, and pipelines where advantage can be taken of the savings in weight produced by the high yield points. Vanadium is also used extensively to provide elevated temperature strength to certain aerospace titanium alloys, the most common of which is an alloy containing 6 weight-percent aluminum and 4 weight-percent vanadium. This alloy is widely used for aircraft engine casings and fans and accounts for about 10% of U.S. vanadium use. Oxides and chlorides of vanadium play important roles as catalysts in the production of sulfuric acid, maleic anhydride, synthetic rubber, and other key intermediate organic chemicals.

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 vanadium oxides to the many small consuming countries. These converters also compete for the major markets for pentoxide exported to Japan and the Republic of Korea. Trade in ferrovanadium is dominated by the major European exporters. 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_0). The principal sources of the magnetite ore were China, the Republic of South Africa, and the U.S.S.R. World vanadium production for 1986-90 is shown in table 17. The other 17% of the vanadium was recovered from 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.

In order to have an easily marketable product, it is customary at this point to either convert the oxides into an alloy or upgrade their purity to greater than 98.5 weight-percent. The two traditional alloy products have been the 80 weight-percent ferrovanadium and 35 weight-percent aluminum-vanadium master alloy. Variations of five different reduction processes are currently in use throughout the world, with aluminum, carbon, or silicon serving as the reductant. These conversion and upgrading plants, which form the fourth tier of the structure, may be located a considerable distance from the mills and

TABLE 2

CHEMICAL SPECIFICATIONS FOR COMMERCIAL FORMS OF FERROVANADIUM

Alloy	Composition, weight-percent							
	Vanadium	Carbon	Nitrogen	Aluminum	Silicon	Phosphorus	Sulfur	Manganese
50 to 60% Ferrovanadium	50-60	0.2 maximum	—	2.0 maximum	1.0 maximum	0.05 maximum	0.05 maximum	—
70 to 80% Ferrovanadium	70-80	—	—	1.0 maximum	2.5 maximum	0.05 maximum	0.10 maximum	—
80% Ferrovanadium	77-83	0.5 maximum	—	0.5 maximum	1.25 maximum	0.05 maximum	0.05 maximum	0.50 maximum
Proprietary alloys:								
Carvan (Stratcor)	82-86	10.5-14.5	—	0.1 maximum	0.10 maximum	0.05 maximum	0.10 maximum	0.05 maximum
Ferovan (Shieldalloy)	42 minimum	0.85 maximum	—	—	7.0 maximum	—	—	4.50 maximum
Nitrovan (Stratcor)	78-82	10-12	6 minimum	0.1 maximum	0.1 maximum	0.05 maximum	0.01 maximum	0.05 maximum

slag plants and frequently blend feed materials to improve recovery.

Of the more than 30 privately owned vanadium companies, only one, the Republic of South Africa's Highveld, operates facilities at all four lower levels and can be considered totally integrated. Highveld has plants that process vanadiferous magnetite ores from the Bushveld Igneous Complex. Two other producers, Shieldalloy Metallurgical Corp. and Stratcor, have extensive operations on the second, third, and fourth tiers. Shieldalloy traditionally used Highveld slag as its starting material for low vanadium grades of ferrovanadium.

The fifth tier is composed of producers of vanadium specialty alloys, high-purity vanadium metal, primary vanadium chemicals, and vanadium catalysts. Reading Alloys Inc., Akzo Chemical, and Teledyne Wah Chang Albany illustrate the diversity of operations at this level.

The Republic of South Africa is the world's largest producer of ore and vanadium-bearing slag. Its annual production of more than 17,000 tons is approached only by production in the U.S.S.R. The bulk of Soviet production is consumed internally or by other Eastern European countries. Other major producers include China and the United States. Canada, Japan, and Western Europe are heavily dependent on imports of vanadium slag and pentoxide from the Republic of South Africa. Any disruption of South African supplies could seriously upset the balance between vanadium supply and demand.

Geology-Resources

Vanadium is found in many parts of the world, usually in association with other minerals. There are few ores from which vanadium can be economically extracted as a single product. It is, therefore, often extracted as a byproduct or coproduct in the production of other elements, such as iron, phosphorus, or uranium. Increasing amounts are being recovered from petroleum residues and spent catalysts. The world also has extensive subeconomic resources of vanadium contained in oil sands, carbonaceous shale, and bauxite.

The crustal abundance of vanadium is estimated to be 100 to 150 parts per million (ppm), about twice that of copper, 10 times that of lead, and almost 100 times that of molybdenum.[2] As a result, trace vanadium mineralization occurs in a wide range of geologic provinces and environments. At the same time, ore deposits of vanadium are rare because much of the vanadium in igneous rocks occurs dispersed in the relatively insoluble trivalent state and is substituting for ferric iron in ferromagnesian silicates, magnetite, ilmenite, and chromite. Because of the substitutional phenomenon at the atomic level, vanadium is more abundant in mafic (those high in magnesium and iron) than silicic rocks. Gabbros and norites typically contain 200 to 300 ppm vanadium compared with 5 to 80 ppm for granites. When mafic rocks weather in a humid climate, the vanadium remains in the trivalent state or is weakly oxidized to the relatively insoluble tetravalent state. In either case, the vanadium is captured along with aluminum in the residual clays. Subsequent leaching of the clays can produce bauxite and lateritic iron ores that contain 400 to 500 ppm vanadium. When mafic rocks are intensely oxidized in an arid climate, some of the vanadium is converted to the pentavalent state. The pentavalent cation is considerably more soluble than the trivalent cation, is readily dissolved by ground water, and can be transported over long distances. This transport phenomenon can be observed in arid parts of Western Australia where carnotite precipitates from ground water in calcreted drainage systems.[3] At Yeelirrie, for example, thin films of carnotite were formed in the voids and cavities of river fill when ground water percolated through a tertiary river channel.

Organic materials frequently play a key role in the depositional process by helping to create a reducing environment. At many locations on the Colorado Plateau, carnotite, tyuyamunite, and other secondary uranium-vanadium minerals replace fossil logs and other carbonized plant debris. Some of the best examples of this phenomenon can be seen in the Monument Valley and White Canyon districts where uranium-vanadium ores have been deposited in paleochannels of the Shinarump Member of the Upper Triassic Chinle Formation. Fossils in the Shinarump indicate that the stream channels were cut into the underlying Moenkopi mudstones and then filled with sands, pebbles, and plant debris before the end of the Triasssic 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 por-

phyrins found in crude oil are approximately identical to the structures of chlorophylls (magnesium-centered porphyrins present in green plants) and hemoglobin (iron-centered porphyrins present in the red corpuscles of blood). The ratio of vanadium to nickel in crude oil is a function of the oxidation-reduction potential (Eh), the hydrogen ion activity (pH), and sulfide activity of the environment in which the oil source rocks were deposited. The two metals both form stable metallo-organic complexes in the high molecular weight fractions of crude oil.[4] Cleavage of these vanadium and nickel bonds will not occur unless the crude oil is subjected to a temperature greater than 300° C. As a result, the vanadium-to-nickel ratio remains constant for a specific reservoir even when the lower molecular weight components migrate away. The ratio is therefore useful in identifying unmetamorphosed crude oil from different depositional facies of the same source rock.

Technology

Mining.—In the United States, vanadium is recovered as a principal mine product, as a coproduct from carnotite ores, and from ferrophosphorus slag as a byproduct in the production of elemental phosphorus. Increasingly, it is also being recovered from petroleum refinery residues, fly ash, and spent catalysts. In China and the Republic of South Africa, vanadium is recovered as a byproduct of pig iron production from titaniferous magnetite.

Processing.—The steel industry accounts for 80% to 85% of the world's consumption of vanadium as an additive to steel. It is added to the steelmaking process as a ferrovanadium alloy, which is produced commercially by the reduction of vanadium pentoxide or vanadium-bearing slag with aluminum, carbon, or ferrosilicon.

The first stage in the processing of vanadium-bearing ore is the production of an oxide concentrate. The ore is crushed, ground, screened, and mixed with a sodium salt. This mixture is roasted at about 850° C to convert the oxides to water soluble sodium metavanadate. The vanadium is extracted by leaching with water and precipitated at pH 3 as sodium hexavanadate (red cake) by the addition of sulfuric acid. The red cake is fused at 700° C to yield a dense black product that is sold as technical-grade vanadium pentoxide. Technical-grade vanadium pentoxide contains a minimum of 86 weight-percent pentoxide and a maximum 8 weight-percent sodium oxide. The red cake may be further purified by dissolving it in an aqueous solution of sodium carbonate. Aluminum, iron, and silicate impurities precipitate from solution upon pH adjustment. Ammonium metavanadate is then precipitated by the addition of ammonium chloride. The precipitate is calcined to give a vanadium pentoxide product of greater than 99.8% purity.

Vanadium is extracted as a coproduct with uranium from carnotite by direct leaching of the ore with sulfuric acid. An alternative method is roasting the ore followed by countercurrent leaching with dilute sulfuric acid. In some cases, the first leach may be with a sodium carbonate solution. The uranium and vanadium are then separated from the pregnant liquor by liquid-liquid extraction techniques.

In China and the Republic of South Africa, vanadium is concentrated in slag resulting from the production of pig iron from magnetite ore. The ore, containing 1.5% to 2.5% vanadium pentoxide, is partially reduced with coal in rotary kilns. The ore is then melted in an enclosed furnace that produces a slag containing most of the titanium and pig iron containing most of the vanadium. After the titanium-bearing slag is removed, the molten pig iron is blown with oxygen to form a slag containing 12 to 24 weight-percent vanadium pentoxide. The slag is separated from the molten metal and may then be used as a high-grade vanadium raw material in the usual roast-leach process.

In the aluminothermic process for preparing ferrovanadium, a mixture of technical-grade pentoxide, aluminum, iron scrap, and a flux are charged into an electric furnace, and the reaction between aluminum and pentoxide is initiated. The reaction is highly exothermic, producing very high temperatures. The temperature can be controlled by adjusting the particle size of the reactants and the feed rate of the charge and by using partially reduced pentoxide or by replacing some of the aluminum by a milder reductant. Ferrovanadium containing up to 80 weight-percent vanadium can be produced by this method.

Ferrovanadium can also be prepared by the thermit reaction, in which vanadium and iron oxides are coreduced by aluminum granules in a magnesia-lined steel vessel or in a water-cooled crucible. The reaction is initiated by a barium peroxide-aluminum ignition charge. This method is also used to prepare vanadium-aluminum master alloys for the titanium industry.

The production of ferrovanadium by the reduction of vanadium concentrates with silicon involves a two-stage process in which technical-grade vanadium pentoxide, ferrosilicon, lime, and flurospar are heated in an electric furnace. An iron alloy containing about 30% vanadium but undesirable amounts of silicon is produced. The silicon content of the alloy can be reduced by adding more pentoxide and lime to effect the extraction of most of the silicon into the slag phase. An alternative process involves the formation of a vanadium-silicon alloy by the reaction of vanadium pentoxide, silica, and coke in the presence of a flux in an arc furnace. The molten metal reacts with vanadium pentoxide yielding ferrovanadium. The silicon reduction method has not been used extensively.

A process developed by Foot Mineral Co., Cambridge, OH (now Shieldalloy Metallurgical Corp.), has been used to produce tonnage quantities of ferrovanadium. This process involves the reaction of vanadium-bearing iron slag with silica, flux, and a carbon reductant followed by refinement by vanadium pentoxide. The reaction takes place in a submerged electric arc furnace yielding a ferrovanadium alloy containing about 40 weight-percent vanadium, 3.5 weight-percent silicon, 3.8 weight-percent manganese, 0.1 weight-percent carbon, and the remainder iron.

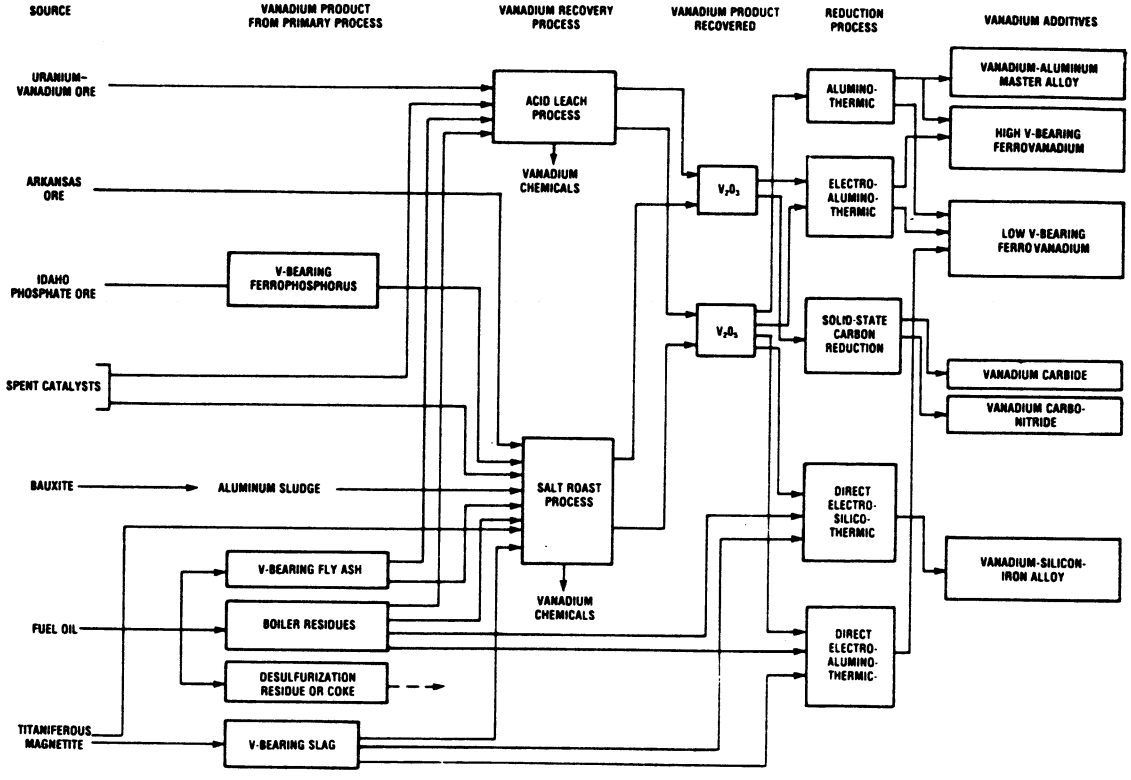
Substitutes

Various metals, such as columbium, manganese, molybdenum, titanium, and tungsten, are, to some degree, interchangeable with vanadium. So far there are no substitutes for vanadium in the all-important aerospace titanium alloys, which were used in jet engine mountings and wing structures. High-purity vanadium compounds were used as catalysts in the production of sulfuric acid, maleic anhydride, and in pollution control technology where it was required to remove hydrogen sulfide gas from flu gases (Stretford Process). In only a few chemical applications could platinum and nickel replace vanadium catalyst.

Reported consumers' and producers' stocks of vanadium oxides, metal, alloys, and chemicals at yearend totaled 2,198

FIGURE 1

GENERALIZED FLOWSHEET FOR THE PROCESSING OF VANADIFEROUS RAW MATERIALS



tons of contained vanadium; at yearend 1989, the number was 1,736 tons.

Economic Factors

Prices.—Highveld Steel & Vanadium Corp. of the Republic of South Africa produced more than 60% of market economy countries' vanadium in 1990. Even though the bulk of Highveld's production was in the form of vanadium-bearing iron slag, its pentoxide price was seen as the benchmark worldwide, with other suppliers indexing some of their contracts on the price. South African producers, who set their prices quarterly, were charging $5.00 per pound for V_2O_5 in first quarter 1990. By the fourth quarter, the price had fallen to $2.95 per pound; spot, or free market, prices were even lower at about $2.40 per pound. On December 11, 1990, Highveld announced that it would maintain the $2.95 price tag through first quarter 1991. These prices were down from $7.50 per pound in second quarter 1989. The poor performance of vanadium prices over this period reflected an oversupplied market and low demand as major consumers reduced their usage of vanadium. This was to be expected after the extraordinary performance of 1989. Given the current state of the world steel industry, markets for vanadium products will remain stable in terms of quantity, but prices will remain low.

Tariffs.—U.S. import duties on selected vanadium items as of January 1, 1990, are listed in table 3. The tariff listing includes rates for both most-favored-nation (MFN) and non-MFN status.

Operating Factors

Environmental Requirements.—Because some segments of the geochemical cycle of uranium and thorium coincide with the vanadium cycle, the environmental considerations of vanadium mining are frequently linked to the management of radioactive mine wastes. In addition to careful placement and containment of tailings ponds, special attention must be given to preventing or limiting radioactive contamination of ground water aquifers and to the impoundment and long-term storage of mill tailings and mine waste to control radon daughter exhalation.

In 1982, the Environmental Protection Agency (EPA) published a regulation dealing specifically with the mining of both vanadium ores and uranium-radium-vanadium ores.[5] Under these rules, the concentration of uranium in mine drainage must be less than 4 milligrams per liter per day for 30 consecutive days. In addition, the U.S. Nuclear Regulatory Commission has issued two regulatory guides dealing with personnel monitoring at uranium mills and processing facilities. The two guides delineate techniques for performing bioassays 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 sand-like surface by wind and rain. The rules also limited radon release from the surface of

TABLE 3

U.S. IMPORT DUTIES, JANUARY 1, 1990

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.

the pile to 20 picocuries per square meter per second.

Toxicity.—Vanadium compounds are irritants chiefly to the conjunctive and respiratory tract. Prolonged exposure may lead to respiratory irritations with mucus discharge and lower respiratory tract irritation with bronchitis and chest pains.[8] Other noted effects of vanadium and its compounds have included contact dermatitis, conjunctivitis, and discoloration of the tongue. Vanadium in high concentrations may alter metabolic processes in animals and humans. The reported toxic effects of exposure to vanadium compounds have been acute, never chronic. Toxic effects vary with the compound involved, e.g., vanadium oxytrichloride ($VOCl_3$) liberates hydrogen chloride gas, and the oral lethal dose (LD_{50}) for V_2O_5 dust in rats is 23 milligrams per kilograms of body weight.[9] The lethal dose value is used to express the toxicity of many compounds and is determined by experiment. As used here, it is milligrams of V_2O_5 per kilogram of body weight (taken by mouth) that is lethal to 50% of the experimental animals.

Vanadium metal and its alloys pose no particular health or safety hazard, but they do react violently with certain materials, including bromine trifluoride (BrF_3), chlorine, and some strong acids. The toxicity of vanadium alloys depends upon other components in the alloy.

The adopted threshold limit values for time-weighted averages for airborne vanadium, including oxide and metal dusts of vanadium, is 0.5 milligrams per cubic meter; the value for fumes of vanadium compounds is 0.05 milligrams per cubic meter. These limits are for normal 8-hour workday and 40-hour workweek exposures. The short-term exposure limit is 1.5 milligrams per cubic meter for dust.[10] The ammonium salts of vanadic acid and vanadium pentoxide have been listed as toxic constituents in solid wastes under the Resource Conservation and Recovery Act.[11]

ANNUAL REVIEW

Legislation and Government Programs

The annual report to Congress by the Secretary of Defense on U.S. stockpile needs for fiscal year 1991 was postponed. Also, Congress was asked to support a moratorium on the National Defense Stockpile (NDS) acquisition of metals and other materials beginning October 1, 1990. According to a Department of Defense spokesman, more time was needed to reassess out-of-date threat assessments and warning times and to develop new war scenarios. A new report was expected to be completed in June or July of 1991.

The Department of Defense was first required to report to Congress on NDS requirements in 1989. In its first report, some changes were recommended, including deletions, increases, reductions, and upgrades for certain items. Vanadium pentoxide (V_2O_5) was one of the materials recommended for upgrading. Solicitations were first issued in August 1989, but were immediately withdrawn after potential bidders raised questions about the composition of the materials to be upgraded. The solicitation was reissued in July 1990 with August 21 as the closing date for receiving bids on upgrading 1.93 million pounds of V_2O_5 contained in 2.12 million pounds of bulk material that was produced in the 1950's.

The Government of Argentina petitioned for duty-free treatment for ferrovanadium (HTS subheading 7202.92.00) under the General Systems of Preferences (GSP). In its request, Argentina stated that (1) this product has not been exported to the United States; (2) duty-free treatment of this product was accorded to certain other countries under the Caribbean Basin Economic Recovery Act and the United States-Israel Free-Trade Agreement; (3) the U.S. steel industry would benefit from a lower priced product; and (4) duty-free treatment would more than double the current Argentinean production level, thereby increasing (Argentinean) employment. The list of materials accorded GSP status is revised annually.

Affiliated Metals and Minerals Inc., Shieldalloy Metallurgical Corp., and the U.S. Vanadium Corp. requested that duty-free treatment of ferrovanadium (FeV) be denied. In its request, Affiliated stated that (1) duty-free treatment would likely drive one of the few domestic producers out of the market by adding another competitor to a small-size market, and (2) duty-free imports of FeV would increase the level of unused industry capacity and cause unemployment in this labor-intensive industry. Shieldalloy and U.S. Vanadium opposed the petition, noting that FeV has been treated by the U.S. Government as a "strategic and critical" mineral in the NDS. Extending duty-free treatment would only serve to further decrease domestic FeV production and increase U.S. dependency on foreign sources.

The International Trade Commission (ITC) accepted comments through January 10, 1991, on the economic effects of the proposed revisions. A GSP subcommittee was to meet in January and February to evaluate ITC's advice and hearing-related testimony. The President and the U.S. Trade Representative were expected to announce GSP selections in early April 1991, with GSP treatment going into effect soon thereafter.[12]

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 equip-

TABLE 4

STOCKPILE STATUS, DECEMBER 31, 1990

(Metric tons of contained vanadium)

Material	Goal	Inventory
Vanadium pentoxide	6,985	654
Ferrovanadium	907	—

ment for defense, energy, and transportation.

The industrialized countries of the Western World are highly dependent on imports of vanadium pentoxide and vanadium-bearing slag from the Republic of South Africa. The Republic of South Africa was the world's largest producer of vanadium in 1990 and was the source of about 60% of the vanadium consumed by market economy countries. Between 1985 and 1990, more than 30% of U.S. vanadium imports came directly from the Republic of South Africa. Additional material was processed in Western Europe and then imported to the United States as FeV, V_2O_5, and other vanadium products. The European Community and Japan are more heavily dependent on South African imports than the United States. Any extended cutback in supplies from the Republic of South Africa would seriously upset the balance between supply and demand in the market economy countries. Sizable, near-term deficits could only be offset by material from China or the U.S.S.R.

The 1990 goal for the NDS was 6,985 tons of vanadium contained in V_2O_5 and 1,000 tons in FeV. Actual yearend stockpile inventories were only 654 tons of vanadium as V_2O_5. At this point, no FeV had been added to the NDS. The 1989 fiscal year Defense Authorization Act required the Department of Defense to outline plans for at least $20 million in upgrading projects. The Department responded by submitting to Congress an ambitious $30 million plan to upgrade vanadium pentoxide and other materials in the NDS. To justify the planned upgrading program, the Department stated that while the need for some traditional stockpile materials remains substantial, current and projected military strategies and high-technology weapons systems would require more of the advanced and upgraded forms of industrial materials and less of the conventional materials and unprocessed mineral ores. On September 29, 1990, U.S. Vanadium Corp., Hot Springs, AR, was awarded a $3.76 million Defense Logistics Agency contract to upgrade 1.93 million pounds of V_2O_5 from the NDS into Grade B fused flake. U.S. Vanadium, a subsidiary of Strategic Minerals Corp., Danbury, CT, won the contract with a bid of about $1.95 per pound. Terms of the contract required U.S. Vanadium to complete the upgrade within 2 years after the contract was awarded. Chemical requirements for the material are listed in table 5.

TABLE 5

COMPOSITION LIMITS FOR VANADIUM PENTOXIDE PURCHASED FOR THE NATIONAL DEFENSE STOCKPILE

Material	Percent by weight (dry basis)		
		Grade A	Grade B
Vanadium pentoxide (V_2O_5)	Minimum	98.0	98.0
Phosphorus (P)	Maximum	.05	.03
Sulfur (S)	do.	.04	.05
Silica (SiO_2)	do.	.50	.25
Arsenic (As)	do.	.05	.03
Iron (Fe)	do.	.20	.15
Total alkali (Na + K)	do.	.75	.50
Boron (B)	do.	—	.005
Chromium (Cr)	do.	—	.10
Copper (Cu)	do.	—	.05
Lead (Pb)	do.	—	.01
Manganese (Mn)	do.	—	.05
Molybdenum (Mo)	do.	—	.10
Nickel (Ni)	do.	—	.05
Nitrogen (N)	do.	—	.05
Silicon (Si)	do.	—	.12
Tungsten (W)	do.	—	.01
Uranium (U_3O_8)	To be determined and reported		

NOTE. — If the weight percent of U_3O_8 is less than 0.71 and the radioactivity is essentially evenly distributed, it is not considered radioactive in terms of Department of Transportation requirements. If the weight percent of U^{238} in the U_3O_8 is in excess of 0.05 weight percent, then it is considered a radioactive material according to the Nuclear Regulatory Commission and CFR 10, Parts 20, 40, and 70 apply.

Issues

Prior to about 1984-85, more than one-half of the vanadium mined in the United States was recovered as a coproduct with uranium from sandstone mined on the Colorado Plateau. Companies recovering vanadium from uranium ores were hurt by the downturn in nuclear powerplant construction in the aftermath of the Three Mile Island nuclear reactor accident and the subsequent reduced demand for enriched uranium. Worldwide recession, high interest rates, and the cancellation of powerplant construction in the United States caused the Nuclear Exchange Corp. (Nuexco) exchange value of uranium oxide (U_3O_8) to decline from $40.75 per pound in early 1980 to less than $10.00 per pound in 1990. 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. The author has performed chemical analyses on some boiler scales that contained as much as 35 weight-percent V_2O_5. More than 30% of the V_2O_5 produced in the United States is now being recovered from refinery residues, fly ash, boiler scale, and spent catalysts. In 1990, the United States recovered 2,308 tons of vanadium oxides from these petroliferous materials, most of which were imported. This source of vanadium may also dry up as clean air standards lead to a tightening of sulfur restrictions on fuel oil products leading to less production of vanadium-containing residues. Gradual depletion of Colorado Plateau vanadiferous uranium ores that have been the principal source of domestic vanadium and the expected reduction of available petroleum residues will require the development of alternative sources to maintain domestic self-sufficiency in this strategic mineral.

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 and Uses

Reported consumption of vanadium was a little more than 4,000 tons of contained vanadium or about 12% less than that in 1989. Part of this reduction was attributed to reduced demand by the steel industry, in which production was down by about 10%. The decrease might have been greater if some consumers had not returned to using vanadium. In 1989, these consumers substituted other materials or treatments for vanadium when the price of V_2O_5 was abnormally high.

Foreign Trade

Overall U.S. export of vanadium products was down by more than 50% in 1990. Canada, Brazil, the Republic of Korea, and Mexico were the leading importers of U.S. materials. Most countries imported almost exclusively V_2O_5. Austria, Canada, and the Republic of Korea also imported substantial quantities of FeV. Exports of V_2O_5 totaled 2,608 tons gross weight, less than one-half of 1989 exports. The average declared value of the pentoxide was $4.99 per pound of contained vanadium; the price averaged $7.62 in 1989. Exports of FeV totaled 334 tons gross weight, down from 493 tons in 1989. The average declared value of the FeV was about $13.00 per kilogram of contained vanadium.

Imports for consumption of vanadium raw materials and downstream vanadium compounds decreased in 1990. FeV imports totaled 323 tons gross weight, down from 650 tons in 1989 and 383 tons in 1987. The imported FeV averaged 81% vanadium with a mean custom value of $7.60 per kilogram of contained vanadium. Canada was the largest source of FeV with shipments of 101 tons, followed by Austria, 95 tons, and Belgium, 28 tons. Vanadium pentoxide imports totaled 83 tons of contained vanadium, down from 133 tons in 1989; the average declared value was $5.15 per pound of contained vanadium. Imports for consumption of vanadium-bearing slag and residues totaled more than 4,600 tons of contained vanadium. About 34% of these imports was from the Republic of South Africa in the form of vanadium-bearing iron slag. Another 18% was vanadium-bearing steel-

TABLE 6

U.S. VANADIUM PENTOXIDE PRODUCERS

Producer	Plant location	Capacity (metric tons pentoxide per year)
AMAX Metals Recovery Corp.	Braithwaite, LA	1,800
Gulf Chemical & Metallurgical Corp.	Freeport, TX	1,400
Kerr McGee Chemical Corp.	Soda Springs, ID	2,000
UMETCO Minerals Corp.	Blanding, UT	6,800
U.S. Vanadium Corp.	Hot Springs, AR	6,800

TABLE 7

U.S. CONSUMPTION AND CONSUMER STOCKS OF VANADIUM MATERIALS, BY FORM

(Kilograms of contained vanadium)

Type	1989		1990	
	Consumption	Ending stocks	Consumption	Ending stocks
Ferrovanadium[1]	r3,805,539	r401,102	3,446,302	290,523
Oxide	19,367	8,880	17,017	14,047
Ammonium metavanadate	W	W	W	W
Other[2]	r820,689	r143,612	634,260	50,414
Total	4,645,595	553,594	4,097,579	354,984

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 8

U.S. CONSUMPTION OF VANADIUM IN 1990, BY END USE

(Kilograms of contained vanadium)

End use	Quantity
Steel:	
Carbon	993,962
Stainless and heat resisting	37,783
Full alloy	814,145
High-strength low-alloy	1,121,745
Tool	420,767
Unspecified	W
Total[1]	3,388,403
Cast irons	18,272
Superalloys	42,070
Alloys (excluding steels and superalloys):	
Cutting and wear-resistant materials	W
Welding and alloy hard-facing rods and materials	5,364
Nonferrous alloys	W
Other alloys[2]	600,922
Chemical and ceramic uses:	
Catalysts	8,217
Other[3]	W
Miscellaneous and unspecified	34,332
Grand total[1]	4,097,579

W Withheld to avoid disclosing company proprietary data, included with "Miscellaneous and unspecified."
[1]Data may not add to totals shown because of independent rounding of converted units.
[2]Includes magnetic alloys.
[3]Includes pigments.

TABLE 9

PRODUCERS OF VANADIUM ALLOYS OR METAL IN THE UNITED STATES IN 1990

Producer	Plant location	Products[1]
Bear Metallurgical, Inc.	Butler, PA	FeV.
KB Alloys Inc.	Henderson, KY	VAl, ZrVAl.
Do.	Wanatchee, WA	Do.
Reading Alloys Inc.	Robesonia, PA	NiV, VAl, V.
Sheildalloy Metallurgical Corp.	Cambridge, OH	FeV, Ferovan.[2]
Do.	Newfield, NJ	FeV.
Strategic Minerals 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 10

COUNTRIES OF ORIGIN OF VANADIUM RAW MATERIALS

Material	Principal producing countries
Ash and residues	Canada, Federal Republic of Germany, Italy, Mexico, Venezuela.
Spent catalyst	Kuwait.
Vanadium-bearing slag	Chile, Republic of South Africa.

making slag from Chile. The remaining 48% consisted of an assortment of petroleum residues, spent catalyst, and fly ash.

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 Western World's market. Most of the Republic of South Africa's exports of vanadium were in 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 slag, fly ash, petroleum residues, and spent catalyst from many other sources. The large importers of vanadium raw materials, e.g., slag, were the chief exporters of V_2O_5, FeV, and other downstream vanadium products. This trade was dominated by a few large West European converters who competed not only within Europe, but also exported to many small and large consumers outside of Europe. Reliable statistics from the U.S.S.R. were not available, but it is believed to be second only to the Republic of South Africa in vanadium production. All Soviet trade was thought to be with other East European countries.

Capacity.—The data in table 15 are rated capacity for mills producing vanadium oxides as of December 31, 1990. Included in this data is capacity to produce vanadium-bearing iron 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 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 only about 0.32% V_2O_5. This deposit was

TABLE 11

U. S. EXPORTS OF VANADIUM IN 1990, 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	—	—	—	—	18,007	$136	5,424	$54
Australia	—	—	116	$5	—	—	—	—
Austria	—	—	—	—	80,068	457	88,672	602
Belgium-Luxembourg	—	—	—	—	544,103	3,569	382,707	1,910
Bolivia	—	—	—	—	—	—	2,074	10
Brazil	—	—	228	8	168,212	1,098	—	—
Canada	186,891	$2,667	123,055	3,878	—	—	298,237	1,847
Chile	—	—	—	—	956	12	10,208	34
Denmark	—	—	782	6	—	—	—	—
France	—	—	34,911	340	—		1,246	26
Germany, Federal Republic of	—	—	10,353	274	156,547	1,135	537	8
Hong Kong	37,376	488	—	—	—	—	—	—
India	—	—	—	—	—	—	32,590	50
Italy	—	—	349	17	—	—	—	—
Jamaica	—	—	501	3	—	—	—	—
Japan	—	—	18,493	465	329,176	2,452	15	9
Korea, Republic of	25,254	420	5,876	52	—	—	—	—
Malaysia	6,106	74	—	—	—	—	—	—
Mexico	9,882	193	114,929	1,542	48,685	444	15,496	114
Netherlands	5,885	147	3,280	92	69,139	534	45	3
Norway	—	—	832	4	—	—	—	—
Pakistan	—	—	—	—	200	3	—	—
Peru	—	—	—	—	5,743	23	—	—
Portugal	—	—	339	3	—	—	—	—
Singapore	768	19	—	—	—	—	295	7
Spain	—	—	6,093	68	—	—	—	—
Sweden	—	—	—	—	—	—	130,201	1,172
Switzerland	—	—	—	—	18,269	120	—	—
Taiwan	5,877	97	41,709	279	725	13	—	—
Thailand	—	—	—	—	—	—	8,485	133
Trinidad	—	—	—	—	4,510	44	149	36
United Kingdom	11,793	81	19,647	429	15,687	79	100	9
Venezuela	44,440	1,294	102	3	1,426	25	—	—
Total[4]	334,272	5,480	381,595	7,468	1,461,453	10,142	976,481	6,024

[1]May include vanadium metal.
[2]May include catalysts containing vanadium pentoxide.
[3]Excludes vanadates.
[4]Data may not add to totals shown because of independent rounding.
Source: Bureau of the Census.

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. Surprisingly, 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.[13]

TABLE 12

U. S. IMPORTS OF FERROVANADIUM, BY COUNTRY

Country	1989			1990		
	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)
General imports:						
Austria	121,318	98,960	$3,283	116,200	94,534	$1,391
Belgium-Luxembourg	67,440	54,859	1,625	36,021	28,284	250
Brazil	17,012	12,135	364	—	—	—
Canada	182,016	148,215	5,142	125,401	100,566	1,737
China	—	—	—	17,355	14,003	210
France	1,122	842	17	—	—	—
Germany, Federal Republic of	188,028	116,311	2,631	22,536	16,896	283
Japan	70,000	56,120	259	5,000	3,970	59
Mexico	2,973	2,498	10	—	—	—
Total[1]	649,909	489,939	13,331	322,513	258,253	3,930
Imports for consumption:						
Austria	121,318	98,960	3,283	116,200	94,534	1,391
Belgium-Luxembourg	72,440	58,804	1,786	36,021	28,284	250
Brazil	17,012	12,135	364	—	—	—
Canada	182,016	148,215	5,142	125,401	100,566	1,737
France	1,122	842	17	—	—	—
Germany, Federal Republic of	188,028	116,311	2,631	22,536	16,896	283
Japan	61,000	48,902	259	5,000	3,970	59
Mexico	2,973	2,498	10	—	—	—
Total[1]	645,909	486,666	13,493	305,158	244,250	3,720

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

Source: Bureau of the Census.

TABLE 13

U.S. IMPORTS OF VANADIUM PENTOXIDE (ANHYDRIDE), BY COUNTRY

Country	1989			1990		
	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)
General imports:						
Canada	495	283	$4	825	429	$3
China	32,000	31,565	565	—	—	—
France	—	—	—	20	19	3
Germany, Federal Republic of	1,734	1,036	48	2,049	1,290	52
South Africa, Republic of	151,045	100,334	2,250	71,000	46,988	444
United Kingdom	469	269	7	34,000	33,901	217
Total[1]	185,743	133,487	2,873	107,894	82,627	719
Imports for consumption:						
Canada	495	283	4	825	429	3
France	—	—	—	20	19	3
Germany, Federal Republic of	1,734	1,036	48	2,049	1,290	52
South Africa, Republic of	134,076	90,638	1,852	71,000	46,988	444
United Kingdom	469	269	7	34,000	33,901	217
Total	136,774	92,226	1,911	107,894	82,627	719

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

Source: Bureau of the Census.

TABLE 14

U.S. IMPORTS OF VANADIUM-BEARING ASH AND RESIDUES, SLAGS, AND OTHER MATERIALS, BY COUNTRY[1]

Material and country	1989			1990		
	Gross weight (kilograms)	Vanadium pentoxide content (kilograms)	Value (thousands)	Gross weight (kilograms)	Vanadium pentoxide content (kilograms)	Value (thousands)
Slag:						
Barbados	13,608	6,804	$30	—	—	—
Belgium	379,999	5,282	43	40,166	21,608	$169
Chile	28,165,198	1,549,086	1,025	28,213,536	1,551,744	1,232
Germany, Federal Republic of	—	—	—	379,000	13,536	20
South Africa, Republic of	10,518,979	2,481,066	17,544	7,248,548	1,734,952	5,282
Venezuela	67,225	30,540	121	—	—	—
Total[2]	39,145,009	4,072,778	18,762	35,881,250	3,321,840	6,702
Ash and residues:						
Barbados	11,294	2,400	7	—	—	—
Belgium	—	—	—	116,078	73,091	104
Canada	563,151	218,527	1,340	1,084,834	448,860	1,212
Dominican Republic	159,213	98,553	68	—	—	—
France	—	—	—	15,408	7,319	18
Germany, Federal Republic of	92,567	16,098	98	808,740	293,036	165
Israel	220,895	79,050	479	37,860	10,222	34
Italy	1,263,256	380,557	964	1,256,091	292,159	608
Jamaica	40,369	13,312	25	—	—	—
Malaysia	63,825	56,284	108	—	—	—
Mexico	706,873	246,706	885	1,513,436	564,228	2,440
Netherlands Antilles	74,676	16,802	28	64,450	14,502	27
Suriname	42,485	7,742	26	—	—	—
United Kingdom	215,125	51,760	251	186,308	39,622	52
Venezuela	954,035	244,303	756	159,592	58,032	126
Total	4,407,764	1,432,094	5,035	5,242,797	1,801,071	4,786
Other (includes spent catalyst):						
Belgium	—	—	—	29,428	4,402	7
Italy	300,092	112,535	25	209,650	54,958	110
Japan	—	—	—	333,390	25,262	131
Kuwait	—	—	—	10,483,900	1,538,887	809
Netherlands	61	100	3	481,632	93,378	72
United Kingdom	—	—	—	1,240,406	26,555	39
Venezuela	55,613	17,796	69	—	—	—
Total[2]	355,766	130,431	97	12,778,406	1,743,442	1,169

[1]General imports.
[2]Data may not add to totals shown because of independent rounding.
Source: Bureau of the Census.

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 with the development of this project despite low vanadium prices in 1990 and pessimistic predictions for 1991. PMA officials believed Australian mining and materials handling technoloy to be more efficient than methods used in the Republic of South Africa. They also believed that the Australian ore would be easier to process. PMA has the disadvantage of higher energy costs.

Canada.—Agra Industries Ltd. of Saskatoon, Saskatchewan, teamed with Renzy Mines Ltd. and Fairfax Financial Holdings Ltd. of Toronto, Ontario, to construct a vanadium pentoxide facility at Fort McMurray, Alberta. The plant, which cost about $14 million, was designed to extract about 2.5 million pounds per year of V_2O_5 from waste fly ash produced by the Suncor Inc. oil sands plant.[14] The Athabasca oil sands in northern Alberta was well known for its wealth of oil, and a number of projects have been launched to extract it. A number of other elements besides vanadium are found in the oil

TABLE 15

WORLD VANADIUM PENTOXIDE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990[1]

(Metric tons of contained vanadium)

Country	Rated capacity[2]
Australia	1,500
Brazil	—
Canada	770
Chile	2,300
China	8,200
South Africa, Republic of	27,200
U.S.S.R.	9,500
United States	11,000
Venezuela	2,500
Other	550
Total	63,520

[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.

sands. The Athabasca oil sands may prove to be the largest reserves of vanadium in North America.

Vanadium and other minerals appear in the oil sands only in trace concentrations making economic recovery impossible. However, when the material was treated to recover heavy oil, vanadium was concentrated in a stream of waste petroleum coke. Subsequent burning of this coke in the plant's power steam boiler produced a fly ash consisting mainly of carbon and V_2O_5 concentrations ranging from 2% to 5%. The Alberta Suncor and Syncrude refineries produced about 43,000 tons of fly ash per year. To secure access to the vanadium-rich fly ash, Carbovan Inc. obtained an exclusive long-term agreement to purchase the waste fly ash produced by Suncor. Carbovan also gained access to fly ash that had been stockpiled by Suncor over the years. In addition to these supplies of raw materials, Carbovan obtained agreements to purchase vanadium-rich spent catalyst discharged by various petroleum processors in Canada.

Initial concepts of Carbovan's recovery process were developed by Renzy Mines in 1972. Between 1972 and 1985, Renzy spent about $500,000 to further develop and improve the process. In mid-1985, Renzy and Agra entered into an agreement to conduct further research and development of the Renzy process. Under terms of the agreement, Agra provided financial, management, and engineering support to the research. After expenditures of $1.5 million and 3 years of research and development, an economical process was developed. The process utilized a hydrometallurgical flotation technique to remove carbon from the fly ash. The carbon-free ash fraction was next treated with a high-temperature alkaline leach and pulse column solvent extraction circuits to extract vanadium.

Carbovan began production of vanadic acid (HVO_3) in September 1990 and shipped the material to consumers in Canada and the United States. The second stage of the process, which was not yet underway at the end of 1990, involved calcining the HVO_3 to produce flake V_2O_5.

China.—Based on its production of pig iron, China's production of vanadium-bearing iron slag was estimated at about 85,000 tons in 1990 or about the same as 1989 production.[15] Approximately 80% of the output was from the Panzhihua Steel Works in Sichuan Province. Slag from this plant averaged 14% V_2O_5, which placed China's vanadium production at about 7,400 tons of contained vanadium; only the Republic of South Africa and the U.S.S.R. produced more.

Exports of V_2O_5 and vanadium-bearing slag were lower than in previous years mostly because of increased internal demand.

South Africa, Republic of.—South Africa, the world's largest producer of vanadium, increased its capacity by 28% in 1990, but is estimated to have produced about the same quantity of vanadium as in 1989. In 1988, production of vanadium marked an alltime high of 63 million pounds of V_2O_5, more than 10% above 1987 production. Production in 1989 was even higher at more than 66 million pounds. Sales in 1989 of vanadium totaled 30,400 tons V_2O_5 with a value of R23.6 million. Eight hundred and thirty-one tons was used internally and the remainder exported.[16]

Most of the increase in capacity was from a new facility, which obtained its feedstock from reserves of titaniferous magnetite in Bophuthatswana. The project, designed to produce 9,900 tons of V_2O_5 annually, was a co-operative venture between Union Steel Corp. (Usco) and Rhombus Exploration (RhoEx) to exploit a high-grade deposit stretching over a distance of 10.5 miles. Ore reserves were estimated to be sufficient to support production for about 100 years.

Usco extracted V_2O_5 by the roast-leach process. The company estimated that the cost of production of V_2O_5 flake would be in the range of R11,500 to R12,000 per ton. Mechanical commissioning of the beneficiation plant at Rhovan's mine, which provided the magnetite concentrate, was completed, and wet commissioning started in March 1990.[17] Brandeis Goldschmidt Ltd., headquartered in London, acted as sole agent for V_2O_5 produced by Usco.

Vansa Vanadium Corp. began production of V_2O_5 in October 1988. Its operations were supplied by the Kennedy's Vale high-grade ore deposit. The plant, in Eastern Transvaal, had a design capacity of 3,000 tons per year of V_2O_5. During the second half of 1990, the company reported that, as a result of postcommissioning problems, the plant had been unable to achieve its full design capacity. For most of the fiscal year ending September 30, 1989, the plant operated at just over 60% of capacity. The company, expecting to achieve full production in 1990, continued to be plagued with technical problems and was never able to reach full production capacity. Finally, Vansa announced in November 1990 that it would stop production of V_2O_5. Vansa's decision was influenced by the entrance of Usco and Carbovan into an already oversupplied market. Meanwhile, Highveld was estimating that the shutdown of Vansa and other curtailments of production would lead a 3,000-ton supply shortfall in 1991.

Other established producers in the Republic of South Africa apart from Highveld and Vansa are Vametco in Bophuthatswana and Transvaal Alloys, which produced V_2O_5 and other vanadium chemicals. The Republic of South Africa's domestic consumption of vanadium was believed to be about 1% of total production.

OUTLOOK

Vanadium consumption in the United States is expected to decline by 10% to about 4,000 tons in 1991 as the recession and consumer uncertainty continues to affect orders for appliances, automobiles, and construction materials. Shipments of vanadium products will decline as demand for steel in most industrial nations falls by 4%. Steel is the largest market for vanadium.

TABLE 16

WORLD VANADIUM 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, Alberta	x				
Masterloy Products Ltd.	Gloucester, Ontario			x		
Federal Republic of Germany:						
Gesellschaft fur Electrometallurgie mbH	Nuremburg		x		x	
Belgium:						
Sadacem (Langerbruggekaai Plant)	Ghent		x			
Spain:						
Ferroastur SA	Poligono de Maqua, Aviles		x			
Sweden:						
Metals & Powders Trollhatten AB (Sandvik AB)	Trollhatten		x			
United Kingdom:						
Ferroalloys & Metals Ltd.	Glossop, Derbyshire		x			
London & Scandinavian Metallurgical Co. Ltd.	Rotherham, South Yorkshire		x			
Murex Ltd.	Rainham, Essex	x	x	x		
Republic of South Africa:						
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	x				
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			
U.S.S.R:						
Chusovskoy Metallurgical Zavod	Chusovoy	x	x			
Novo-Tagilskiy	Nizhniy-Tagil	x	x			
Novo-Tulskiy Metallurgical Zavod	Tula	x	x			
Serovskiy Metallurgical Zavod	Serov	x	x			

[1]A, Nitrovan, proprietary product; B, Ferovan, proprietary product; C, Vanadium metal producer; D, Vanadium-Zirconium alloy producer; and E, Unsupported vanadium catalyst.

TABLE 17

VANADIUM: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons of contained vanadium)

Country	1986	1987	1988	1989[p]	1990[e]
Production from ores, concentrates, slag:[2]					
China (in vanadiferous slag product)[e]	4,500	4,500	4,500	4,500	4,500
South Africa, Republic of:[3]					
Content of pentoxide and vanadate products[e]	5,761	4,156	5,080	5,200	5,700
Content of vanadiferous slag product[e 4]	9,600	10,100	11,300	11,300	11,300
Total	15,361	14,256	16,380	[e]16,500	17,000
U.S.S.R.[e]	9,600	9,600	9,600	9,600	9,500
United States (recoverable vanadium)	W	W	W	W	W
Total[5]	29,461	28,356	30,480	30,600	31,000
Production from petroleum residues, ash, spent catalysts:[6]					
Japan (in vanadium pentoxide product)[e]	[7]843	840	[r]880	[r]560	560
United States (in vanadium pentoxide and ferrovanadium products)	2,114	2,275	2,950	2,389	[7]2,308
Total	2,957	3,115	3,830	2,949	2,868
Grand total	32,418	31,471	34,310	33,549	33,868

[e]Estimated. [p]Preliminary. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]In addition to the countries listed, vanadium in also recovered from petroleum residues in the Federal Republic of Germany, the U.S.S.R., and several other European countries, but available information is insufficient to make reliable estimates. Table includes data available through June 28, 1991.

[2]Production in this section is credited to the country that was the origin of the vanadiferous raw material.

[3]Includes production for Bophuthatswana.

[4]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.

[5]Excludes U.S. production.

[6]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.

[7]Reported figure.

World demand is forecast to increase by about 2% per year, with total world demand reaching 45,000 tons by the year 2000. World production in 1990, including production from petroliferous materials and spent catalysts, was estimated to have been more than 34,000 tons, of which about 2,300 tons was produced in the United States from petroleum residues and spent catalysts. U.S. production from domestic ores and concentrares was not reported.

Prolonged unrest in the Persian Gulf would have consequences that reach far beyond the region and the oil industry, and that would include the vanadium industry. A protracted war in the region would not only have a huge effect on oil prices, but it would also threaten vanadium pentoxide producers who depend on spent catalyst from this area as a source of feed material. Higher oil prices would slow or halt economic growth around the world, cutting into demand for industrial and consumer products that are markets for vanadium.

The likely drawdown of inventories by vanadium consumers through the first and second quarters of 1991 should also have an adverse effect on domestic demand. Consumers were expected to draw down their inventories because they would no longer be concerned about difficulties in obtaining vanadium in a timely manner and at a reasonable price. Prices of most products were projected to stabilize in the third or fourth quarter of 1991 and could begin to rise as the country draws itself out of the economic downturn.

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 has occurred in the industry since 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.

About 85% of the demand for vanadium is driven by the iron and steel industry. This dependence of the vanadium industry on the demand for steel products is not likely to change in the near future. The remaining 15% of demand is driven by aerospace titanium alloys (13%) and chemicals (2%). The reader is referred to the outlook section of the Iron and Steel Annual Report for more information on the long-term outlook for the steel industry.

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[4]Lewan, M. D. Factors Controlling the Proportionality of Vanadium to Nickel in Crude Oils. Cosmochim. Acta, v. 49, No. 11, Nov. 1984, pp. 2231- 2238.

[5]U.S. Code of Federal Regulations. Title 40—Protection of Environment; Chapter I—Environmental Protection Agency; Part 440—Ore Mining and Dressing Point Source Category; July 1, 1984, pp. 302-304, 312-313.

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[13]Metal Bulletin, No. 7425, Oct. 16, 1989.

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VERMICULITE

By Michael J. Potter

Mr. Potter, a physical scientist with 24 years of industry and U.S. Bureau of Mines experience, has been the acting commodity specialist for vermiculite since 1989. Domestic survey data were prepared by Pam Shorter, minerals data assistant.

Vermiculite is a micalike mineral that rapidly expands upon heating to produce a low-density material. The expanded (exfoliated) product is used as lightweight aggregate and thermal insulation in construction applications; as a fertilizer carrier and soil conditioner in agriculture; and as a filler and texturizer for plastics and rubber, among many other uses.

U.S. vermiculite concentrate sold and used was 230,000 short tons, a decrease from that of the previous year, according to the Bureau of Mines, U.S. Department of the Interior. The tonnage of exfoliated vermiculite sold and used was 157,000 tons, also a decrease from that of 1989. Markets have been affected by competition from other building product materials and by reduced construction activity.

Domestic production data for vermiculite were developed by the U.S. Bureau of Mines from two separate, voluntary surveys, one for domestic mine operations and the other for exfoliation plant operations. Of the six mining operations to which a survey request was sent, data or estimated data were received from five operations. The one nonrespondent's data were estimated by the U.S. Bureau of Mines. Of the 33 active exfoliating plants to which a survey request was sent, data were obtained from 27. This represented 63% of the total exfoliated vermiculite sold and used shown in table 1. The six nonrespondents' data were estimated by the U.S. Bureau of Mines using previous years' production levels.

The leading domestic producer of vermiculite concentrate continued to be W.R. Grace & Co. with sales of material from its Libby, MT, location (from stockpiles) and from its operation at Enoree, SC. Other producers during the year were Virginia Vermiculite Ltd., Louisa County, VA; Carolina Vermiculite Div. of Virginia Vermiculite Ltd. mine near Woodruff, SC; Patterson Vermiculite Co., Enoree, SC; and Enoree Minerals Corp., Spartanburg County, SC. South Carolina, with four producers, was the leading producing State for the fourth consecutive year. W.R. Grace closed its Libby, MT, mine in late 1990, although shipments of concentrate were to continue through 1992. The company also closed five exfoliating plants in 1990.

Domestic sales of exfoliated vermiculite by 13 producers came from 33 plants in 20 States. Of these plants, 20 in 16 States were operated by W.R. Grace. In descending order of output sold and used, the principal exfoliated vermiculite-producing States were estimated to be Ohio, South Carolina, California, New Jersey, Illinois, Florida, and Texas.

The average value of vermiculite concentrate sold and used by U.S. producers was $83 per ton, f.o.b. plant, or a decrease from that of 1989. The average value of exfoliated vermiculite, f.o.b. plant, was approximately $251 per ton, although some of the data used to arrive at this figure were estimated.

Imports of vermiculite concentrate were approximately 50,000 tons and were mainly from the Republic of South Africa. U.S. imports in 1989 were approximately 55,000 tons. U.S. exports to Canada were estimated to be 20,000 tons, about 9% of total U.S. sales of vermiculite concentrate.

The data in table 4 are rated annual capacity for vermiculite plants as of December 31, 1990. Rated capacity is defined as the maximum quantity of product that can be produced on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Plant capacity for vermiculite is based on engineering capacity provided by the companies or estimated by considering recent peak production during the past 5 years to be equal to rated capacity.

Vermiculite has been facing competition from other materials, especially in the building products market. Another adverse

TABLE 1

SALIENT VERMICULITE STATISTICS

(Thousand short tons and thousand dollars unless otherwise specified)

	1986	1987	1988	1989[e]	1990
United States:					
Sold and used by producers:					
Concentrate	317	303	304	275	230
Value	$34,400	$33,100	$33,900	$30,500	$19,100
Average value[1] dollars per ton	$108.52	$109.24	$111.51	$110.91	$83.04
Exfoliated	253	252	249	215	157
Value	$53,200	$54,600	$55,100	$48,800	$39,400
Average value[1] dollars per ton	$210.28	$216.67	$221.29	$226.98	$250.96
Exports to Canada	[e]25	[e]20	[e]20	20	[e]20
Imports for consumption	[e]35	32	[e]35	55	[e]50
World: Production[2]	[r]685	[r]726	710	695	646

[e]Estimated. [r]Revised.

[1]Based on rounded data.

[2]Excludes production by countries for which data were not available.

TABLE 2

EXFOLIATED VERMICULITE SOLD AND USED IN THE UNITED STATES, BY END USE

(Short tons)

End use	1989[e]	1990
Aggregates:		
Concrete	33,200	29,500
Plaster	1,800	400
Premixes[1]	64,300	19,500
Total	99,300	49,400
Insulation:		
Loose-fill	17,900	14,400
Block	21,100	19,200
Other[2]	2,300	3,000
Total	41,300	36,600
Agricultural:		
Horticultural	15,100	20,101
Soil conditioning	15,200	8,100
Fertilizer carrier	36,700	35,100
Total	67,000	63,300
Other[3]	7,800	7,400
Grand total[4]	215,000	157,000

[e]Estimated.
[1]Includes acoustic, fireproofing, and texturizing uses.
[2]Includes high-temperature and packing insulation and sealants.
[3]Includes various industrial uses not specified.
[4]Data do not add to totals shown because of independent rounding.

factor has been the general level of construction activity, which has been at a reduced level. Possible new growth in vermiculite use might occur in such areas as waste disposal and treatment of contaminated air and water. China may emerge as a new source for imports of vermiculite.[1]

[1]Hindman, J. R. Vermiculite. Min. Eng. (Littleton, CO), v. 43, No. 6, 1991, pp. 617-618.

TABLE 3

ACTIVE VERMICULITE EXFOLIATING PLANTS IN THE UNITED STATES IN 1990

Company	County	State
A-Tops Corp	Beaver	Pennsylvania.
Anitox Corp.	Gwinnett	Georgia.
Brouk Co.	St. Louis	Missouri.
Enoree Minerals Corp.	Spartanburg	South Carolina.
W. R. Grace & Co., Construction Products Div.	Jefferson	Alabama
	Maricopa	Arizona.
	Alameda	California.
	Orange	Do.
	Denver	Colorado.
	Broward	Florida.
	Duval	Do.
	Hillsborough	Do.
	Du Page	Illinois.
	Campbell	Kentucky.
	Prince Georges	Maryland.
	Hampshire	Massachusetts.
	Wayne	Michigan.
	St. Louis	Missouri.
	Mercer	New Jersey.
	Multnomah	Oregon.
	Lawrence	Pennsylvania.
	Greenville[1]	South Carolina.
	Dallas	Texas.
Koos Inc.	Kenosha	Wisconsin.
O.M. Scott & Sons.	Union	Ohio.
Patterson Vermiculite Co.	Laurens	South Carolina.
The Schundler Co.	Middlesex	New Jersey.
Strong-Lite Products Corp.	Jefferson	Arkansas.
Do.	De Kalb	Illinois.
Verlite Co.	Hillsborough	Florida.
Vermiculite Industrial Corp.	Allegheny	Pennsylvania.
Vermiculite Products Inc.	Harris	Texas.

[1]Two plants in county.

TABLE 4

WORLD VERMICULITE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1990

(Thousand short tons)

Country	Rated capacity[1 2]
North America:	
Mexico	1
United States	355
Total	356
South America:	
Argentina	25
Brazil	21
Total	46
Europe:	
U.S.S.R.	107
Africa:	
Egypt	1
Kenya	5
South Africa, Republic of	260
Total	266
Asia:	
India	8
Japan	20
Total	28
World total[3]	r800

rRevised.

[1]Includes capacity at operating plants as well as at plants on standby basis.

[2]Excludes countries for which data were not available.

[3]Data do not add to total shown because of independent rounding.

TABLE 5

VERMICULITE: WORLD PRODUCTION, BY COUNTRY[1]

(Short tons)

Country[2]	1986	1987	1988	1989p	1990e
Argentina	5,740	20,516	21,275	e21,000	20,000
Brazil	15,598	18,546	20,777	20,944	21,000
Egypt	546	e550	260	3300	300
India	r5,438	r2,689	4,467	3,047	4,400
Japane	17,000	17,000	17,000	17,000	17,000
Kenya	2,804	4,285	4,086	2,685	32,927
Mexico	243	177	240	331	3455
South Africa, Republic of	213,470	252,278	230,578	247,469	3242,851
U.S.S.R.e	107,000	107,000	107,000	3106,924	107,000
United States (sold and used by producers)	317,000	303,000	304,000	275,000	3230,000
Total	r684,839	r726,041	709,683	694,700	645,933

eEstimated. pPreliminary. rRevised.

[1]Excludes production by countries for which data are not available and for which general information is inadequate for formulation of reliable estimates. Table includes data available through July 19, 1991.

[2]In addition to the countries listed, Tanzania may produce vermiculite, but available information is inadequate to make reliable estimates of output levels, if any.

[3]Reported figure.

WOLLASTONITE AND ZEOLITES

By Michael J. Potter and Robert L. Virta

Mr. Potter, a physical scientist with 24 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for wollastonite since 1976. Domestic survey data were prepared by Pam Shorter, mineral data assistant.

Mr. Virta, a physical scientist with 15 years of U.S. Bureau of Mines experience, has been the commodity specialist for natural zeolites since 1986. Domestic survey data were prepared by Maureen Riley, mineral data assistant.

WOLLASTONITE

Wollastonite is natural calcium silicate and has a theoretical composition of $CaO \cdot SiO_2$. It has developed a significant role as a high-performance mineral filler in paint, plastics, and thermal board. It is used in asbestos replacement and in ceramics such as wall tile, where it promotes low shrinkage, good strength, low warpage, and fast firing.

After preliminary drilling of an extensive wollastonite deposit on the Gilbert properties near Tonopah, NV, Sikaman Gold Resources Ltd. was considering a proposed followup drilling program to prove a minimum of 2 million tons grading more than 50% wollastonite. If successful, this would be followed by a further expenditure for detailed reserve definition, extensive sample testing, and market evaluation. In late 1990, ownership of the Gilbert properties remained uncertain. During early 1990, Vancouver-listed White Plains Resources Corp. purchased a 25% stake in the properties from Sikaman. In mid-1990, White Plains raised its option to 100% by intending to purchase Sikaman's remaining 75% interest in the properties.[1]

Domestic sold and used data for wollastonite were developed by the U.S. Bureau of Mines by means of a voluntary survey. Both active operations responded, representing 100% of the total canvassed. Specific data were withheld to avoid disclosing company proprietary data.

The two U.S. producers were NYCO, a division of NYCO Minerals Inc., Essex County, NY, and R. T. Vanderbilt Co. Inc., Lewis County, NY. The tonnage of wollastonite sold or used in 1990 decreased compared with that of the previous year.

Wollastonite is used as a filler in ceramic tile, paint, and plastics. It serves as an asbestos replacement in some applications such as a reinforcement filler for boards and panels in various heat containment applications, including ovens, dryers, thermal ducting, and many other thermal applications. Wollastonite also replaces asbestos in certain cement formulations, in ceilings and floor tile, and in friction applications such as brake linings.

Prices from Industrial Minerals, December 1990, for wollastonite, exworks, converted to dollars per metric ton, were approximately $278 to $292 for acicular, minus 200 mesh; $193 to $204 for minus 325 mesh; and $209 to $215 for minus 400 mesh. Prices per metric ton for wollastonite, f.o.b. plant, bulk, were $125 to $177 for 200 mesh and $235 for 325 mesh.

In Canada, a joint venture between Cominco Ltd. and Platinova Resources Ltd. continued to assess the Deloro wollastonite property near Marmora, Ontario, halfway between Toronto and Ottawa. Four zones had been outlined, with the grade of wollastonite ranging from 28% to 60%. The mineralization consisted of calcite-wollastonite-diopside marbles. Wollastonite concentrates were obtained by cofloating wollastonite and diopside from calcite and then magnetically separating diopside from the wollastonite. Both companies were reassessing calcite and wollastonite markets and conducting further tests to optimize products.

Another wollastonite project involved Ram Petroleums Ltd.'s evaluation of a deposit at Mount Grove in eastern Ontario. Drilling in late 1990 had proved 2.8 million tons of ore grading an average of 35% wollastonite with calcite and minor diopside. Laboratory work was being carried out.

In British Columbia, Performance Minerals of Canada Ltd. agreed to acquire a 50% working interest in Tri-Sil Minerals Inc.'s Wormy Lake wollastonite property about 45 kilometers northwest of Vancouver. Potential reserves were estimated to be more than 50 million tons. During the next 5 years, Performance Minerals was to prove up the reserves. Material tested down to minus 100 mesh showed high aspect ratios of 20:1 on average. A crushing plant was sizing low-grade wollastonite and selling it to Tilbury Cement of Richmond, British Columbia.

In the Yukon Territory, Archer, Cathro, & Associates discovered a deposit about 450 kilometers from the port town of Haines, AK. Surface grab samples indicated some material containing 60% and 80% to 85% wollastonite; but drilling of core samples had yet to be carried out.[2]

In China, wollastonite production in Jilin and Hubei Provinces was estimated to be at least 70,000 tons per year. In Yunnan Province, a deposit was reportedly discovered in early 1989 containing an estimated 50 million to 100 million tons of reserves. If proven, this would represent the world's largest wollastonite deposit.

Domestic consumption probably accounted for the bulk of the wollastonite

produced in China. Wall tile was the major end use, but increasing quantities were being used in other applications such as pigments, paper and plastic fillers, ceramics and porcelains, electrode coatings, and other uses. The most rapid increase in consumption was in steelmaking, where wollastonite is used as a protective slag for continuous casting carbon steel and for casting silicon steel sheet.

Exact figures for total annual wollastonite exports from China were not available. However, exports in 1985 from the Jilin branch of the China Metallurgical Imports and Export Corp. were an estimated 36,000 tons.[3]

In Greece, Metallic & Industrial Minerals Mevior SA of Thessaloniki was developing a wollastonite deposit in Kimmeria. The deposit contained 300,000 tons of 60% to 70% wollastonite and 10% calcite. Construction of a 500-ton-per-year pilot plant was to begin in late 1990.

In Mexico, Cia Minera Constelacion S.A. de C.V., an affiliate of Cominco Resources International Ltd., continued to develop the San Martin wollastonite deposits about 50 kilometers northwest of Hermosillo in the State of Sonora. Drilling was being carried out in the South Body, which contains 0.7 million tons grading 70% wollastonite. Mineralization consisted of wollastonite-calcite-quartz-diopside marble. Some hand-sorted material was ground into test quantities of powder and acicular grades suitable for the ceramics, plastics, and coatings markets. Marketing studies were underway, and a small-scale production test was being planned.

In the Republic of South Africa, the country's first commercial wollastonite operation appeared ready to come on-stream in early 1991. Pella Refractory Ores' mine at Modderfontein, 18 kilometers northeast of Garies in Namaqualand, contained in excess of 2 million tons. The ore, containing 50% to 60% wollastonite, requires a complex three-stage beneficiation process, including electrostatic and high-intensity magnetic separation and flotation, to give a product containing more than 90% wollastonite. An output of 13,600 tons per year of wollastonite was anticipated from treating 72,000 tons per year of ore.

Initial production was slated to be about 500 tons per month, increasing to 1,000 tons per month as markets develop. Two grades would be produced for the ceramics and asbestos replacement markets. Much of the output would be exported.[4]

Research on the synthesis of B-wollastonite (synthetic wollastonite) was performed. Highly reactive silica such as diatomite was used, important deposits of which occur in Spain. Other silica materials were also used for comparison, such as quartz and silica gel. In the whiteware industry, modern fast-firing technology has almost fully replaced traditional double firing, resulting in high energy savings. B-wollastonite is one of the raw materials suitable for compositions to be fast fired because of the good characteristics it gives to ceramic bodies, such as low drying and low firing shrinkage, high bending strength, etc.[5]

A paper described the surface modification of silica and silicate minerals by silanes, on which Quartzwerke GmbH has done development work and has commercialized since the early 1970's. A variety of silanes are used to coat silica flour, cristobolite, wollastonite, alumina trihydrate, and calcined clay.

The company's TREMIN-wollastonite (silane-treated wollastonite) is used in the improvement of polyamide, polypropylene, and polyurethane engineering resins as well as fluorosilicone elastomers. TREMIN-wollastonite used in polyamide compounds in the automotive industry adds toughness and impact strength to the polymer. It may be used partially to replace glass fiber reinforcement without loss of strength and stiffness of the composite. TREMIN-wollastonite can also be employed in fluoroelastomers instead of carbon black.[6]

The outlook appears to be favorable for wollastonite, especially in fine particle size, high aspect ratio, and chemically modified grades.

The plastics market is one area of further potential growth. Chemically treated grades of wollastonite are increasing by being required to satisfy customer and product requirements. In the United States, plastics consumption has been affected by reduced activity in two major markets, construction and automobiles. However, plastic consumption in Europe in 1990 was at a high level.

Wall tile has been a major end use of wollastonite. U.S. consumption of tile increased during the past 10 years, including U.S. output and imports from Europe. In 1990, the U.S. remodeling market was strong, although the construction industry was experiencing a slowdown. European tile producers generally rely on cheaper lime, silica, and feldspar raw materials rather than on wollastonite for their wall tile bodies.

Asbestos replacement is a possible growth area because of a proposed ban in the United States on almost all asbestos-containing materials in stages during the next 7 years. Outside the United States, asbestos is being replaced to some extent by wollastonite in brake linings, gaskets, and products where short-fiber asbestos was previously used. If legislation should be taken up by authorities in Europe and Asia, prospects of a growing market for high aspect ratio wollastonite are good.[7]

ZEOLITES

Zeolites are hydrated aluminosilicates of the alkaline and alkaline-earth metals. Approximately 40 natural zeolites have been identified during the past 200 years, the most common of which are analcime, chabazite, clinoptilolite, erionite, ferrierite, heulandite, laumontite, mordenite, and phillipsite. Zeolites are commercially valuable because of their unique ion-exchange, molecular sieving, and catalytic properties.

Commercial zeolite deposits in the United States are associated with the alteration of volcanic tuffs in saline, alkaline lake deposits, and open hydrologic systems. The deposits are in Arizona, California, Idaho, Oregon, Nevada, New Mexico, Texas, and Utah. The major components of these deposits are chabazite, clinoptilolite, mordenite, and phillipsite. Erionite, orthoclase and plagioclase feldspar, montmorillonite, opal, quartz, and volcanic glass may be present in some deposits as minor components. The composition of these deposits was determined primarily by the temperature and pressure of formation and the chemistry of the altering fluids. When the alteration process went to completion, the zeolite content of portions of some deposits approached 100%.

Conventional mining techniques were used in the mining of natural zeolites. The overburden was removed to permit

access to the ore, and the ore was stripped for processing using front-end loaders or tractors equipped with ripper blades. The fractured ore was dried and then crushed using either jaw crushers or roller mills. The crushed ore was packaged directly for shipping or was screened to remove fine material when a granular product was required.

Nine companies mined or sold natural zeolites in the United States in 1990. Clinoptilolite was mined in California, New Mexico, Nevada, Oregon, Texas, and Wyoming. Chabazite was mined in Arizona. Total domestic production and sales were 15,569 metric tons (17,162 short tons) in 1990, an increase of 28% from those of 1989.

Natural zeolites were used for pet litter, odor control, animal feed supplement, desiccant, chemical carrier, aquaculture, wastewater cleanup, aquarium filters, gas adsorbent, water purification, and oil and/or grease adsorbent, in decreasing order of consumption. The properties that made natural zeolites commercially valuable included ammonium adsorption (aquaculture, aquarium filters, odor control applications, pet litter, and water purification), moisture adsorption (desiccants, odor control, and pet litter), and ion-exchange capabilities (wastewater cleanup).

Atlantic Richfield Co., Steelhead Specialty Minerals, and the Advanced Minerals and Hazardous Waste Processing Center for Excellence at Montana Tech investigated the use of clinoptilolite for removing heavy and toxic metals from mine water in a former copper mine in Montana. The mine water contained arsenic, copper, and zinc that potentially could contaminate the local ground water. Preliminary tests indicated that the heavy-metals content of the water could be reduced with the application of lime, but that the water did not meet drinking water standards. The partnership will perform tests to determine if the levels of heavy metals can be reduced further through an ion-exchange process using clinoptiliolite as the exchange media.[8]

TABLE 1

DOMESTIC ZEOLITE PRODUCERS, 1990

State and company	Type of zeolite
Arizona:	
GSA Resources Inc.	Chabazite
NRG Inc.	Do.
UOP Inc.	Do.
Non Scents	Do.
California:	
Steelhead Resources Ltd.	Clinoptilolite
Idaho:	
Teague Mineral Products Co.	Do.
Nevada:	
East-West Minerals Inc.	Do.
Texas:	
Zeotech Corp.	Do.
Wyoming:	
U.S. Zeolites	Do.

The Montana Bureau of Mines and Geology received a grant for a 2-year study of the potential use of natural zeolites to remove metals from polluted waters and soils. The zinc content of one polluted water was reduced from 175 parts per liter to 0.02 parts per liter in a preliminary ion-exchange test.[9]

Mordenite, a natural zeolite, performed poorly as a shape-selective catalyst. It was rapidly deactivated during the reaction process. Researchers at Dow Chemical Co. modified the mordenite structure through an acid washing, calcining, and activation process to improve its performance as a shape-selective catalyst. The treatment increased the ratio of silicon to aluminum from 5:1 for the natural zeolite to 15:1 for the modified form of mordenite and increased the pore volume of the zeolite. The modified mordenite was suitable for use as a shape-selective catalyst for industrial applications such as the alkylation of biphenyl with propylene.[10]

Zeolites were fed to roosters and breeder hens in an effort to increase the strength of shells of eggs for market. The zeolite additive strengthened the shell strength by increasing the absorption of calcium. Researchers at Ethyl Corp. began feeding pigs, cows, and sheep zeolite as a feed additive to see if it improves bone strength and increases growth rates of the animals.[11]

Researchers at the University of California, Santa Barbara, studied molecular interactions on the surface of a zeolite by using an atomic force microscope. The study examined how positively charged t-butyl ammonium ions and neutral t-butanol molecules were bound to the surface of a zeolite that is used to remove ammonium and phosphate ions during wastewater treatment. Positively charged t-butyl ammonium ions occurred as clumps on the surface of the zeolite, while the neutral t-butanol molecules spread over the surface as a sheet. A better understanding of the molecular interactions that affect catalytic reactions was gained through the use of the atomic force microscope.[12]

Demand for synthetic zeolites for detergents continued to grow in Europe and the United States. Annual consumption in Europe was estimated to be 325,000 tons. Present U.S. demand was estimated to be 100,000 tons per year.[13] Manufacturers substituted synthetic zeolites for phosphates because phosphates promoted plant growth that degraded the quality of the water into which the phosphate-rich wastewater was released. Zeolites exchanged sodium for calcium and magnesium in the washwater much the same as the phosphate additives but at a slower rate. Fine grinding was used to enhance ion exchange and avoid visible zeolite deposition on clothes. Zeolite additives were nontoxic to marine and freshwater life.[14]

[1]O'Driscoll, M. Wollastonite Production—Tempo Rises as Markets Grow. Ind. Miner. (London), No. 279, Dec. 1990, pp. 15, 19.

[2]Pages 17 and 19 of work cited in footnote 1.

[3]Roskill Information Services Ltd. (London). The Economics of Wollastonite 1990. 4th ed., 1990, pp. 26–27.

[4]Page 19 of work cited in footnote 1.

[5]Ibanez, A., J. M. Gonzalez Pena, and F. Sandoval. Solid-State Reaction for Producing B-Wollastonite. Am. Ceram. Soc. Bull., No. 69, No. 3, Mar. 1990, p. 374.

[6]Hofmann, F. A., and D. Skudelny. Surface Treated Mineral Fillers—Growing Markets for Specialty Products. Paper in 9th "Industrial Minerals" International Congress, ed. by J. B. Griffiths (Proc. Conf. Sydney, Australia, Mar. 25–28, 1990). Met. Bull. PLC, 1990, pp. 90–103.

[7]Pages 21–23 of work cited in footnote 1.

[8]The Miner's News. California Zeolites Studied for Role in Mine Drainage Cleanup at Montana's Berkeley Pit. Feb.-Mar. 1990, p. 9A.

[9]Great Falls (Montana) Tribune. Zeolites Studied for Mining Potential. Nov. 22, 1990.

[10]Haggin, J. Mordenite Used as Shape Selective Catalyst. Chem. & Eng. News, v. 68, No. 32, 1990, p. 29.

[11]Business Week. A New Chicken Feed That Arouses Roosters. No. 3173, Aug. 13, 1990, p. 120.

[12]Science News. High-Tech Microscope Makes Molecules Move. V. 137, No. 11, Mar. 17, 1990, p. 165.

[13]Chemical Week. Soaps and Detergents. V. 148, No. 4, Jan. 31, 1990, pp. 20–64.

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ZINC

By James H. Jolly

Mr. Jolly is a physical scientist (geologist) with more than 30 years of mining experience, including positions with Hecla Mining Co., Roan Selection Trust, and the U.S. Geological Survey. He has been a mineral commodity specialist for the U.S. Bureau of Mines for 18 years and the zinc specialist for the past 9 years. Domestic survey data were prepared by Tony E. Morris, statistical assistant. International production tables were prepared by Virginia A. Woodson and Harold D. Willis, international data coordinators. Historical figures were prepared by James W. Smith, Branch of Metals.

Zinc is an essential element for health and for development and maintenance of modern society. It has been used by humankind in compounds, alloys, and metal for more than 2,000 years and has been surpassed only by iron, aluminum, and copper 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.

The state of the domestic zinc industry was variable in 1990. Zinc mine output was the highest in 24 years, and smelters operated at high-capacity utilization rates. Industrial consumption of zinc, however, declined to its lowest level since 1985. The value of unmanufactured zinc exports, about $370 million, was up significantly owing largely to a threefold increase in the value of exported zinc concentrates. The value of unmanufactured zinc imports, $1,133 million, was down more than $200 million from that of the previous year.

World mine production was a record high, whereas world smelter output was third highest. In 1990, U.S. mines produced 7.4% of the world zinc output and U.S. smelters produced 5% of the world refined metal output. World zinc consumption exceeded 7 million tons for the fourth straight year but was estimated to have been only the third highest, after 1988 and 1989. The United States continued to be the world's largest consumer of zinc metal, consuming about 14% of the world total.

Major changes in the U.S. zinc pricing structure were underway as virtually all producers had switched to a London Metals Exchange (LME) pricing basis before yearend. Zinc prices held at high levels through midyear, but rapidly declined in the last quarter of the year with the onset of a decline in U.S. economic activity.

DOMESTIC DATA COVERAGE

Domestic data for zinc were developed by the U.S. Bureau of Mines from five separate, voluntary surveys of U.S. operations. Typical of these was the "Slab Zinc" consumption survey sent out monthly or annually, depending on consumption quantities; small consumers are canvassed annually. Of the 299 operations to which the survey was sent, 281 responded, representing an estimated 94% of the total slab zinc consumption shown for 1990 in tables 1, 15, 16, 17, and 18. Consumption for the nonrespondents was estimated using prior-year levels adjusted for general industry trends.

BACKGROUND

Zinc is the fourth most widely used metal, yet through most of its history, it was not known as a distinct metal. Zinc has been found in bronze artifacts made 5,000 years ago and has been used as a component of brass in Europe and Asia for more than 2,500 years. Although a few artifacts composed mainly of zinc metal have been dated back to 500 B.C., the extreme scarcity of such items before A.D. 500 suggest the metal was made by accident or the technology was short lived and forgotten. The Chinese are known to have produced articles from zinc metal in the 6th century A.D. and are generally credited with being the first to develop the technology to make zinc metal. Zinc was smelted in the Zawar area of India as early as A.D. 1000 and was produced there on a large scale beginning in the 13th century. Europeans apparently were unfamiliar with zinc metal until the 16th century, even though they had used earthy forms of zinc compounds for many years to make brass.

Uses before zinc metalmaking involved the naturally occurring zinc minerals and oxidic zinc materials resulting from smelting lead and copper ores. Zinc's presence in bronze was most likely accidental and dependent on the ores used, whereas zinc compounds were recognized and were deliberately mixed with copper to produce brass by the cementation process. Some cosmetics and medicines of ancient Egypt contained appreciable amounts of zinc carbonate and/or zinc oxide.

The technology of smelting zinc is thought to have been brought to Europe from China around 1730, and in the early 1740's, the first European zinc smelter was erected in England. By the end of the 18th century, large-scale commercial smelting had begun in Europe, mainly using the Silesian method, an improved distillation process utilizing horizontal muffles of large capacity. Zinc distillation by the Belgian method, which employed numerous small horizontal retorts in a single furnace, followed within a few years. The Belgian method gained widespread acceptance and became the preferred production method for the next 100 years.

In the United States, the first zinc metal was produced in 1835 at the Arsenal in Washington, DC. The Government brought in workers from Belgium to build and operate a small spelter furnace to produce zinc from zincite ore from New Jersey. The primary purpose for the zinc produced was to provide alloying metal to make brass for the manufacture of U.S. standard units of weight and measure.

The U.S. zinc mining industry began about 1850 with production of oxides and compounds from zinc ores in New Jersey and Pennsylvania. The first commercial zinc metal production began in 1859 in

TABLE 1

SALIENT ZINC STATISTICS

(Metric tons unless otherwise specified)

		1986	1987	1988	1989	1990
United States:						
Production:						
Domestic ores, recoverable content	thousands	202,983	216,327	244,314	275,883	515,355
Value		$170,050	r$199,924	$324,249	$499,103	$847,485
Slab zinc:						
From domestic ores		191,079	205,275	196,476	r165,038	157,562
From foreign ores		62,290	56,070	44,818	r95,267	105,142
From scrap		62,912	82,589	88,492	r97,904	95,708
Total		316,281	343,934	329,786	358,209	358,412
Secondary zinc[1]		255,752	r269,319	248,461	r249,122	245,644
Exports:						
Ores and concentrates (zinc content)		3,269	16,921	33,590	78,877	220,446
Slab zinc		1,938	1,082	482	5,532	1,238
Imports for consumption:						
Ores and concentrates (zinc content)		75,786	46,464	62,966	40,974	46,684
Slab zinc		665,126	705,985	749,133	711,554	631,742
Stocks of slab zinc, Dec. 31:						
Industry		100,563	96,372	85,854	90,711	88,104
Government stockpile		340,577	340,577	340,577	340,577	340,577
Consumption:						
Slab zinc:						
Reported		705,963	798,148	833,473	r884,655	826,489
Apparent (rounded)[2]		999,000	1,052,000	1,089,000	1,060,000	991,000
All classes (rounded)[3]		1,274,000	1,383,000	1,340,000	r1,311,000	1,239,000
Price: High-Grade, cents per pound (delivered)		38.00	41.92	60.20	r82.02	74.59
World:						
Production:						
Mine	thousand metric tons	r6,842	r7,176	6,967	P7,191	e7,325
Smelter	do.	r6,693	r7,038	7,113	P7,203	e7,041
Price: London, cents per pound		34.19	36.20	51.11	r77.64	66.46

eEstimated. PPreliminary. rRevised.

[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.

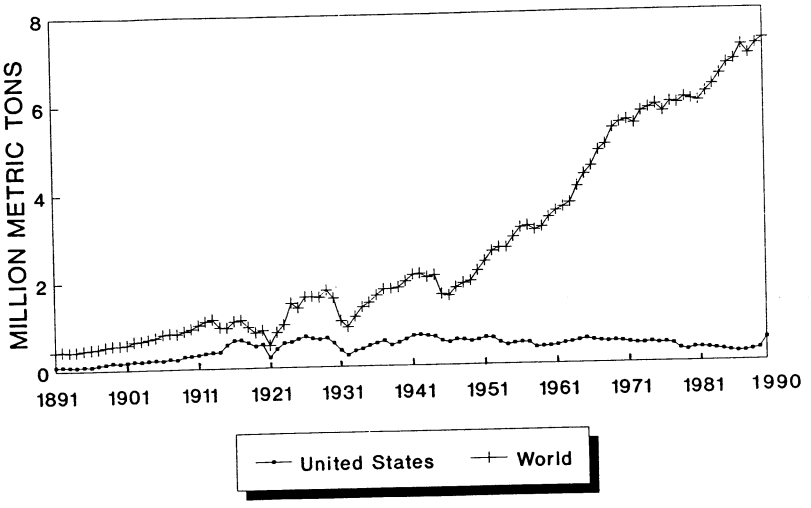
Pennsylvania. In 1860, smelters were built in Illinois and New Jersey to treat nearby ores. By the turn of the century, U.S. zinc mining and smelting activity had grown rapidly, mainly developing in Illinois, Kansas, Missouri, and Pennsylvania because of closeness to zinc ores and adequate coal for smelting fuel. The discovery of low-cost natural gas in Kansas in the mid-1890's led to increased smelting in that State and made Kansas the leading zinc-producing State by 1899. The development of mineral flotation processes early in the 20th century made it possible to recover zinc from complex ores and produce high-grade concentrates. This led to zinc production in many areas of the United States.

World zinc metal production was centered in Europe in the 18th and 19th centuries; however, toward the end of the latter century, U.S. zinc production had risen substantially, resulting in a second major world production center. By 1901, the United States had become the leading world zinc metal producer, a position held for most of the next 70 years. After World War I, a number of countries, including Australia, Canada, Japan, and the U.S.S.R., developed substantial zinc smelting industries. Despite increased zinc production elsewhere, Europe, except during the two World War periods, and the United States continued to be the main zinc smelting centers, in part because they also were the high zinc consumption areas. From the late 1960's, U.S. zinc metal production declined because numerous smelters closed for environmental and technical reasons, resulting in the reduction of U.S. zinc smelter capacity to one-third of its former level.

Trends in U.S. zinc mine and smelter production compared with world production from 1981 are shown in figure 1 and figure 2, respectively. For the most part, the trends are similar. U.S. mine and smelter output of zinc was dominant until

FIGURE 1

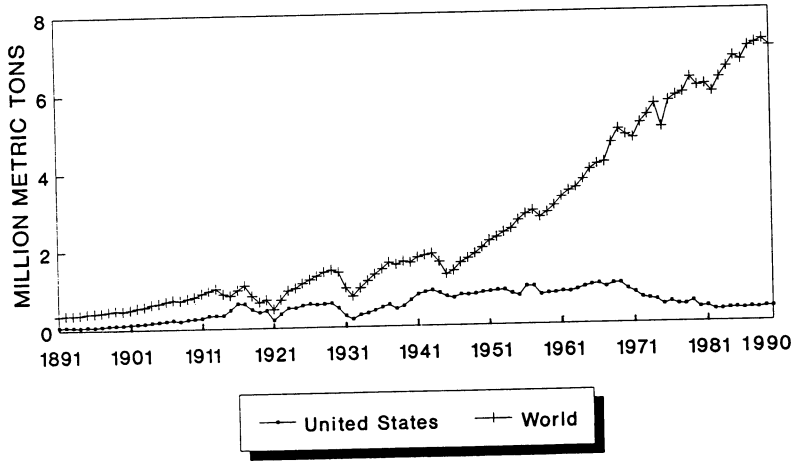
U.S.[1] AND WORLD ZINC MINE PRODUCTION



[1]Recoverable content.

FIGURE 2

SLAB ZINC PRODUCTION, UNITED STATES AND WORLD



after World War II, but declined in relative importance thereafter owing to new production in many foreign countries. Despite production decreases in recent decades, the United States, cumulatively, has accounted for more of the world's zinc mine and smelter output than any other country. Cumulative U.S. recoverable mine production through 1990 has totaled about 41 million metric tons, or about 15% of the world total output (about 270 million tons). U.S. primary and secondary slab zinc production cumulatively has totaled about 51 million tons, about 20% of the world total (about 250 million tons).

Historical salient zinc statistics and graphical illustrations of various aspects of U.S. production and consumption of zinc are given in table 42 and in figures 3 through 7. In the above-mentioned table and figures, some data, especially those prior to 1907, were estimated. Data for the U.S. zinc industry, for the most part, have been well documented in annual volumes of Mineral Resources of the United States and subsequent volumes of the Minerals Yearbook. These were the principal sources for the statistical data used.

Zinc has been mined in 30 States. New Jersey has been the largest producing State, followed by Oklahoma, Tennessee, Missouri, and Idaho. Figure 3 shows, graphically, historical zinc mine production by State through 1990.

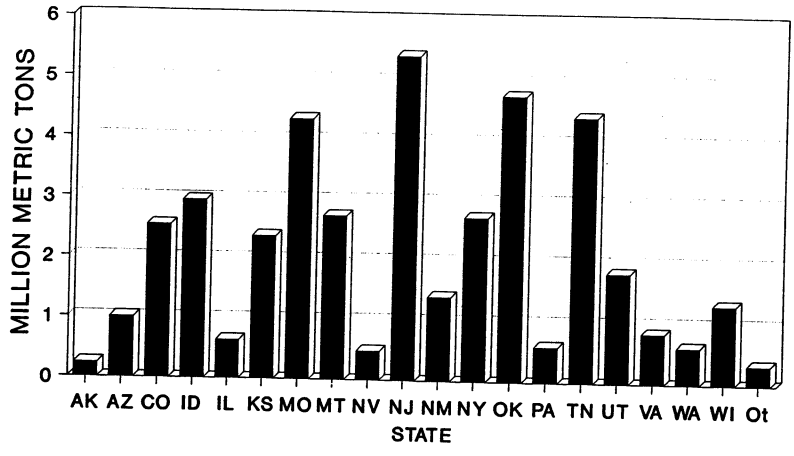
Since 1859, domestic smelters in 16 States have processed an estimated 61 million tons of zinc contained in ores and concentrates, yielding about 47 million tons of slab zinc and about 8 million tons of zinc contained in compounds, mainly American-process zinc oxide. Pennsylvania has been the largest metal-producing State. Other principal metal producers, in decreasing order of output, are Illinois, Oklahoma, Montana, and Texas. Historical cumulative smelter output of metal by State is graphically given in figure 4. A breakdown of ore-sourced zinc compound production by State is not available, but Pennsylvania, followed by Illinois, Kansas, and Ohio, have been the leading producing States of American-process oxide.

An additional 4 million tons of refined zinc metal was produced in the 1859-1990 period from secondary materials at primary and secondary smelters in the United States. Secondary slab zinc production has accounted for less than 8% of the total historical U.S. refined metal output, but percentagewise it has increased in the past few decades, owing mainly to decreased primary production and, in 1990, accounted for about one-fourth of U.S. production. The trends and sources of U.S. slab zinc production over the past 100 years are shown in figure 5.

The United States has been the world's largest zinc-consuming country since the early 1900's. U.S. zinc consumption was about 14% of the world total in 1990, but, cumulatively, since 1850, the United States has accounted for an estimated one-fourth of the total world consumption. Figure 6

FIGURE 3

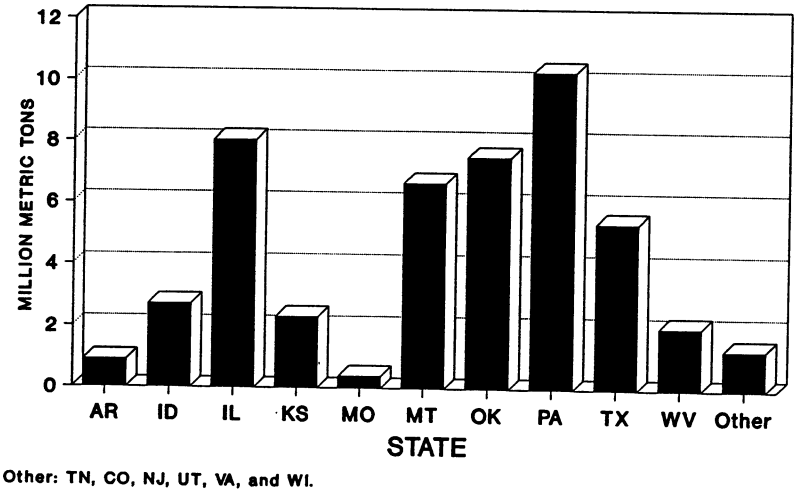
CUMULATIVE RECOVERABLE ZINC MINE PRODUCTION, BY STATE



Ot-Other: AR, CA, IA, KY, NH, NC, ME, OR, SD, and TX.

FIGURE 4

CUMULATIVE ZINC SMELTER PRODUCTION, BY STATE



Other: TN, CO, NJ, UT, VA, and WI.

shows the 100-year trend in U.S. zinc consumption and the component sources of consumption. The consumption shown is an approximation only because figures on net trade with foreign countries in zinc compounds and alloys generally were not available and are not included. Net trades in ores and slab zinc, by far the largest components of U.S. zinc trade, however, are considered in the data.

In figure 6, the "consumed as ore" category mainly reflects ore-sourced zinc oxide production. This category has declined sharply in the past few decades owing to plant closings; only a few thousand tons of zinc fell into this category in 1990. The "slab zinc" component includes net metal trade with foreign countries, stock changes, and U.S. production, including that from secondary sources. The secondary zinc component includes compound and alloy production from wastes and scrap but not from secondary slab zinc. About one-half of this component is brass scrap, most of which is remelted to make additional brass rather than being separated into its component elements.

A breakdown of the basic use areas of U.S. slab zinc consumption for the past 90 years is given in figure 7. Galvanizing has been the largest consumer of slab zinc, and, overall, has accounted for about one-half of domestic slab zinc consumption. The most significant change in slab zinc consumption was the rapid rise in the use of zinc-base alloy following development of satisfactory alloys for diecasting purposes in the mid-1920's. Spurred on mainly by use in the automobile industry, zinc diecasting use expanded manyfold, reaching its highest level in the 1960's and early 1970's. In the mid-1970's, the energy crisis led to downsizing and weight reduction programs in the automotive industry and substantial reductions in zinc-base alloy use. Rolled zinc use increased 20,000 to 30,000 tons per year from 1982 when "zinc penny" production started. To protect proprietory data, rolled zinc in figure 7 was included in "Other" from the mid-1980's.

ANNUAL REVIEW

Legislation and Government Programs

The Environmental Protection Agency (EPA) conditionally exempted 15 of 20 mineral processing wastes from hazardous waste regulations as provided by the Resource Conservation and Recovery Act (RCRA).[1] Slag from primary zinc processing was one of the wastes exempted. A final rule on how these wastes were to be regulated was expected in early 1991.

The EPA promulgated wastewater treatment standards for zinc, cadmium, chromium, and nickel in steelmaking electric arc furnace (EAF) dust and treatment standards for zinc phosphide before disposal.[2] Effective dates for both standards were August 8, 1990. In this final rule, EPA extended the existing interim treatment standard for EAF solid waste for 1 more year to August 1991.

EPA published its Toxics Release Inventory of 1988 data.[3] Zinc compounds and

FIGURE 5

U.S. SLAB ZINC PRODUCTION, PRIMARY AND SECONDARY

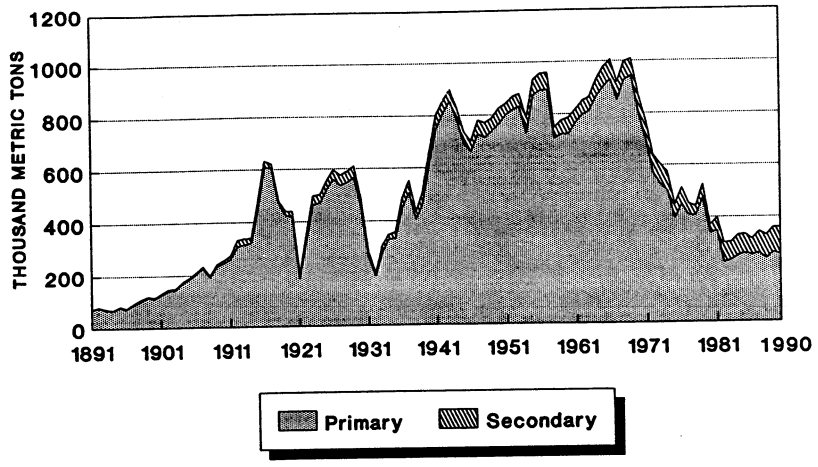
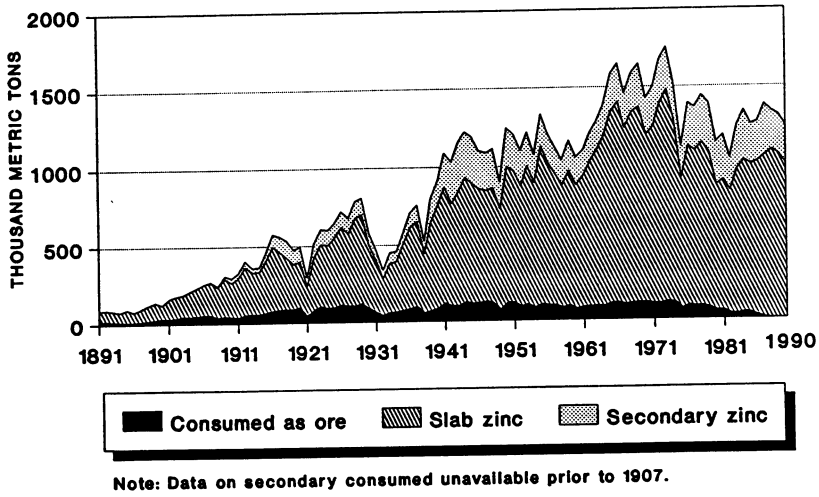


FIGURE 6

U.S. ZINC CONSUMPTION, ALL CLASSES



Note: Data on secondary consumed unavailable prior to 1907.

zinc fume were 2 of the top 25 chemicals with the largest releases and transfers in 1988.

U.S. zinc-producing companies continued to be granted a depletion allowance of 22% on domestic production of zinc and 14% on foreign production in 1990. The Superfund taxes on production of zinc chloride and zinc sulfate also were unchanged, remaining at $2.22 and $1.90 per ton, respectively.

Strategic Considerations

Supply.—U.S. zinc mine and smelter production and available capacity are inadequate to supply U.S. zinc requirements. Ore reserves are sufficient at operating mines to permit increased output on a short-term basis, and some mines now on a care-and-maintenance basis could be reactivated in 3 to 12 months.

The domestic ore reserve base is large (see table 41) but could not be tapped adequately until after the first year or so of an emergency condition. Domestic smelter capacity is woefully lacking and would be the limiting factor for increased U.S. refined zinc output. Inadequate zinc smelter capacity also severely limits the Nation's ability to produce a number of strategic and critical zinc byproduct materials, such as cadmium, germanium, and indium.

Although the Red Dog Mine in northwest Alaska nearly doubled U.S. zinc mine output in 1990, this new output was not expected to improve U.S. self-sufficiency because all of the zinc concentrates were scheduled for export. Even if Red Dog concentrates were redirected for U.S. consumption only, little or no smelter capacity is available to process the material. In 1990, for example, domestic zinc mine production substantially exceeded U.S. smelter feed requirements, resulting in net exports of about 174,000 tons of zinc in concentrate.

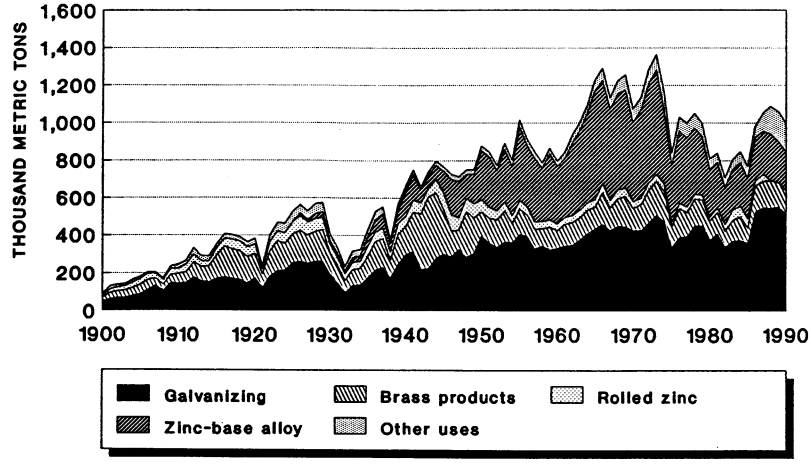
Although imports constitute a large proportion of U.S. zinc supply, about 60% of the zinc metal, concentrate, and compound imports comes from Canada and Mexico, and, therefore, the risk of supply disruption is low. Other traditional sources of zinc supply depend on sea transport, and the risk of supply disruption is considerably higher.

Stockpile.—A stockpile of zinc for national defense purposes has been maintained by the Government for more than 50 years. Materials in the National Defense Stockpile (NDS), managed by the Department of Defense since July 1988, can be released by the President if deemed necessary for defense or essential civilian purposes.

During World War II, the Government regulated the zinc industry and accumulated zinc stocks to ensure adequate supplies for the war effort. Concerns related to national defense after the war resulted in various stockpiling programs that evolved into the current NDS. The stockpiles contained a record-high inventory of 1.44 million tons of zinc in 1959, but sales of zinc considered excess of goals reduced this inventory to 340,194 tons by the end of 1975. The stockpile goal for zinc,

FIGURE 7

U.S. SLAB ZINC CONSUMPTION



Source: Bureau of Mines IC 7450, 1900-45 and Minerals Yearbook 1946-90.

1.293 million tons, was established in April 1980, but no zinc had been purchased through 1990 to meet this goal. At the end of 1990, the zinc stockpile totaled 343,202 tons, including 2,625 tons of zinc contained in brass. Sharply lower goals for zinc have been proposed in the past few years, but none have been approved.

Production

Mine Production.—U.S. zinc mine output was the highest since 1966 and almost double that of 1989. The newly opened Red Dog Mine in Alaska accounted for most of the additional production. Contributing to production was the opening of a new mine in Nevada and the reopening of a zinc-lead mine in Idaho. The Idaho mine, however, closed after operating for only 7 months.

The 20 leading U.S. zinc-producing mines accounted for more than 98% of production, with the 5 leading mines accounting for 60%. Alaska supplanted Tennessee as the principal zinc-producing State; those two States were followed by New York, Missouri, Colorado, and Montana. The leading domestic zinc mine producers were ASARCO Incorporated, Cominco Alaska Inc., Union Zinc Co., and Zinc Corporation of America (ZCA).

Two mines, Red Dog and Greens Creek, accounted for all of Alaska's zinc production and an estimated 40% of total U.S. output. Cominco Alaska, a subsidiary of Cominco Ltd., officially opened its Red Dog Mine in northwestern Alaska in August. The mine was operated all year, although in the early part of the year startup problems hindered production. In 1990, the company milled 904,000 tons of ore averaging 26.5% zinc, 8.5% lead, and 3.6 ounces of silver per ton and produced 306,100 tons of zinc concentrate averaging 56.9% zinc, 51,400 tons of lead concentrate averaging 55.1% lead, and 45,000 tons of bulk concentrate averaging 31.7% zinc and 22.9% lead. Ore reserves at yearend were 61 million tons averaging 18.5% zinc, 5.4% lead, and 2.7 ounces of silver per ton. An additional 14.5 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.—reached normal production and operated its mine on Admiralty Island at design capacity in 1990. Greens Creek Mining, the mine operator, milled 348,000 tons of ore grading 9.7% zinc, 4.4% lead, 22 ounces of silver per ton, and 0.11 ounce of gold per ton and produced 33,660 tons of zinc, 15,200 tons of lead, 7.6 million ounces of silver, and 38,200 ounces of gold in concentrates. Three types of concentrates—zinc, lead, and bulk zinc-lead—were produced; all were exported to foreign smelters. Exploration during 1990 more than doubled the ore reserves. At yearend, ore reserves were about 5.8 million tons averaging 12.4% zinc, 4.2% lead, 16.6 ounces of silver per ton, and 0.14 ounce of gold per ton.

In Tennessee, zinc was produced at six underground mines by Asarco and two divisions of Union Zinc, Jersey Miniere Zinc Co. (JMZ), and Jefferson City Zinc Div. Asarco's production at four mines was 63,050 tons of zinc in concentrate, down slightly from that of 1989. At yearend, ore reserves at the four mines were 5.7 million tons averaging about 3.3% zinc, about the same ore tonnage and grade reported at the end of 1989.

Production at Union Zinc's two mines was about the same as that of last year. JMZ's Elmwood-Gordonsville Mine was developing the nearby Stonewall ore body and planned to integrate Stonewall production into present operations.

In Missouri, zinc was produced as a coproduct of lead at nine underground lead mines along the Viburnum Trend by three companies, Asarco, Doe Run Co., and Cominco American Inc., a subsidiary of Cominco Ltd. According to Asarco's annual report, zinc output in concentrate at the West Fork Mine was 14,250 tons, up about 1,200 tons from that of 1989, and at the Sweetwater Mine, production was 3,175 tons, down about 1,200 tons. At yearend, ore reserves at the West Fork Mine were 7.8 million tons averaging 1.38% zinc and 5.8% lead with some copper and silver, and at the Sweetwater Mine, 21.1 million tons of ore averaging 4.9% lead and 0.58% zinc. Zinc output at the Magmont Mine, a joint venture of Cominco American and Dresser Industries Inc., increased over that of 1989 owing to an increase in ore output. According to the Cominco annual report, the Magmont mill processed about 0.98 million tons of ore grading 1% zinc, yielding 8,030 tons of zinc in 13,800 tons of concentrate in 1990. Ore reserves continued to decline and were expected to be exhausted in about 3 years. At yearend, ore reserves totaled 3.2 million tons and averaged 8.2% lead, 1.3% zinc, and 0.3% copper.

Fluor Corp. became the sole owner of Doe Run in May when it bought out for $125 million the 42.5% interest held in the company by Homestake Lead Co. of Missouri. According to Fluor, Doe Run produced about 25,000 tons of zinc in 44,500 tons of zinc concentrate at its six

TABLE 2

MINE PRODUCTION OF RECOVERABLE ZINC IN THE UNITED STATES, BY MONTH

(Metric tons)

Month	1989	1990
January	21,994	39,042
February	20,794	36,880
March	24,038	38,542
April	23,315	38,323
May	24,816	40,064
June	24,130	39,222
July	20,605	51,462
August	25,068	57,934
September	22,868	45,335
October	24,864	43,252
November	22,643	41,001
December	20,746	44,298
Total[1]	275,883	515,355

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

TABLE 3

MINE PRODUCTION OF RECOVERABLE ZINC IN THE UNITED STATES, BY STATE

(Metric tons)

State	1986	1987	1988	1989	1990
Alaska	—	—	—	W	W
Colorado	W	W	W	W	W
Idaho	351	W	W	W	W
Illinois	W	W	W	W	W
Kentucky	—	10	W	—	W
Missouri	37,919	34,956	41,322	50,790	48,864
Montana	—	W	18,935	W	W
Nevada	—	—	—	—	7,889
New Jersey	W	—	—	—	
New Mexico	—	—	—	W	W
New York	W	W	W	W	W
Tennessee	102,118	115,699	119,954	W	W
Total	202,983	216,327	244,314	275,883	515,355

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

lead mines and four mills in the fiscal year ended October 31. Fiscal 1989 zinc production was about 3,000 tons higher. At yearend, Doe Run's ore reserves were estimated to be about 70 million tons grading 4.8% lead, 0.9% zinc, and 0.3% copper.

In Montana, the Montana Tunnels Mining Co., a subsidiary of Pegasus Gold Inc., mined and milled 3.8 million tons of ore at its Montana Tunnels Mine in 1990; concentrates containing 15,500 tons of zinc, 6,030 tons of lead, 1.2 million ounces of silver, and 59,100 ounces of gold were produced. The discovery of low-grade zones in the ore body and harder than expected ore in 1989 resulted in redesigning the pit, cutting the stripping ratio in half, adding additional flotation cells, and installing a clast reject gravity circuit in the mill. Net losses in ore reserves owing to pit changes were minor. At yearend, ore reserves were down only slightly more than the mining rate and totaled 31.1 million tons averaging 0.6% zinc, 0.24% lead, 0.34 ounce of silver per ton, and 0.021 ounce of gold per ton. At expected mining rates, a mine life of 8 years was anticipated.

New Butte Mining Co., a subsidiary of Butte Mining PLC, continued to reactivate mine stopes closed several decades ago at Butte, MT. A mining rate of 450 tons per day was attained in March; this rate was sharply reduced at midyear owing to a strike at the smelter processing New Butte's concentrate. The ore was custom milled at the Contact Mill in Phillipsburg. Ore grades milled at midyear averaged 4.75% zinc, 2.12% lead, 0.13 ounce of gold per ton, and 13 ounces of silver per ton.[4] Zinc recovery was 95%. According to Butte Mining, exploration in 1990 resulted in the defining of an additional 4.1 million tons of inferred ore reserves between the 400 and 1,000 levels in the Rainbow Block. At yearend, ore reserves totaled about 1 million tons averaging 5% zinc, 2% lead, 10 ounces of silver, and 0.06 ounce of gold per ton.

In Colorado, zinc was produced as a coproduct of gold-silver operations at the Leadville Unit (managed by Asarco, but jointly owned with the Resurrection Mining Co.) and the Sunnyside Mine (owned by San Juan County Mining Venture, a company composed of Alta Bay Venture, 67%, and Washington Mining Co., 33%). Asarco produced almost 12,900 tons of zinc in concentrates, down about 100 tons from that of 1989. At yearend, ore reserves were up about 92,000 tons from those of 1989 and totaled 801,000 tons averaging 7.77% zinc, 3.56% lead, 1.7 ounces of silver per ton, and 0.07 ounce of gold per ton.

In Idaho, Hecla Mining Co. fully implemented its Lucky Friday Underhand Longwall (LFUL) mining method at the Lucky Friday Mine. The LFUL method, which utilizes rubber-tired vehicles, more mechanized equipment, a ramp system, and cemented sandfill, was developed to enhance safety and improve efficiency. In 1990, ore milled increased about 9,000 tons to 134,000 tons, resulting in an output of 3,000 tons of zinc in concentrates, up slightly from that of 1989. Zinc recovery from ore was about 76%. Ore reserves were up by about 60,000 tons, and at yearend, totaled 479,000 tons and averaged 2.7% zinc, 13.4% lead, and 16 ounces of silver per ton.

Star Phoenix Mining Co. rehabilitated its leased Star-Morning Mine in Idaho and began ore production in mid-April. Although production levels increased as the year progressed, financial difficulties led to the closure of the mine in mid-November. Star-Phoenix had estimated ore reserves at 2 million tons grading 10% to 12% combined lead and zinc with good silver values when the mine reopened.

Cyprus Minerals Co. increased zinc production at its Pinos Altos Mine in New Mexico to 3,600 tons in concentrate compared with only 900 tons in 1989. Zinc ore reserves at yearend totaled 3.4 million tons grading 8.46% zinc; the ore reserve tonnage was up almost fourfold from that of 1989.

Cyprus and Mitsui Mining and Smelting Co. Ltd. formed Western Zinc Inc., a joint-venture company set up to explore for and develop zinc deposits in western North America. Included in the agreement was the possibility of building a zinc smelter to process zinc concentrates produced by the venture.

TABLE 4

LEADING ZINC-PRODUCING MINES IN THE UNITED STATES IN 1990, 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. America	Do.
5	Pierrepont	do.	do.	Do.
6	Young	Jefferson, TN	ASARCO Incorporated	Do.
7	Bunker Hill	Shoshone, ID	Bunker Hill Mining Co. (U.S.) Inc.	Do.
8	Montana Tunnels	Jefferson, MT	Montana Tunnels Mining Inc.	Do.
9	Immel	Knox, TN	ASARCO Incorporated	Do.
10	Jefferson City	Jefferson, TN	Union Zinc Co.	Do.
11	Buick	Iron, MO	The Doe Run Co.	Lead-zinc ore.
12	New Market	Jefferson, TN	ASARCO Incorporated	Zinc ore.
13	West Fork	Reynolds, MO	do.	Lead-zinc ore.
14	Leadville Unit	Lake, CO	do.	Do.
15	Coy	Jefferson, TN	do.	Zinc ore.
16	Ward	White Pine, NV	Alta Gold Co.	Lead-zinc ore.
17	Magmont	Iron, MO	Cominco American Inc.	Do.
18	Sunnyside	San Juan, CO	San Juan County Mining Venture	Do.
19	Fletcher	Reynolds, MO	The Doe Run Co.	Do.
20	Star	Shoshone, ID	Star Morning Mining Co.	Zinc ore.
21	Rosiclare	Hardin and Pope, IL	Ozark-Mahoning Co.	Fluorspar.
22	Pinos Altos	Grant, NM	Cyprus Sierrita Corp.	Copper ore.
23	Sweetwater	Reynolds, MO	ASARCO Incorporated	Lead-zinc ore.
24	Viburnum No. 29	Iron, MO	The Doe Run Co.	Do.
25	Viburnum No. 28	do.	do.	Copper-lead ore.

TABLE 5

PRIMARY AND SECONDARY SLAB ZINC PRODUCED IN THE UNITED STATES

(Metric tons)

	1986	1987	1988	1989[r]	1990
Primary:					
From domestic ores	191,079	205,275	196,476	229,870	230,470
From foreign ores	62,290	56,070	44,818	30,435	32,234
Total	253,369	261,345	241,294	260,305	262,704
Secondary:					
At primary smelters	49,852	W	W	W	W
At secondary smelters	13,060	W	W	W	W
Total	62,912	82,589	88,492	97,904	95,708
Grand total (excludes zinc recovered by remelting)	316,281	343,934	329,786	358,209	358,412

[r]Revised. W Withheld to avoid disclosing company proprietary data.

In Nevada, the Ward Mine, owned by Alta Gold Co., and the leased Taylor mill officially opened in May, processing ore at a 900-ton-per-day rate. More than 100,000 tons of ore had been stockpiled prior to the opening of the mill. Plans called for an annual production of about 10,500 tons of zinc, 600 tons of copper, 700 tons of lead, and 300,000 ounces of silver in concentrates. At yearend, ore reserves were about 1.4 million tons averaging 6.1% zinc, 1.1% copper, 1.1% lead, and 2.4 ounces of silver per ton. The Ward Mine last operated in 1880.

Two long-closed zinc mines in Washington were being evaluated and could open in 1991. Equinox Resources Ltd. completed a feasibility study on the Van Stone Mine near Coville, WA, and planned to reopen the mine in the first half of 1991. The mine last produced in 1970. Ore was to be produced by open pit methods for the first 3 years with underground mining thereafter. At capacity, annual production was projected to be 15,000 tons zinc and 2,000 tons lead in concentrates. Ore reserves were estimated to be 2.5 million tons averaging 5.7% zinc and 1.1% lead.

Resource Finance Co. (RFC) continued to evaluate the Pend Oreille lead-zinc mine near Metaline Falls, WA, for possible reopening in late 1991. The Pend Oreille Mine last operated in 1977. RFC estimated ore reserves to be 3.4 million tons averaging 8.8% zinc and 1.6% lead. Reserves were adequate for a 9-year mine life at anticipated production rates.

Smelter and Refinery Production.—Refined metal production was up slightly from that of 1989 and was the highest since

1981. Three companies, ZCA, JMZ, and Big River Zinc Co., operated four primary zinc refineries in 1990. 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 EAF dust by a sister company, Horsehead Resource Development Co. (HRD). The largest producers of zinc metal at secondary plants were Huron Valley Steel Corp., Interamerican Zinc Co., and Gulf Metals Corp.

ZCA's zinc production capacity at Monaca continued to increase and was expected to attain 146,000 tons per year in early 1991. Most of the new capacity, 45,000 tons since 1988, was expected to be dedicated to the processing of EAF zinc calcine. The processing of EAF dusts gained new urgency in 1990 as the total landfill ban on disposal of these dusts was to be implemented in August 1991. Thermal processing was expected to be required on all dusts containing more than 15% zinc. The number of plants processing these materials increased in 1990. A list of operating and proposed domestic plants and their EAF dust capacities is given in table 10.

TABLE 6

PRODUCTION OF ZINC AND LEAD IN THE UNITED STATES IN 1990, BY STATE AND CLASS OF ORE, FROM OLD TAILINGS, ETC., IN TERMS OF RECOVERABLE METALS

(Metric tons)

State	Zinc ore			Lead ore			Zinc-lead ore		
	Gross weight (dry basis)	Zinc	Lead	Gross weight (dry basis)	Zinc	Lead	Gross weight (dry basis)	Zinc	Lead
Alaska	W	W	W	—	—	—	—	—	—
Colorado	—	—	—	—	—	—	W	W	W
Idaho	W	W	W	—	—	—	W	W	W
Illinois	—	—	—	—	—	—	—	—	—
Kentucky	W	W	W	—	—	—	—	—	—
Missouri	—	—	—	—	—	—	5,898,904	45,884	315,876
Montana	W	W	W	—	—	—	W	W	W
Nevada	—	—	—	—	—	—	157,581	7,889	830
New Mexico	—	—	—	—	—	—	—	—	—
New York	W	W	W	—	—	—	—	—	—
Tennessee	W	W	W	—	—	—	—	—	—
Total	10,673,413	430,777	74,397	—	—	—	W	W	W
Percent of total zinc or lead	XX	84	16	XX	—	—	XX	W	W

State	Copper-zinc, copper-lead, copper-zinc-lead ores			All other sources[1] [2]			Total[3]		
	Gross weight (dry basis)	Zinc	Lead	Gross weight (dry basis)	Zinc	Lead	Gross weight (dry basis)	Zinc	Lead
Alaska	—	—	—	—	—	—	W	W	W
Colorado	—	—	—	W	W	W	W	W	W
Idaho	—	—	—	W	W	W	W	W	W
Illinois	—	—	—	—	W	W	—	W	W
Kentucky	—	—	—	—	—	—	W	W	W
Missouri	[4]1,572,198	[4]2,979	[4]56,507	—	—	—	7,471,102	48,864	372,383
Montana	—	—	—	27,216	—	20	W	W	W
Nevada	—	—	—	—	—	—	157,581	7,889	830
New Mexico	—	—	—	W	W	W	W	W	W
New York	—	—	—	—	—	—	W	W	W
Tennessee	—	—	—	—	—	—	W	W	W
Total	1,572,198	2,979	56,507	W	W	W	19,427,966	515,355	473,992
Percent of total zinc or lead	XX	1	12	XX	W	W	XX	100	100

W Withheld to avoid disclosing company proprietary data; included in "Total." XX Not applicable.
[1]Includes zinc and lead recovered from copper, gold, goldsilver, and silver ores, from fluorspar and from mill tailings.
[2]Excludes tonnages of fluorspar in Illinois from which zinc and lead were recovered as byproducts.
[3]Data may not add to totals shown because of independent rounding.
[4]Includes Brushy Creek Mill.

TABLE 7

DISTILLED AND ELECTROLYTIC ZINC, PRIMARY AND SECONDARY, PRODUCED IN THE UNITED STATES, BY GRADE

(Metric tons)

Grade	1986	1987	1988	1989	1990
Special High	78,979	85,010	90,034	113,819	116,647
High	84,737	88,952	74,870	79,145	86,006
Continuous Galvanizing	20,589	38,751	44,890	48,252	50,577
Controlled Lead	18,883	W	W	W	W
Prime Western	113,093	131,221	119,992	116,993	105,182
Total	316,281	343,934	329,786	358,209	358,412

W Withheld to avoid disclosing company proprietary data; included in "Prime Western."

TABLE 8

SLAB ZINC CAPACITY OF PRIMARY ZINC PLANTS IN THE UNITED STATES, BY TYPE OF PLANT AND COMPANY

Type of plant and company	Slab zinc capacity (metric tons)	
	1989	1990
Electrolytic:		
Big River Zinc Corp., Sauget, IL	76,000	82,000
Jersey Miniere Zinc Co., Clarksville, TN	95,000	98,000
Zinc Corp. of America, Bartlesville, OK	51,000	51,000
Electrothermic:		
Zinc Corp. of America, Monaca, PA[1]	103,000	123,000
Total available capacity	325,000	354,000
Total operating capacity	325,000	354,000

[1]Includes secondary capacity.

TABLE 9

SECONDARY ZINC PLANT CAPACITY IN THE UNITED STATES, BY COMPANY

Company	Plant location	Capacity (metric tons)	
		1989	1990
Arco Alloys Corp.	Detroit, MI	58,000	58,000
W.J. Bullock Inc.	Fairfield, AL		
T.L. Diamond & Co. Inc.	Spelter, WV		
Florida Steel Co.	Jackson, TN		
Gulf Reduction Corp.	Houston, TX		
Hugo Neu-Proler Co.	Terminal Island, CA		
Huron Valley Steel Corp.	Belleville, MI		
Interamerican Zinc Inc.	Adrian, MI		
New England Smelting Works, Inc.	West Springfield, MA[1]		
Nucor Yamato Steel Co.	Blytheville, AR		
The River Smelting & RFG Co.	Cleveland, OH		
Zinc Corp. of America	Palmerton, PA		

[1]Closed in 1990.

Zinc Oxide.—Domestic American- and French-process zinc oxide was produced entirely from zinc metal and scrap by eight companies in 1990. All but one company, Eagle Zinc Co. of Hillsboro, IL, produced French-process zinc oxide. Some impure oxide produced at secondary plants was sold directly for use in animal feed and for other agricultural purposes. The principal zinc oxide producers in 1990 were Asarco, Pasco Zinc Corp., and ZCA. Hitox Corp. of America permanently closed its zinc oxide plant in Spokane, WA, in March.

In 1990, Asarco produced 12,000 tons of zinc oxide, down about 3,600 tons from last year, at its 17,300-ton-per-year Hillsboro, IL, plant. In July, North American Oxide Inc., an affiliate of the Rogers Group Inc., began production at its new 18,000-ton-per-year French-process zinc oxide plant at Clarksville, TN.

Byproduct Sulfur.—Production of sulfur in byproduct sulfuric acid at primary zinc plants was 134,700 tons, about the same as that produced in 1989. Acid production at zinc plants in 1990 was valued at $17.4 million.

Consumption and Uses

Zinc is found in all sectors of the economy, but its role is not obvious to the public because zinc tends to lose its identity in the end products. Zinc-containing products were used extensively in 1990 by the military, industry, and general public 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 steelworks, tanks, and pipes. Brass was used as shell casings in ammunition and 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, scientific equipment, and electronic equipment. Zinc dust was used in primers and paints; in alkaline dry cell batteries; in the sherardizing

TABLE 10

U.S. PROCESSORS OF STEELMAKING ELECTRIC ARC FURNACE DUSTS AND CAPACITIES

(Metric tons)

Company	Location	Process	Date of startup	Annual EAF capacity	Potential zinc recovery
Florida Steel Co.	Jackson, TN	Plasma	1989	7,200	1,400
Horsehead Resources	Calumet City, IL	Waelz	1988	72,000	—
Do.	Monaca, PA[1]	Flame reactor	1990	18,000	—
Do.	Palmerton, PA	Waelz	1981	245,000	75,000
Do.	Rockwood, TN	Do.	1990	90,000	—
Laclede Steel Co.	St. Louis, MO	Elkem	1991	36,000	6,000
North Star Steel Corp.	Beaumont, TX	Flame reactor	1992	27,000	5,000
Nucor-Yamamoto Steel Co.	Blytheville, AR	Plasma	1989	11,000	1,800
Zia Technology of TX, Inc.	Caldwell, TX	Inclined rotary	1992	27,000	4,500
Total				533,200	93,700

[1]Inactive.

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. Zinc oxide was a necessary ingredient in the vulcanization of rubber and as pigment in paints. The metal casings of zinc-carbon dry cell batteries were zinc. In 1990, about 30,000 tons of Special High Grade (SHG) rolled zinc was used by the U.S. Mint to produce 12.5 billion pennies.

Zinc compounds were used in corrosion-inhibiting paint primers, chemical catalysts, welding and soldering fluxes, fungicides and pharmaceuticals, phosphors for cathode tubes and radar scopes, chemical smoke, and additives to lubricating oils and greases. Zinc ferrites were used in electrical devices in transformers, coils, amplifiers, motors, and tuners, and in electronic devices in radio, television, and computers.

Domestic consumption of slab zinc fell about 70,000 tons to slightly less than 1 million tons in 1990. Galvanizing and electrogalvanizing, mainly for sheet and strip, continued to be the principal use of zinc metal, consuming an estimated 52%, followed by zinc-base die-cast alloys, 20%; brass alloys, 13%; and other uses, 15%. SHG accounted for about 53% of the reported slab zinc consumed, followed by Prime Western (PW), 23%; High-Grade (HG), 14%; and other grades, 10%.

Overall, the construction sector of the economy was the largest consumer of zinc, accounting for an estimated 46%, followed by transportation, 20%; machinery, 11%;

TABLE 11

STOCKS AND CONSUMPTION OF NEW AND OLD ZINC SCRAP IN THE UNITED STATES IN 1990, BY TYPE OF SCRAP

(Metric tons, zinc content)

Type of scrap	Stocks, January 1	Receipts	Consumption			Stocks, December 31
			New scrap	Old scrap	Total	
Diecastings	358	5,035	—	5,137	5,137	256
Flue dust	W	4,568	2,248	2,243	4,491	W
Fragmentized diecastings	W	29,410	—	29,230	29,230	W
Galvanizer's dross	1,997	71,621	71,649	—	71,649	1,969
Old zinc[1]	83	1,594	—	1,587	1,587	90
Remelt diecast slab	W	W	—	W	W	W
Remelt zinc[2]	W	238	240	—	240	W
Skimmings and ashes[3]	4,421	23,241	23,123	—	23,123	4,539
Steelmaking dust	4,899	25,983	15,441	15,441	30,882	—
Other[4]	5,527	24,649	5,243	19,160	24,403	6,028
Total	17,285	186,339	117,944	72,798	190,742	12,882

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 12

PRODUCTION OF ZINC PRODUCTS FROM ZINC-BASE SCRAP IN THE UNITED STATES

(Metric tons)

Product	1986	1987	1988	r1989	1990
Electrogalvanizing anodes	—	—	—	W	W
Redistilled slab zinc	62,912	82,589	88,492	97,904	95,708
Remelt die-cast slab	2,564	825	907	4,167	5,144
Other metal alloys	99	163	317	272	257
Other zinc metal products	7,098	6,741	8,016	W	W
Secondary zinc in chemical products	44,891	79,361	55,972	57,576	56,135
Zinc dust	26,682	28,620	24,205	24,909	24,105

rRevised. W Withheld to avoid disclosing company proprietary data.

TABLE 13

ZINC RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1989	1990
KIND OF SCRAP		
New scrap:		
Zinc-base	105,203	97,914
Copper-base	r124,522	134,360
Magnesium-base	163	181
Total	r229,888	232,455
Old scrap:		
Zinc-base	93,919	86,607
Copper-base	r22,705	21,633
Aluminum-base	338	512
Magnesium-base	176	194
Total	r117,138	108,946
Grand total	r347,026	341,401
FORM OF RECOVERY		
Metal:		
Slab zinc	r97,904	95,708
Zinc dust	r24,909	24,105
Other[1]	r15,564	11,804
Total	r138,377	131,617
In zinc-base alloys	r4,167	5,144
In brass and bronze	r146,634	148,247
In other metal alloys	272	257
In chemical products:		
Zinc oxide (lead free)	r37,028	34,726
Zinc sulfate	r12,320	12,770
Zinc chloride	7,269	7,436
Miscellaneous	959	1,204
Total	r208,649	209,784
Grand total	r347,026	341,401

rRevised.
[1]Includes electrogalvanizing anodes and zinc content of slab made from remelt die-cast slab.

TABLE 14

U.S. CONSUMPTION OF ZINC

(Metric tons)

	1986	1987	1988	1989	1990
Slab zinc, apparent (rounded)	999,000	1,052,000	1,089,000	1,060,000	991,000
Ores and concentrates (zinc content)	19,236	2,536	2,412	2,107	2,178
Secondary (zinc content)[1]	255,752	r269,319	248,461	r249,122	245,644
Total (rounded)	1,274,000	r1,324,000	1,340,000	r1,311,000	1,239,000

rRevised.
[1]Excludes secondary slab and remelt zinc.

TABLE 15

ESTIMATED[1] APPARENT CONSUMPTION OF SLAB ZINC, ACCORDING TO INDUSTRY USE AND PRODUCT

(Metric tons)

Industry use and product	1989	1990
Galvanizing:		
Sheet and strip	402,000	365,800
Other	150,000	151,100
Total	552,000	516,900
Brass and bronze	130,000	136,700
Zinc-base alloys	220,000	200,800
Zinc oxide	71,000	67,600
Other uses[2]	87,000	69,000
Estimated apparent consumption	1,060,000	991,000

[1]Based on reported slab zinc consumption.
[2]Includes zinc used in making zinc dust, wet batteries, desilverizing lead, powder, alloys, anodes, chemicals, castings, light metal alloys, rolled zinc, and miscellaneous uses not elsewhere specified.

TABLE 16

U.S. REPORTED CONSUMPTION OF SLAB ZINC, BY INDUSTRY USE AND PRODUCT

(Metric tons)

Industry use and product	1989	1990
Galvanizing:		
Sheet and strip	323,684	290,461
Other	120,919	123,394
Total	444,603	413,855
Brass and bronze	95,798	104,278
Zinc-base alloy	r189,690	171,771
Zinc oxide	70,417	67,532
Other uses[1]	r84,147	69,053
Grand total	r884,655	826,489

rRevised.
[1]Includes zinc used in making zinc dust, wet batteries, desilverizing lead, powder, alloys, anodes, chemicals, castings, light metal alloys, rolled zinc, and miscellaneous uses not elsewhere specified.

electrical, 11%; and other, 12%. Zinc metal accounted for about three-fourths of the total zinc in end-use products and zinc chemicals about one-fourth in 1990.

According to the American Iron and Steel Institute, shipments of galvanized sheet and strip totaled 9.0 million tons, down 0.7 million tons from those of 1989. Of the total shipments, electrogalvanized sheet accounted for 21% of the tonnage compared with 20% in 1989. Consumption of galvanized sheet and strip slowed in the latter part of the year in line with the slowing economy, reduced automobile manufacture, and decreased construction activity.

According to the Bureau of the Census, zinc-base alloy die and foundry casting shipments totaled about 188,000 tons, down from 200,000 tons reported in 1989. The decline was attributable to a weaker economy in 1990. Zinc die-cast shipments by weight were estimated to have been equally distributed between automotive, hardware, and other uses.

Zinc consumption in the production of copper-base alloy by brass mills, ingot makers, and foundries was down slightly from that of 1989 according to the Copper Development Association Inc. (CDA). The brass and bronze industries were estimated to have consumed about 280,000 tons of zinc, the source of which was about equally divided between refined zinc metal and brass and bronze scrap metal. According to CDA data, brass mills accounted for 85% of the total zinc consumed as metal and scrap in making copper-base alloys.

The zinc content in typical U.S. manufactured automobiles was estimated to average about 40 pounds in 1990, about the same as that in 1989. Diecastings accounted

for about 20 pounds; corrosion protection via galvanizing and coatings, 17 pounds; and other, including rubber, brass, and zinc solder, 3 pounds.

The apparent domestic consumption of zinc oxide was about 165,000 tons, down from 176,000 tons in 1989. Domestic production declined; exports and imports also declined. Because the U.S. Bureau of Mines information on zinc oxide consumption by industry sector reflects only shipments as reported by the domestic producers, the consumption data listed in table 22 only account for about three-fourths of the apparent market. Of the reported amounts, the rubber and chemical industries continued to be the principal consumers.

Stocks

Metal stocks held by domestic producers, consumers, and merchants declined slightly in 1990 and were near the record-low stock levels of 1988. In recent years, stock levels have tended to range in the 4- to 6-week consumption range, reflecting the general trend by consumers and merchants for low inventories and just-in-time delivery. In 1990, yearend stock levels were strongly influenced by anticipation of further declines in the zinc price in 1991. Metal stocks in the market economy countries (MEC), according to the International Lead and Zinc Study Group (ILZSG), were 545,000 tons at the end of 1990, down 47,000 tons from those at the end of 1989. The LME terminated its HG zinc contract in March 1990 in favor of the SHG zinc contract introduced in September 1988. As a result, SHG stock levels on the LME had built up to 74,800 tons by the end of 1989. However, in early 1990, stock levels fell to the mid-40,000 tons and remained at that level through November. At yearend, stocks totaled 55,000 tons.

TABLE 19

ROLLED ZINC PRODUCED AND QUANTITY AVAILABLE FOR CONSUMPTION IN THE UNITED STATES

(Metric tons)

	1989	1990
Production[1]	52,475	47,882
Exports	16,515	11,881
Imports for consumption	3,066	929
Available for consumption	37,222	38,875

[1]Includes other plate more than 0.375 inch thick and rod and wire.

TABLE 17

U.S. REPORTED CONSUMPTION OF SLAB ZINC IN 1990, BY INDUSTRY USE AND GRADE

(Metric tons)

Industry use	Special High Grade	High-Grade	Prime Western	Remelt and other grades	Total[1]
Galvanizing	88,942	70,454	188,533	65,926	413,855
Zinc-base alloys	169,150	W	—	W	171,771
Brass and bronze	65,497	17,306	W	W	104,278
Zinc oxide	W	W	W	—	67,532
Other	W	W	W	W	69,053
Total[1]	445,427	92,424	210,373	78,265	826,489

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Data may not add to totals shown because of withheld figures.

TABLE 18

U.S. REPORTED CONSUMPTION OF SLAB ZINC IN 1990, BY STATE[1]

(Metric tons)

State	Galvanizers	Brass mills[2]	Diecasters[3]	Other[4]	Total
Alabama	W	W	—	—	10,152
California	18,568	W	—	W	19,956
Connecticut	W	2,798	W	W	12,229
Florida	5,028	—	—	—	5,028
Illinois	58,136	W	35,524	W	130,424
Indiana	41,944	W	W	W	47,702
Michigan	W	W	39,725	W	67,578
Nebraska	W	—	—	W	8,439
New York	2,884	W	57,809	W	85,392
Ohio	75,655	W	25,614	W	104,165
Pennsylvania	60,537	W	W	W	139,967
Tennessee	W	—	—	W	48,535
Texas	13,706	—	—	W	13,816
Undistributed	91,308	101,364	13,022	137,877	88,115
Total	367,766	104,162	171,694	137,877	781,498

W Withheld to avoid disclosing company proprietary data; included with "Total" and "Undistributed."
[1]Excludes remelt zinc.
[2]Includes brass mills, brass ingot makers, and brass foundries.
[3]Includes producers of zinc-base alloys for diecastings, stamping dies, and rods.
[4]Includes slab zinc used in rolled zinc products and in zinc oxide.

TABLE 20

ZINC CONTENT OF PRODUCTION AND SHIPMENTS OF ZINC PIGMENTS AND COMPOUNDS[1] IN THE UNITED STATES

(Metric tons)

	1989		1990	
	Production	Shipments	Production	Shipments
Zinc chloride[2]	7,269	7,076	7,436	6,530
Zinc oxide	103,642	102,515	98,047	98,987
Zinc sulfate	14,427	13,671	14,947	14,115

[1]Excludes leaded zinc oxide and lithopone.
[2]Includes zinc content of zinc ammonium chloride.

TABLE 21

ZINC CONTENT OF ZINC PIGMENTS AND COMPOUNDS[1] PRODUCED BY DOMESTIC MANUFACTURERS, BY SOURCE

(Metric tons)

	1989				1990			
	Zinc in pigments and compounds produced from			Total	Zinc in pigments and compounds produced from			Total
	Ore	Slab zinc	Secondary material		Ore	Slab zinc	Secondary material	
Zinc chloride[2]	—	—	7,269	7,269	—	—	7,436	7,436
Zinc oxide	—	66,615	37,027	103,642	—	63,321	34,726	98,047
Zinc sulfate	W	—	14,427	14,427	W	—	14,947	14,947

W Withheld to avoid disclosing company proprietary data; included with "Secondary material."
[1]Excludes leaded zinc oxide and lithopone.
[2]Includes zinc content of zinc ammonium chloride.

TABLE 22

REPORTED DISTRIBUTION OF ZINC CONTAINED IN ZINC OXIDE SHIPMENTS, BY INDUSTRY[1]

(Metric tons)

Industry	1986	1987	1988	1989	1990
Agriculture	3,128	3,477	1,988	1,520	1,764
Ceramics	4,010	4,901	3,302	2,780	2,618
Chemicals	18,163	22,789	21,898	22,462	20,723
Paints	8,638	8,007	3,441	4,695	4,579
Photocopying	W	W	W	W	W
Rubber	56,246	63,589	55,213	57,781	56,622
Other	6,999	7,814	12,189	13,277	12,681
Total	97,184	110,577	98,031	102,515	98,987

W Withheld to avoid disclosing company proprietary data; included in "Other."
[1]In addition, zinc oxide was imported as follows, in metric tons: 1986—43,924; 1987—57,276; 1988—73,042; 1989—59,557; and 1990—49,454; distribution cannot be distinguished by industry.

TABLE 23

DISTRIBUTION OF ZINC CONTAINED IN SULFATE SHIPMENTS

(Metric tons)

Industry	1986	1987	1988	1989	1990
Agriculture	18,616	14,934	13,602	10,922	12,337
Other	3,171	3,096	2,599	2,749	1,778
Total	21,787	18,030	16,201	13,671	14,115

Inventories of zinc in concentrate at domestic primary smelters totaled 34,800 tons at yearend compared with 35,500 tons at the end of 1989, according to the American Bureau of Metal Statistics Inc. Concentrate stocks were at their lowest level at midyear.

Markets and Prices

Zinc metal prices continued a 10-month downtrend through January 1990 before improving toward the end of February. Prices moved upward in the summer months in response to strong world demand; production problems at smelters in Australia, Canada, and Peru; and fears of concentrate shortages owing to mine strikes and startup problems at the Red Dog Mine. Weaker demand, especially in North America, and stock buildup on the LME led to declining prices in the last quarter of 1990.

By yearend, virtually all North American slab zinc producers had switched to an LME price-basis for zinc metal. This resulted in the demise at yearend of the Metals Week (MW) North America producers' average used in the Minerals Yearbook since 1971. A new MW price quote for North America based on the LME cash price plus a premium was expected to be instituted in January 1991. The LME planned to establish a number of warehouse facilities in the United States; the first to be approved was expected to be located in Baltimore, MD, in early 1991.

Foreign Trade

U.S. exports of zinc concentrates were the highest ever and were almost three times higher than those of 1989. Exports of waste and scrap were also at record levels; Taiwan imported about two-thirds of the total.

General imports of zinc concentrate relative to imports for consumption continued to be high. The large disparity was due to shipments of Canadian concentrate through Skagway, AK, to world markets. Imports of slab zinc and zinc oxide both fell, reflecting the general decline in domestic zinc consumption.

According to CDA, 347,600 tons of brass mill products was imported and 158,000

TABLE 24

U.S. PRODUCERS OF ZINC OXIDE AND CAPACITY, BY COMPANY

Company	Plant location	Capacity (metric tons)	
		1989	1990
Asarco Incorporated	Hillsboro, IL	156,000	165,000
Big River Zinc Corp.	Sauget, IL		
Eagle Zinc Co.	Hillsboro, IL		
Hitox Corp. of America[1]	Spokane, WA		
Interamerican Zinc Inc.	Adrian, MI		
Midwest Zinc Corp.	Chicago, IL		
North American Oxide Inc.[2]	Clarksville TN		
Pasco Zinc Products Corp.[3]	Memphis, TN		
Zinc Corp. of America	Monaca, PA		
Do.	Palmerton, PA		

[1]Closed permanently in Mar. 1990.
[2]New plant opened in 1990.
[3]Pigment & Chemical Inc. acquired plant from Pacific Smelting in May 1989.

TABLE 25

U.S. PRODUCERS OF ZINC SULFATE AND CHLORIDE PRODUCTS IN 1990

Company	Plant location	Sulfate production	Chloride production
American Microtrace	Fairbury, NE	X	—
B & W Micronutrients	Bartlesville, OK	X	—
Bay Zinc Co.	Moxee City, WA	X	—
Big River Zinc Corp.	Sauget, IL	X	—
The Chemical & Pigment Co.	Pittsburg, CA	X	X
Cozinco Inc.	Denver, CO	X	—
Frit Industries Inc.	Ozark, AL	X	—
Liquid Chemical Corp.	Hanford, CA	X	—
Madison Industries Inc.	Old Bridge, NJ	X	X
Mineral Research & Development Corp.	Freeport, TX	—	X
Zaclon Inc.	Cleveland, OH	—	X
Zinc Corp. of America	Monaca, PA	X	—

X Denotes producer of product.

TABLE 26

ESTIMATED STOCKS OF SLAB ZINC IN THE UNITED STATES, DECEMBER 31

(Metric tons)

	1986	1987	1988	1989	1990
Primary producers	16,722	13,448	6,005	7,200	6,000
Secondary producers	3,203	3,162	695	1,031	633
Consumers	54,079	57,410	64,864	60,297	61,027
Merchants	26,559	22,352	14,290	22,183	20,444
Total	100,563	96,372	85,854	90,711	88,104

tons exported in 1990, compared with 397,500 tons imported and 133,200 tons exported in 1989.

World Review

World zinc mine production was a record high 7.3 million tons in 1990. Metal output exceeded 7 million tons for the fourth straight year and was the third highest ever recorded. Zinc consumption was slightly less than the record level of 1988 but was the second highest in history.

According to ILZSG, the MEC consumed 5.24 million tons of zinc metal compared with 5.20 million tons in 1989 and 5.27 million tons in 1988. The MEC accounted for three-fourths of consumption and the Eastern European and Socialist (EES) countries slightly less than one-fourth, or about 1.75 million tons. The world's leading consuming nations, in order of estimated consumption, were the United States, the U.S.S.R., Japan, and Federal Republic of Germany. The United States, Japan, and Western Europe accounted for one-half of world consumption and about 70% of the MEC total. According to ILZSG,[5] the principal uses of zinc metal in 1989 in the major western countries were as follows: galvanizing, 47%; brass and bronze, 20%; zinc-base alloys, 14%; chemicals, 8%; zinc semimanufactures, 7%; and other, 4%. In 1990, galvanizing was estimated to have increased slightly to about 48%.

Although many countries produced less in 1990, world zinc mine output rose sharply owing mainly to new production in the United States, Australia, and Bolivia. Canada, because of strikes and closure of the Sullivan Mine; Denmark, because of the August closing of the Black Angel Mine in Greenland; and the U.S.S.R., because of labor and supply problems, recorded the largest drops in production.

On a geographic basis, the Americas accounted for about 40% of world mine output. Europe, including Greenland and the U.S.S.R., Asia, and Australia with 27%, 16%, and 13%, respectively, were the other principal producing areas. Despite 3 straight years of declining output, Canada remained the world's largest producer. Canada, together with Australia, Peru, the U.S.S.R., and the United States, accounted for 54% of the world's zinc mine production.

World exports of zinc in concentrates totaled about 2.3 million tons, of which more than 90% was from the MEC.

TABLE 27

AVERAGE MONTHLY U.S., LME,[1] AND EUROPEAN PRODUCER PRICES FOR EQUIVALENT ZINC

(Metallic zinc, cents per pound)

Month	1989			1990		
	United States[2]	LME cash	European producer	United States[2]	LME cash	European producer
January	79.27	78.57	79.30	67.63	58.66	58.43
February	87.70	87.54	88.62	64.75	63.28	63.02
March	93.71	88.89	87.67	73.78	75.57	73.22
April	88.52	75.04	75.35	80.74	76.46	74.72
May[3]	84.64	78.24	76.25	85.60	80.50	78.76
June	80.59	75.65	73.30	87.19	77.78	76.24
July	79.67	75.63	73.69	86.10	74.25	73.02
August	81.32	82.04	78.74	78.98	73.26	71.41
September	81.08	75.56	74.90	77.77	69.74	67.99
October	79.95	69.25	73.77	67.54	61.35	61.22
November	75.92	65.65	64.89	62.94	57.96	57.69
December	72.33	68.28	64.98	62.09	57.40	57.13
Average	82.02	77.64	75.95	74.59	66.46	67.74

[1]London Metal Exchange.
[2]Based on High-Grade zinc delivered.
[3]As of May 1989, LME cash price changed to Special High Grade from High-Grade.

Source: Metals Week.

Australia, Canada, Peru, and the United States accounted for 78% of MEC concentrate exports. Canada, Japan, the Republic of Korea, and the Western European countries, were the largest importers.

World refined metal production was about 160,000 tons less than that in 1989. The largest decrease in production occurred in the U.S.S.R. The MEC and EES countries accounted for 73% and 27%, respectively, of world output. The largest producers were Canada, China, Japan, and the U.S.S.R.; these countries accounted for about 38% of world zinc metal output in 1990.

World zinc mine capacity was about 8.35 million tons, up about 150,000 tons from that of 1989. Twelve mines opened, 5 expanded, and 11 closed, including 3 that had opened or expanded capacity in 1990. The Golden Grove Mine in Australia, rated at 95,000 tons capacity, was the largest new mine to open. The Black Angel, Caribou, and Daniels Harbor Mines in Canada and the Morro Agudo Mine in Brazil, with combined capacities of 196,000 tons, were the largest to close.

World smelter capacity totaled about 8.24 million tons at yearend, increasing about 73,000 tons through expansions at existing smelters. According to ILZSG,[6] an additional 540,000 tons of smelter capacity was scheduled to come on-stream by 1995. Greenfield smelters were under construction in China, India, and Iran, and major expansions were underway in Belgium, the Federal Republic of Germany, and Spain.

OUTLOOK

U.S. demand for zinc was forecast to rise slowly, increasing from slightly less than 1.0 million tons in 1990 to about 1.2 million tons by the year 2000. No major shifts in domestic zinc use were foreseen, although some present uses may yield further to substitution.

Although the United States has an adequate zinc resource base, imports were expected to continue to account for more than one-half of U.S. zinc supply in the next decade. Mine output was anticipated to reach record-high levels in the 1990's, but smelter capacity was expected to rise only modestly. No new primary zinc smelters will likely be built in the United States during the 1990's owing to permitting delays and economic indecision caused by the uncertainty of environmental regulations and the long-term liability threat posed by Superfund legislation. Ironically, the United States was expected to be a major world exporter of zinc concentrates, and, at the same time, to remain the world's largest importer of refined zinc metal.

Secondary zinc recovery from waste and scrap was anticipated to be a strong growth sector for the zinc industry. Domestic secondary zinc production could increase by more than 50% above the present level in the next decade and constitute the source of 40% of total U.S. zinc metal and compound consumed annually by the year 2000. Increased secondary recovery was expected to be driven by public policies related to waste and scrap recycle, environment, and public health.

World zinc metal consumption was expected to continue upward, rising to about 8.5 million tons by the year 2000 from the 7.0 million tons consumed in 1990. No new major uses of zinc were on the horizon. Traditional zinc uses in meeting the needs of a rapidly growing and more affluent world population were expected to be the driving force for increased zinc use in the next decade. World per capita consumption of zinc metal was about 1.32 kilograms per person in 1990, down from 1.40 kilograms per person in 1988 and 1.35 kilograms in 1989. Global per capita use of zinc, despite being significantly affected by periodic economic downturns, has tended to climb steadily since 1800, as shown in table 43. Assuming the 1980's decade per capita average rate of about 1.35 kilograms is unchanged in the 1990's decade, the above forecast zinc consumption in the year 2000 would be attained.

World zinc resources and ore reserves were adequate to supply the increased demands of the 1990's. Cumulative zinc mine output for the 1991-2000 period, about 80 million tons, however, would result in the extraction of more than one-half of the 145 million tons of estimated 1990 world zinc ore reserves (see table 41).

Since 1800, quarter-century cumulative world zinc metal production and consumption has been, at least, double that of the previous quarter century, except for the 1926-50 quarter when it was only 1.9 times the previous 25-year period. The cumulative production and consumption forecast for the last quarter of this century is expected to total about 175 million tons, again only 1.9 times that previous quarter; but, interestingly, more zinc metal will have been produced and consumed in the 1976-2000 period than the world had produced and consumed throughout history up to 1975.

[1]Federal Register. Mine Waste Exclusion: Section 3010 Notification for Mineral Processing Facilities. V. 55, No. 15 Jan. 23, 1990, pp. 2322-2354.

[2]———. Land Disposal Restriction for Third Third Scheduled Wastes: Final Rule. V. 55, No. 106, June 1, 1990, pp. 22520-22720.

[3]Toxics in the Community. National and Local Perspectives. U.S. Environmental Protection Agency. EPA 560/4-90-017, Sept. 1990, 375 pp.

[4]Tatman, C., and A. Richardson. Butte Mining PLC's Operation in Montana. Min. Mag., v. 162, No. 5, May 1990, pp. 330-337.

[5]International Lead and Zinc Study Group. Principal Uses of Lead and Zinc, 1984-1989. Jan. 1991, 41 pp.

[6]———. Lead and Zinc New Mine and Smelter Projects. Nov. 1990, 49 pp.

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Other Sources

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TABLE 28

U.S. EXPORTS OF ZINC AND ZINC ALLOYS, BY COUNTRY

Country	1988		1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Unwrought zinc and zinc alloys:						
Belgium	23	$81	—	—	145	$103
Canada	1,574	4,175	2,023	$5,275	4,338	7,973
Germany, Federal Republic of	60	48	4,787	7,187	500	872
Hong Kong	67	99	210	411	—	—
India	100	84	19	20	—	—
Israel	18	57	6	36	1	9
Jamaica	62	68	207	451	27	52
Japan	10	28	8	14	130	323
Korea, Republic of	2,281	3,364	10	36	156	470
Mexico	45	115	86	162	97	205
Netherlands	15	54	9	32	—	—
Panama	4	5	18	49	11	24
Singapore	63	107	—	—	2	15
Taiwan	1,186	875	454	455	181	295
United Kingdom	602	1,194	(1)	3	—	—
Other[2]	120	300	118	302	216	963
Total	6,230	10,654	7,955	14,433	5,804	11,304
Wrought zinc and zinc alloys:						
Australia	2	16	34	86	339	662
Bahamas	67	151	4	7	15	51
Brazil	—	—	44	81	27	109
Canada	1,076	2,130	1,932	2,293	2,574	6,833
Chile	6	28	17	62	28	79
Colombia	14	47	19	61	10	54
Costa Rica	4	14	9	52	2	36
Dominican Republic	9	21	131	307	15	27
Ecuador	14	34	10	38	38	78
France	307	101	96	66	99	31
Germany, Federal Republic of	2,091	1,121	1,218	466	2,081	632
Guyana	6	10	2	5	215	79
Hong Kong	181	239	192	138	4	37
India	77	53	3	23	321	212
Jamaica	124	186	1,691	1,820	58	101
Japan	83	225	50	223	55	188
Korea, Republic of	108	77	28	77	131	187
Mexico	712	1,170	488	1,312	633	1,254
Netherlands Antilles	41	39	3	10	12	67
Panama	12	23	20	37	7	21
Philippines	26	74	14	62	56	161
Saudi Arabia	380	370	12	33	7	19
Singapore	101	591	6	46	17	120
South Africa, Republic of	4	18	8	104	10	31
Spain	3	11	(1)	2	(1)	11
Sudan	153	231	127	241	—	—
Taiwan	72	77	12,548	9,697	7,900	5,444
United Kingdom	6	35	199	333	46	114
Venezuela	39	114	5	27	29	73
Other[3]	112	281	258	739	883	1,830
Total	5,830	7,487	19,168	18,448	15,612	18,541

[1]Less than 1/2 unit.

[2]Includes Algeria, Chile, China, Colombia, Dominican Republic, El Salvador, Guyana, Iraq, Jordan, Malaysia, New Zealand, Nigeria, Spain, Sweden, Syria, Trinidad and Tobago, the United Arab Emirates, and Venezuela.

[3]Includes Aruba, Austria, Belgium, Bermuda, British Virgin Islands, China, El Salvador, Greece, Guatemala, Honduras, Iceland, Indonesia, Ireland, Israel, Italy, Pakistan, Peru, St. Christopher-Nevis, Suriname, Sweden, Switzerland, Syria, Trinidad and Tobago, Turkey, the United Arab Emirates, Uruguay, and Yugoslavia.

Source: Bureau of the Census.

TABLE 29

U.S. EXPORTS OF ZINC

Year	Zinc oxide		Ores and concentrates		Blocks, pigs, anodes, etc.			
					Unwrought		Unwrought alloys	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1988	530	$822	33,590	$19,699	482	$933	5,748	$9,721
1989	12,286	17,872	78,877	64,224	5,532	8,783	2,423	5,650
1990	7,141	10,032	220,446	188,686	1,238	2,347	4,566	8,957

	Wrought zinc and zinc alloys				Waste and scrap (zinc content)		Dust and flakes	
	Sheets, plates, strips		Angles, bars, pipes, rods, etc.					
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1988	3,814	$4,416	2,016	$3,071	103,732	$66,052	2,221	$3,929
1989	16,515	14,816	2,653	3,632	108,086	75,947	8,137	13,861
1990	11,881	9,893	3,731	8,648	109,316	85,749	8,701	17,039

Source: Bureau of the Census.

TABLE 30

U.S. EXPORTS OF ZINC ORES AND CONCENTRATES, BY COUNTRY

(Zinc content)

Country	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	3,500	$1,942	3,615	$2,060
Belgium	10,752	21,016	61,393	39,058
Brazil	5,126	3,291	—	—
Canada	42,770	26,843	86,105	94,368
France	—	—	5,240	1,845
Israel	5	11	—	—
Italy	—	—	12,567	12,024
Japan	13,126	6,891	42,928	30,247
Korea, Republic of	1,386	1,663	1,915	1,819
Mexico	478	759	254	211
Philippines	(1)	2	—	—
Taiwan	547	580	5	7
Trinidad and Tobago	13	7	—	—
United Kingdom	1,174	1,219	6,424	7,047
Total	78,877	64,224	220,446	188,686

[1]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 31

U.S. EXPORTS FOR CONSUMPTION OF ZINC PIGMENTS AND COMPOUNDS

	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Lithopone	48	$205	370	$541
Zinc chloride	583	510	2,267	2,275
Zinc compounds, n.s.p.f.	3,682	29,661	2,205	29,935
Zinc oxide	12,286	17,872	7,141	10,032
Zinc sulfate	1,239	4,368	3,200	6,180
Zinc sulfide	133	303	47	251

Source: Bureau of the Census.

TABLE 32

U.S. GENERAL IMPORTS OF ZINC, BY COUNTRY

Country	1988		1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
ORES AND CONCENTRATES (zinc content)						
Australia	458	$61	600	$78	316	$41
Bolivia	50	6	28	6	5,055	3,061
Canada	r[1]182,588	73,816	r[1]183,122	72,346	209,081	41,287
Chile	—	—	15	10	—	—
Honduras	1,172	614	—	—	24,455	7,753
Japan	—	—	—	—	35	11
Mexico	7,218	3,164	16,408	9,114	—	—
Peru	31,633	11,748	5,301	3,036	1,843	245
Total	223,119	89,409	205,474	84,590	240,785	52,398
BLOCKS, PIGS, OR SLABS[2]						
Algeria	2,300	2,152	—	—	—	—
Argentina	—	—	3,013	4,490	2,312	3,611
Australia	25,000	26,701	42,766	69,473	44,510	69,658
Austria	300	243	—	—	—	—
Belgium	11,635	13,993	2,562	4,221	5,779	9,477
Brazil	3,997	5,318	8,899	15,158	19,211	31,384
Canada	424,390	474,621	435,254	730,463	372,458	590,460
China	93	105	317	524	2,283	3,482
Finland	14,779	17,591	24,321	41,386	17,085	27,769
France	9,308	9,818	8,110	13,789	2,179	3,280
Germany, Federal Republic of	7,321	7,806	3,512	5,884	2,340	3,968
Guinea	—	—	—	—	133	207
Hong Kong	—	—	150	252	1,193	1,981
Italy	7,981	8,155	—	—	6,000	9,659
Japan	1,492	1,298	([3])	2	([3])	3
Korea, Republic of	18,122	20,702	2,352	3,776	([3])	2
Mexico	60,947	70,494	70,817	115,330	72,330	109,916
Monaco	—	—	136	231	—	—
Netherlands	11,097	12,332	4,685	7,532	1,733	2,442
Norway	31,695	30,150	28,801	47,325	23,247	36,569
Peru	11,943	12,213	34,409	54,772	23,333	34,186
Poland	4,177	4,909	—	—	822	1,066
South Africa, Republic of	—	—	201	331	—	—
Spain	65,231	76,679	26,277	44,747	23,919	37,460
Sweden	—	—	8	137	—	—
Taiwan	200	202	220	426	200	325
United Kingdom	4,311	5,206	1,239	2,114	660	1,028
Yugoslavia	792	1,010	—	—	38	59
Zaire	21,086	22,830	13,155	20,720	9,975	13,569
Zambia	1,000	1,304	749	1,159	—	—
Zimbabwe	1,663	1,421	—	—	—	—
Total[4]	740,860	827,253	711,953	1,184,244	631,742	991,562

rRevised.

[1]Canada adjusted by U.S. Bureau of Mines; data being subjected to verification.

[2]In addition, in 1990, 3,482 tons of zinc anodes was imported from Australia, Canada, China, Cook Islands, the Federal Republic of Germany, France, Hong Kong, India, Italy, Japan, Mexico, the Republic of Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, and the United Kingdom.

[3]Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 33

U.S. IMPORTS FOR CONSUMPTION OF ZINC, BY COUNTRY

Country	1988		1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
ORES AND CONCENTRATES (zinc content)						
Bolivia	—	—	—	—	5,007	$3,053
Canada	25,463	$10,934	20,161	$11,150	17,187	7,153
Honduras	1,172	614	—	—	—	—
Japan	—	—	—	—	35	11
Mexico	5,967	2,618	16,408	9,114	24,455	7,753
Peru	30,364	11,580	4,405	2,783	—	—
Total	62,966	25,746	40,974	23,047	46,684	17,970
BLOCKS, PIGS, OR SLABS[1]						
Algeria	2,300	2,152	—	—	—	—
Argentina	—	—	3,013	4,491	2,312	3,611
Australia	25,000	26,701	42,766	69,473	44,510	69,658
Austria	300	243	—	—	—	—
Belgium	16,739	17,037	2,562	4,221	5,779	9,477
Brazil	3,997	5,318	8,899	15,158	19,211	31,384
Canada	427,558	477,855	435,254	730,463	372,458	590,460
China	93	105	317	524	2,283	3,482
Finland	14,780	17,591	24,321	41,386	17,085	27,769
France	9,308	9,818	8,110	13,789	2,179	3,280
Germany, Federal Republic of	7,321	7,806	3,512	5,884	2,340	3,968
Guinea	—	—	—	—	133	207
Hong Kong	—	—	150	252	1,193	1,981
Italy	7,982	8,155	—	—	6,000	9,659
Japan	1,492	1,298	(2)	2	(2)	3
Korea, Republic of	18,122	20,702	2,352	3,776	· (2)	2
Mexico	60,947	70,494	70,817	115,330	72,330	109,916
Monaco	—	—	136	231	—	—
Netherlands	11,097	12,332	4,685	7,532	1,733	2,442
Norway	31,695	30,150	28,801	47,325	23,247	36,569
Peru	11,943	12,213	34,010	54,051	23,333	34,186
Poland	4,176	4,909	—	—	822	1,066
South Africa, Republic of	—	—	201	331	—	—
Spain	65,231	76,679	26,277	44,747	23,919	37,460
Sweden	—	—	8	137	—	—
Taiwan	200	202	220	426	200	325
United Kingdom	4,311	5,206	1,239	2,114	660	1,028
Yugoslavia	792	1,010	—	—	38	59
Zaire	21,086	22,830	13,155	20,720	9,975	13,569
Zambia	1,000	1,304	749	1,159	—	—
Zimbabwe	1,663	1,421	—	—	—	—
Total[3]	749,133	833,531	711,554	1,183,523	631,742	991,562

[1]In addition, in 1990, 3,499 tons of zinc anodes was imported from Australia, Canada, China, Cook Islands, the Federal Republic of Germany, France, Hong Kong, India, Italy, Japan, Mexico, the Republic of Korea, Sweden, Switzerland, Taiwan, Thailand, and the United Kingdom.

[2]Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 34

U.S. IMPORTS FOR CONSUMPTION OF ZINC

Year	Ores and concentrates (zinc contents)		Blocks, pigs, slabs[1]		Sheets, plates, strips other forms	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1988	62,966	$25,746	749,133	$833,531	4,100	$5,395
1989	40,974	23,047	711,554	1,183,523	3,066	5,436
1990	46,684	17,970	631,742	991,562	929	1,641

	Waste and scrap		Dross, ashes, and fume (zinc content)		Dust, powder, flakes		Total value[2] (thousands)
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	
1988	5,727	$3,615	6,346	$4,279	7,652	$11,958	$884,524
1989	9,367	6,674	9,031	7,856	7,253	15,123	1,241,659
1990	31,720	15,101	6,411	5,942	8,834	17,724	1,049,940

[1]Unwrought alloys of zinc were imported as follows, in metric tons: 1988—50 ($76,864); 1989—632 ($952,159) and 1990—736 ($1,042,096).
[2]In addition, the value of manufactures of zinc imported was as follows: 1988—$1,415,747; 1989—$2,080,347; and 1990—$6,729,670.

Source: Bureau of the Census.

TABLE 35

U.S. IMPORTS FOR CONSUMPTION OF ZINC PIGMENTS AND COMPOUNDS

	1989		1990	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Lithopone	3,365	$2,155	2,487	$2,189
Zinc chloride	2,578	2,301	2,833	2,595
Zinc compounds, n.s.p.f.	1,098	2,151	604	1,177
Zinc oxide	59,557	93,448	49,454	71,998
Zinc sulfate	3,387	1,856	4,204	2,234
Zinc sulfide	1,840	3,178	1,525	3,256

Source: Bureau of the Census.

TABLE 36

TARIFF CODES FOR IMPORTS AND EXPORTS OF ZINC, IN 1990

Material	Exports HTS[1] No.
Ore and concentrate (zinc content)	2608.00.0030 2608.00.0045
Slab zinc	7901.11.0000 7901.12.0000 7901.20.0000
Zinc chloride	2827.36.0000
Zinc compounds, other	2830.20.0000 2841.20.0000 3206.42.0000
Zinc oxide (gross weight)	2817.00.0000
Zinc powders and flakes (zinc content)	7903.10.0000 7903.90.0000
Zinc sulfate	2833.26.0000
Zinc waste and scrap (zinc content)	2620.11.0000 2620.19.0000 7902.00.0000
	Imports
	HTS[1] No.
Dross, ashes, and fume (zinc content)	2620.19.3000 2620.19.6030 2620.11.0000
Ore and concentrate (zinc content)	2603.00.0030 2607.00.0030 2608.00.0030 2608.00.0045 2616.10.0030 2616.90.0030
Slab zinc	7901.11.0000 7901.12.5000
Zinc oxide (gross weight)	2817.00.0000 3206.49.3000
Zinc powders and flakes (zinc content)	7903.10.0000 7903.90.3000 7903.90.6000
Zinc sheets	7905.00.0000
Zinc waste and scrap (zinc content)	7902.00.0000

[1]Harmonized Tariff Schedule of the United States.

Source: Bureau of the Census.

TABLE 37

U.S. IMPORT DUTIES FOR ZINC MATERIALS, JANUARY 1, 1990

Item	HTS No.	Most favored nation (MFN) Jan. 1, 1990	Canada Jan. 1, 1990	Non-MFN Jan. 1, 1990
Ores and concentrates	2608.00.0030	1.7¢ per kilogram on lead content	1.3¢ per kilogram on lead content	3.7¢ per kilogram on zinc content.
Unwrought metal	7901.11.1250	1.5% ad valorem	1.2% ad valorem	5.0% ad valorem.
Alloys, casting-grade	7901.12.1000	19.0% ad valorem	15.2% ad valorem	45.0% ad valorem.
Alloys	7901.20.0000	19.0% ad valorem	15.2% ad valorem	45.0% ad valorem.
Waste and scrap	7902.00.0000	2.1% ad valorem	Free	11.0% ad valorem.
Hard zinc spelter	2620.11.0000	1.5% ad valorem	1.2% ad valorem	5.0% ad valorem.
Zinc oxide, dry	2817.00.0000	Free	Free	5.5% ad valorem.

TABLE 38

ZINC: WORLD MINE PRODUCTION (CONTENT OF CONCENTRATE AND DIRECT SHIPPING ORE UNLESS NOTED), BY COUNTRY[1]

(Thousand metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
Algeria	14.0	[e]13.0	10.0	11.6	11.0
Argentina	39.5	35.6	36.8	43.2	40.0
Australia	712.0	778.4	759.0	803.0	[2]937.0
Austria	16.3	15.7	17.1	14.8	17.9
Bolivia	33.5	39.3	57.0	74.8	107.9
Brazil	123.9	133.4	155.5	157.1	[2]132.1
Bulgaria[e]	[r]56.0	[r]56.0	[r]56.0	[2]55.6	55.5
Burma	4.6	2.6	1.6	1.4	[2]2.2
Canada	1,290.8	1,481.5	1,370.0	1,272.9	[2]1,177.0
Chile	10.5	19.6	19.2	18.4	[2]25.1
China	396.0	458.0	527.0	620.0	619.0
Colombia	6.0	—	.1	.4	.4
Congo (Brazzaville)[e]	2.3	2.3	[r]1.8	[r]1.0	1.0
Czechoslovakia[e]	7.3	7.5	[r]7.5	7.5	7.5
Ecuador[e]	.1	.1	.1	.1	.1
Finland	60.4	55.1	63.9	58.4	51.7
France	39.5	31.3	31.1	26.7	23.9
Germany, Federal Republic of:					
Western states	103.7	98.9	75.6	63.9	[2]59.2
Greece	22.3	[r]20.7	21.2	24.6	26.5
Greenland	62.1	69.2	77.5	71.5	[2]47.9
Honduras	25.4	15.4	23.5	37.2	30.0
India	[r]46.5	[r]54.5	61.4	65.4	67.6
Indonesia	.5	—	—	—	—
Iran[e]	29.0	36.0	25.0	25.0	14.8
Ireland	181.7	177.0	173.2	[e]168.8	166.5
Italy	26.3	33.1	37.2	43.3	45.0
Japan	222.1	165.7	147.2	131.8	[2]127.3
Korea, North[e]	225.0	220.0	225.0	[r]230.0	230.0
Korea, Republic of	37.3	23.5	21.8	23.2	[2]22.8
Mexico	271.4	271.5	262.2	284.1	[2]322.5
Morocco	17.2	10.3	10.9	18.7	[2]18.8
Namibia	35.4	39.7	36.7	41.7	42.0
Norway	27.5	22.2	17.8	15.0	17.5
Peru	597.6	612.5	485.4	597.4	[2]576.8
Philippines	1.6	1.1	1.4	1.2	—
Poland	185.0	184.0	[e]184.0	[e]184.0	180.0
Romania[e]	43.0	41.0	41.0	[2]54.5	48.0
Saudi Arabia	—	—	.7	[e]2.0	3.0
South Africa, Republic of	101.9	112.7	89.6	77.3	[2]74.8
Spain	[r]233.3	[r]272.6	274.7	281.7	258.0
Sweden	219.3	218.6	189.0	173.5	157.4
Thailand	[r]66.0	[r]74.0	81.0	91.0	81.0
Tunisia	4.5	5.9	9.4	[e]9.0	[2]13.3
Turkey[3]	[r]40.6	[r]42.2	37.5	[r e]38.6	43.0
U.S.S.R.[e]	810.0	810.0	810.0	810.0	750.0
United Kingdom	5.6	6.5	5.5	5.8	[2]6.6
United States	220.8	232.9	256.4	288.3	[2]543.2

See footnotes at end of table.

TABLE 38—Continued

ZINC: WORLD MINE PRODUCTION (CONTENT OF CONCENTRATE AND DIRECT SHIPPING ORE UNLESS NOTED), BY COUNTRY[1]

(Thousand metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
Vietnam[e]	5.0	5.0	5.5	5.5	5.5
Yugoslavia[e]	[r]54.0	[r]65.0	[r]65.0	[r]65.0	62.0
Zaire	81.3	74.7	75.7	72.8	50.0
Zambia[4]	[r]27.0	[r]30.3	25.2	22.9	25.0
Total	[r]6,842.4	[r]7,176.1	6,966.8	7,191.3	7,325.2

[e]Estimated. [p]Preliminary. [r]Revised.
[1]Table includes data available through July 2, 1991.
[2]Reported figure.
[3]Content in ore hoisted.
[4]Data are for years beginning Apr. 1 of that stated. Content of ore milled.

TABLE 39

ZINC: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1986	1987	1988	[p]1989	[e]1990
Algeria, primary	29.0	19.0	38.0	28.0	30.0
Argentina:					
Primary	29.1	31.9	30.5	[e]29.0	29.0
Secondary	3.0	2.6	2.5	[e]2.5	2.5
Total	32.1	34.5	33.0	[e]31.5	31.5
Australia:					
Primary[2]	303.1	307.6	302.5	294.0	295.0
Secondary[e]	4.5	4.5	4.5	[r]5.5	5.5
Total[e]	307.6	312.1	307.0	[r]299.5	300.5
Austria, primary and secondary	24.0	24.3	23.9	26.1	26.8
Belgium, primary and secondary	288.8	308.6	323.8	306.0	309.0
Brazil:					
Primary	130.6	138.7	139.7	155.9	150.0
Secondary	5.9	9.4	4.3	6.4	5.5
Total	136.5	148.1	144.0	162.3	155.5
Bulgaria, primary and secondary	[e]90.0	92.0	[e]90.0	86.8	86.0
Canada, primary	571.0	609.9	703.2	670.3	592.0
China, primary and secondary[e]	[3]336.0	383.0	340.0	[r]451.0	470.0
Czechoslovakia, secondary	[e]1.1	1.1	1.4	1.3	1.3
Finland, primary	155.4	150.5	156.1	162.5	176.4
France, primary and secondary	257.4	249.3	274.0	264.5	[3]263.1
Germany, Federal Republic of:					
Eastern states, primary and secondary[e]	17.0	18.0	21.0	[r]18.5	15.0
Western states:					
Primary	344.3	348.2	309.9	297.5	282.6
Secondary	26.6	29.3	42.5	45.3	37.4
Total	370.9	377.5	352.4	342.8	320.0

See footnotes at end of table.

TABLE 39—Continued

ZINC: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
Hungary, secondary[e]	0.6	0.6	0.6	0.6	0.6
India:					
Primary	[r]73.8	68.9	68.9	71.6	78.8
Secondary[e]	.2	.2	.2	.2	.2
Total[e]	[r]74.0	69.1	69.1	[r]71.8	79.0
Italy, primary and secondary	229.4	247.0	242.1	259.5	250.0
Japan:					
Primary	626.5	591.5	601.1	591.2	[3]605.7
Secondary	81.5	74.1	77.1	73.3	[3]81.8
Total	708.0	665.6	678.2	664.5	[3]687.5
Korea, North, primary[e]	180.0	210.0	210.0	210.0	210.0
Korea, Republic of, primary	127.4	186.1	223.0	240.2	[3]248.2
Mexico, primary	173.5	184.8	192.5	193.3	[3]199.3
Netherlands, primary and secondary	196.2	207.1	211.0	203.0	[3]207.0
Norway, primary	90.4	116.5	121.2	120.4	[3]125.1
Peru, primary	155.8	144.2	123.1	[e]137.8	[3]120.6
Poland, primary and secondary	179.0	177.0	174.0	164.0	132.0
Portugal, primary	5.7	5.8	5.5	[e]5.0	5.0
Romania, primary and secondary[e]	39.0	39.0	42.0	42.0	40.0
South Africa, Republic of, primary	81.0	96.1	84.4	85.0	[3]90.3
Spain, primary and secondary	202.0	[r]249.0	256.0	257.0	265.0
Thailand, primary	[r]58.6	66.9	68.6	68.4	71.0
Turkey, primary	15.4	[r]22.2	22.5	24.2	23.0
U.S.S.R.:[e]					
Primary	880.0	890.0	848.0	862.0	780.0
Secondary	105.0	110.0	115.0	115.0	110.0
Total	985.0	1,000.0	963.0	977.0	890.0
United Kingdom, primary and secondary	85.9	81.4	76.0	79.8	[3]93.3
United States:					
Primary	253.4	261.3	241.3	263.1	[3]262.7
Secondary	62.9	82.6	88.5	95.1	[3]95.7
Total	316.3	343.9	329.8	358.2	[3]358.4
Vietnam, undifferentiated[e]	4.2	4.2	4.2	4.2	4.2
Yugoslavia, primary and secondary	82.0	118.1	127.5	119.4	[3]113.7
Zaire, primary	63.9	54.9	61.1	54.0	40.0
Zambia, primary	22.5	21.0	20.2	12.9	11.0
Grand total	[r]6,692.6	[r]7,038.4	7,113.4	7,203.3	7.041.3
Of which:					
Primary	[r]4,370.4	[r]4,526.0	4,571.3	4,576.3	4,425.7
Secondary	291.3	314.4	336.6	345.2	340.5
Undifferentiated	[r]2,030.9	[r]2,198.0	2,205.5	2,281.8	2,275.1

[e]Estimated. [p]Preliminary. [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 2, 1991.

[2]Excludes zinc dust.

[3]Reported figure.

TABLE 40

ZINC: WORLD MINE AND PRIMARY SMELTER CAPACITY, BY COUNTRY

(Thousand metric tons)

Country	Mine	Smelter
Algeria	15	40
Argentina	42	35
Australia	1,085	345
Austria	20	28
Belgium	—	345
Bolivia	110	—
Brazil	170	169
Bulgaria	40	90
Burma	5	—
Canada	1,360	745
Chile	35	—
China	620	500
Congo	3	—
Czechoslovakia	6	—
Ecuador	1	—
Finland	55	170
France	40	305
Germany, Federal Republic of:		
Western states	70	410
Greece	30	—
Greenland	75	—
Honduras	50	—
Hungary	1	—
India	75	99
Indonesia	1	—
Iran	105	—
Ireland	170	—
Italy	76	253
Japan	160	864
Korea, North	230	260
Korea, Republic of	25	265
Mexico	320	218
Morocco	20	—
Namibia	42	—
Netherlands	—	205
Norway	20	130
Peru	625	172
Philipines	3	—
Poland	205	137
Portugal	—	11
Romania	45	60
Saudi Arabia	3	—
South Africa, Republic of	80	105
Spain	290	268
Sweden	180	—
Thailand	85	70
Tunisia	10	—

TABLE 40—Continued

ZINC: WORLD MINE AND PRIMARY SMELTER CAPACITY, BY COUNTRY

(Thousand metric tons)

Country	Mine	Smelter
Turkey	45	25
U.S.S.R.	870	1,165
United Kingdom	7	105
United States	605	360
Vietnam	10	10
Yugoslavia	90	160
Zaire	80	72
Zambia	40	40
Total	8,350	8,236

Sources: U.S. Bureau of Mines and International Lead and Zinc Study Group.

TABLE 41

ZINC: WORLD RESERVES AND RESERVE BASE, BY CONTINENT AND COUNTRY

(Million metric tons)

Continent and country	Reserves	Reserve base
North America:		
Canada	22	56
Mexico	6	8
United States	20	50
Other	(1)	1
Total	48	115
South America:		
Brazil	2	3
Peru	7	12
Other	1	2
Total	10	17
Europe:		
Finland	1	2
France	1	1
Germany, Federal Republic of	1	2
Greece	1	1
Ireland	5	7
Italy	2	3
Poland	3	4
Portugal	2	3
Spain	5	7
Sweden	1	3
U.S.S.R.	10	15
Yugoslavia	2	3
Other	2	4
Total	36	55
Africa:		
South Africa, Republic of	3	14
Zaire	5	7
Other	1	4
Total	9	25
Asia:		
China	5	9
India	11	15
Iran	2	6
Japan	4	6
Korea, North	4	6
Thailand	1	1
Turkey	1	2
Other	1	2
Total	29	47
Oceania:		
Australia	18	62
Grand total	150	321

[1]Less than 1 million metric tons.

TABLE 42

U.S. HISTORICAL SALIENT ZINC STATISTICS

(Metric tons)

Year	Slab zinc production		Mine[1] production (recoverable)	Imports for consumption		Exports		Consumption			Net import reliance (percent)[7]	Price, cents per pound[8]
	Primary	Secondary		Slab zinc	Ore (zinc content)[2]	Slab zinc	Ore (zinc content[3]	Slab zinc[4]	Consumed as ore[5]	All classes[6]		
1859	45	NA	245	NA	NA	NA	NA	NA	NA	NA	NA	NA
1860	725	NA	925	NA	NA	NA	NA	NA	NA	NA	NA	NA
1861	1,350	NA	1,650	NA	NA	NA	NA	NA	NA	NA	NA	NA
1862	1,350	NA	1,600	NA	NA	NA	NA	NA	NA	NA	NA	NA
1863	1,550	NA	1,800	NA	NA	NA	NA	NA	NA	NA	NA	NA
1864	1,630	NA	1,900	NA	NA	43	671	NA	NA	NA	NA	13.90
1865	1,900	NA	2,200	NA	NA	83	450	NA	NA	NA	NA	NA
1866	1,800	NA	2,000	NA	NA	63	203	NA	NA	NA	NA	NA
1867	2,900	NA	3,300	NA	NA	141	166	7,700	NA	[9] 7,700	NA	NA
1868	3,350	NA	3,800	NA	NA	463	378	8,731	NA	[9] 8,731	NA	NA
1869	3,900	NA	4,500	NA	NA	NA	NA	13,660	NA	[9]13,660	NA	NA
1870	4,900	NA	5,400	NA	NA	49	693	13,362	NA	[9]13,362	NA	NA
1871	6,250	NA	7,000	NA	NA	34	436	14,746	NA	[9]14,746	NA	NA
1872	7,070	NA	8,200	NA	NA	28	167	17,251	NA	[9]17,251	NA	NA
1873	6,661	NA	8,000	NA	NA	33	10	16,627	NA	[9]16,627	NA	NA
1874	11,900	NA	13,500	NA	NA	19	115	16,240	NA	[9]16,240	NA	NA
1875	14,363	NA	17,200	NA	NA	17	139	19,376	NA	[9]19,376	NA	7.00
1876	15,400	NA	18,500	NA	NA	61	461	17,860	NA	[9]17,860	NA	7.20
1877	14,150	NA	16,900	NA	NA	644	291	14,684	NA	[9]14,684	NA	6.00
1878	17,800	NA	19,700	NA	NA	1,154	728	17,791	NA	[9]17,791	NA	4.90
1879	19,300	NA	23,000	NA	NA	967	483	19,481	NA	[9]19,481	NA	5.20
1880	21,082	NA	28,400	NA	NA	620	590	27,646	7,335	[10]34,981	NA	5.50
1881	27,450	NA	34,800	NA	NA	676	516	29,308	7,257	[10]36,565	NA	5.20
1882	30,631	NA	38,000	NA	NA	675	494	40,306	7,257	[10]47,563	NA	5.30
1883	33,451	NA	42,000	NA	NA	386	138	42,315	8,709	[10]51,024	NA	4.50
1884	34,967	NA	44,000	NA	NA	57	216	38,004	9,435	[10]47,439	NA	4.40
1885	36,911	NA	47,000	NA	NA	46	310	39,294	10,886	[10]50,180	NA	4.30
1886	38,683	NA	52,000	NA	NA	349	396	40,445	13,063	[10]53,508	NA	4.40
1887	45,667	NA	58,000	NA	NA	164	54	49,217	13,063	[10]62,280	NA	4.60
1888	50,714	NA	65,000	NA	NA	28	206	52,555	14,515	[10]67,070	NA	4.90
1889	53,397	NA	66,000	NA	NA	399	1,213	54,388	12,316	[10]66,704	NA	5.00
1890	57,772	NA	75,000	NA	NA	1,494	3,508	57,538	17,200	[10]57,538	NA	5.50
1891	73,367	NA	90,000	NA	NA	1,948	171	71,327	17,200	[10]88,527	NA	5.00
1892	79,161	NA	99,000	NA	NA	5,667	41	73,465	19,958	[10]93,423	NA	4.60
1893	71,515	NA	89,000	NA	NA	3,301	44	69,058	17,461	[10]86,519	NA	4.00
1894	68,336	NA	82,000	NA	NA	1,636	—	64,028	14,506	[10]78,534	NA	3.50
1895	81,361	NA	96,000	NA	NA	1,388	21	79,557	15,030	[10]94,587	NA	3.60
1896	73,934	NA	88,000	NA	NA	9,189	1,882	63,609	14,515	[10]78,124	NA	3.90
1897	90,700	NA	109,000	NA	NA	12,923	3,746	80,541	18,144	[10]98,685	NA	4.10
1898	104,688	NA	129,000	NA	NA	9,524	4,771	98,157	23,950	[10]122,107	NA	4.60
1899	117,073	NA	146,000	NA	NA	6,127	11,429	113,021	29,135	[10]142,156	NA	5.80
1900	112,388	NA	150,546	NA	NA	20,322	19,079	90,173	35,446	[10]125,619	NA	4.40
1901	127,752	NA	167,646	NA	NA	3,075	20,029	128,529	35,198	[10]163,727	NA	4.10
1902	142,362	NA	192,922	406	NA	2,937	25,280	138,511	40,591	[10]179,102	NA	4.80
1903	144,441	NA	180,194	183	NA	1,380	17,876	140,052	48,308	[10]188,360	NA	5.40
1904	169,378	NA	201,951	309	727	9,205	16,289	164,120	49,343	[10]213,463	NA	5.10
1905	184,929	NA	213,003	388	7,301	5,004	14,037	181,834	53,724	[10]235,558	NA	5.90

See footnotes at end of table.

TABLE 42—Continued

U.S. HISTORICAL SALIENT ZINC STATISTICS

(Metric tons)

Year	Slab zinc production		Mine[1] production (recoverable)	Imports for consumption		Exports		Consumption			Net import reliance (percent)[7]	Price, cents per pound[8]
	Primary	Secondary		Slab zinc	Ore (zinc content)[2]	Slab zinc	Ore (zinc content[3]	Slab zinc[4]	Consumed as ore[5]	All classes[6]		
1906	203,908	NA	201,147	926	17,816	4,237	12,574	200,289	58,915	[10]259,204	NA	6.10
1907	226,669	6,396	235,824	1,550	33,168	511	9,234	205,903	59,944	272,538	NA	5.80
1908	190,893	6,495	212,758	704	17,614	1,119	11,842	194,289	43,549	244,104	NA	4.60
1909	232,022	8,412	277,075	8,545	37,356	303	5,650	245,602	49,114	310,094	NA	5.40
1910	244,200	11,597	297,295	897	23,078	3,388	8,941	223,062	45,896	296,733	NA	5.40
1911	259,932	12,740	313,215	293	14,933	13,023	8,292	254,065	41,841	330,140	NA	5.70
1912	307,360	23,645	343,656	9,724	15,936	6,808	10,591	308,752	58,089	408,701	NA	6.90
1913	314,499	23,579	368,694	4,686	12,244	12,234	8,034	267,955	64,067	361,587	NA	5.60
1914	320,281	18,638	377,082	177	11,006	67,594	5,040	272,140	64,064	364,877	NA	5.10
1915	444,084	27,001	533,057	57	52,316	119,213	377	330,991	72,187	459,036	NA	14.20
1916	605,506	26,105	638,039	19	134,397	137,211	71	416,685	81,897	577,969	NA	13.60
1917	607,427	15,272	647,159	16	65,747	199,639	1,197	375,251	88,517	564,368	NA	8.90
1918	469,856	8,997	577,052	10	22,506	96,751	56	334,458	93,239	537,589	NA	8.00
1919	422,515	17,915	497,905	29	15,430	132,718	—	293,895	90,909	475,194	NA	7.00
1920	420,369	19,387	532,993	—	23,265	103,661	—	293,060	106,122	497,362	NA	7.80
1921	181,891	15,942	232,820	5,986	12,963	4,495	—	184,703	51,917	295,881	NA	4.70
1922	321,395	29,926	428,220	36	NA	31,571	1,538	338,462	86,104	513,990	NA	5.70
1923	463,058	35,774	554,009	1	788	29,885	2,544	405,071	106,633	609,178	NA	6.70
1924	469,322	32,192	578,763	10	5,489	69,165	334	406,652	99,207	602,735	NA	6.30
1925	519,768	35,544	644,870	—	18,566	69,264	62,551	453,680	100,698	647,160	NA	7.66
1926	561,023	37,012	702,672	—	12,508	38,936	86,411	505,326	117,934	723,867	NA	7,37
1927	537,522	38,813	651,850	35	5,572	41,454	42,380	468,446	110,677	679,990	NA	6.25
1928	546,652	44,149	630,648	—	3,951	22,942	4,099	568,351	112,491	788,199	NA	6.03
1929	567,396	42,953	657,236	205	1,705	13,073	64	575,427	125,192	808,952	NA	6.49
1930	451,819	31,614	540,161	255	23,264	4,203	—	409,050	95,254	582,693	NA	4.56
1931	264,894	19,618	372,234	249	706	583	12	355,658	68,039	470,783	NA	3.64
1932	187,922	13,352	258,757	281	1,727	5,870	—	234,961	49,895	339,731	NA	2.88
1933	278,671	27,294	348,618	1,715	1,935	1,039	734	317,787	65,317	453,193	NA	4.03
1934	329,843	17,868	398,006	1,565	12,952	4,631	3,285	326,496	68,946	458,948	NA	4.16
1935	381,593	25,991	469,834	4,032	9,544	1,467	418	429,099	78,018	581,967	NA	4.33
1936	446,455	38,291	522,152	10,578	156	34	222	527,982	87,090	709,871	NA	4.90
1937	505,215	46,769	568,226	33,755	3,035	226	285	553,383	101,605	758,104	NA	6.52
1938	404,914	28,679	468,745	6,559	4,409	—	122	381,925	62,596	522,944	NA	4.61
1939	460,157	45,748	529,621	28,086	30,393	4,096	275	567,898	77,111	798,679	NA	5.12
1940	612,599	44,377	603,340	9,204	40,494	71,750	406	665,018	87,090	907,883	NA	6,34
1941	745,724	53,980	679,595	36,549	140,171	81,020	—	750,637	122,470	1,086,368	NA	7.48
1942	809,093	48,258	696,741	32,978	256,885	121,507	—	660,584	104,326	1,031,676	NA	8.25
1943	854,849	43,740	675,123	50,943	468,694	88,395	1	740,968	104,326	1,157,226	NA	8.25
1944	788,618	44,486	651,941	57,721	376,485	19,578	—	806,148	128,820	1,223,677	NA	8.25
1945	693,598	44,672	557,336	87,779	300,762	7,060	—	773,204	118,841	1,191,969	NA	8.25
1946	660,668	40,384	521,480	94,406	151,396	42,841	81	735,039	121,563	1,101,486	24	8.73
1947	728,011	54,016	578,428	65,374	176,740	96,769	1,274	713,374	132,449	1,087,273	25	10.50
1948	714,648	56,536	571,506	83,910	121,394	59,454	3,218	741,837	120,656	1,114,419	E	13.58
1949	739,158	49,932	538,145	113,910	99,369	53,260	2,654	645,771	79,832	900,135	1	12.15
1950	765,181	60,754	565,516	140,915	215,514	11,718	1,034	877,369	121,563	1,247,865	39	13.88
1951	799,804	44,141	617,964	79,871	179,618	33,121	2,803	847,284	121,653	1,203,002	24	17.99
1952	820,530	49,996	604,186	102,560	491,979	52,357	3,057	773,632	99,134	1,099,189	39	16.21

See footnotes at end of table.

TABLE 42—Continued

U.S. HISTORICAL SALIENT ZINC STATISTICS

(Metric tons)

Year	Slab zinc production		Mine[1] production (recoverable)	Imports for consumption		Exports		Consumption			Net import reliance (percent)[7]	Price, cents per pound[8]
	Primary	Secondary		Slab zinc	Ore (zinc content)[2]	Slab zinc	Ore (zinc content[3]	Slab zinc[4]	Consumed as ore[5]	All classes[6]		
1953	831,077	47,967	496,620	206,524	407,990	16,301	2,679	894,418	107,269	1,217,795	47	10.86
1954	727,948	61,700	429,526	145,277	436,282	22,674	—	802,223	90,035	1,071,106	49	10.69
1955	874,076	59,912	466,902	176,955	348,947	16,392	—	1,015,877	107,170	1,332,727	43	12.30
1956	892,316	65,433	492,003	222,012	419,463	7,995	775	915,159	102,864	1,200,226	45	13.49
1957	894,299	65,764	482,382	243,873	616,356	9,784	6	848,780	100,072	1,117,283	47	11.40
1958	708,735	42,279	373,765	168,458	487,792	1,881	—	787,733	86,126	1,036,155	56	10.31
1959	724,538	52,452	385,829	149,197	384,769	10,550	1	867,448	98,039	1,159,724	53	11.46
1960	725,309	62,352	395,013	109,701	347,396	68,170	12	796,403	80,082	1,051,371	46	12.95
1961	768,200	50,110	421,288	113,567	324,457	45,409	1,515	844,782	88,225	1,095,398	46	11.55
1962	797,774	53,415	458,574	123,373	351,372	32,751	123	936,053	92,154	1,209,560	47	11.63
1963	809,739	54,706	480,181	120,050	337,399	30,711	15	1,002,542	94,987	1,282,956	49	12.01
1964	865,531	64,951	521,503	121,670	282,529	24,054	35	1,095,215	96,114	1,393,210	44	13.57
1965	902,107	75,858	554,429	139,667	365,537	5,388	NA	1,228,412	111,486	1,580,377	51	14.50
1966	929,924	75,535	519,416	254,290	359,585	1,276	NA	1,291,528	114,937	1,651,088	54	14.50
1967	851,692	66,683	498,419	201,397	391,286	15,249	NA	1,134,592	103,692	1,456,814	52	13.85
1968	926,137	72,452	480,305	276,407	439,806	29,947	NA	1,225,295	112,590	1,583,362	58	13.50
1969	944,014	64,005	501,736	294,616	512,772	8,435	NA	1,256,796	114,951	1,645,785	59	14.65
1970	796,337	69,995	484,560	235,988	408,932	261	NA	1,076,784	113,199	1,425,728	53	15.32
1971	695,297	73,412	455,899	294,159	423,989	12,107	NA	1,137,664	108,185	1,497,485	60	16.13
1972	574,411	66,876	433,922	468,691	157,907	8,923	NA	1,286,705	107,325	1,672,870	61	17.75
1973	529,323	75,466	434,406	535,920	139,864	13,214	NA	1,364,350	117,617	1,752,613	65	20.66
1974	503,658	71,246	453,476	493,333	121,321	17,293	NA	1,168,178	115,315	1,517,732	60	35.95
1975	397,394	52,513	425,792	340,124	388,769	6,257	NA	839,445	75,053	1,117,484	63	38.96
1976	452,554	62,192	439,543	630,612	141,342	3,187	NA	1,028,876	91,844	1,394,268	59	37.01
1977	408,364	45,913	407,889	503,621	109,277	215	NA	999,505	86,940	1,367,704	58	34.39
1978	406,698	34,774	302,669	622,470	106,315	723	10,973	1,050,585	89,959	1,441,810	67	30.97
1979	472,481	53,212	267,341	524,130	87,499	279	20,095	1,000,606	79,710	1,394,314	63	37.30
1980	340,456	29,396	317,103	410,163	182,370	302	54,457	811,146	58,986	1,142,409	60	37.43
1981	346,563	50,192	312,418	612,007	245,710	323	54,232	840,875	60,643	1,189,369	65	44.56
1982	228,176	74,288	303,160	456,233	66,809	341	77,289	795,000	35,515	1,038,600	58	38.47
1983	235,694	69,390	275,294	617,679	63,156	427	60,168	933,000	36,912	1,246,300	65	41.39
1984	253,432	78,113	252,768	639,228	86,172	760	30,579	980,000	45,487	1,344,000	68	48.60
1985	261,209	72,563	226,545	610,900	90,186	1,011	23,264	961,000	39,886	1,257,000	70	40.37
1986	253,369	62,912	202,983	665,126	75,786	1,938	3,269	999,000	19,236	1,274,000	73	38.00
1987	261,345	82,589	216,327	705,985	46,464	1,082	16,921	1,052,000	2,536	1,383,000	69	41.92
1988	241,294	88,492	244,314	749,130	62,966	482	33,590	1,092,000	2,412	1,340,000	70	60.20
1989	260,305	97,904	275,883	711,554	40,974	5,532	78,877	1,060,000	2,107	1,311,000	61	82.02
1990	262,704	95,708	515,355	631,742	46,684	1,238	220,446	991,000	2,178	1,239,000	40	74.59

E Net exporter. NA Not available.

[1]Recoverable mine production is estimated for 1859-99.

[2]Imports ore: 1904-09 were estimated (Minerals Yearbook 1926) and for 1910-36 were zinc content of General Imports.

[3]Exports ore: 1897-15 zinc content estimated at 50% of ore shipped; 1907-15 virtually all willemite concentrate (50% zinc).

[4]Data through 1981 are reported consumption of slab zinc; 1982 forward, data are apparent consumption of slab zinc.

[5]1880-1900 data for zinc oxide from ore; 1901-07 data for zinc oxide and zinc lead from ore; 1908-18 data for pigments from ore; 1919-24 data for pigments and salts from ore; 1925-56 data for zinc oxide from ore; 1957-88 includes ore directly to galvanizing.

[6]Based on apparent consumption of slab zinc plus zinc content of ores and concentrates and secondary materials used to make zinc dust and chemicals.

[7]Net import reliance is expressed as a percent of apparent consumption. Net import reliance is defined as exports minus imports plus adjustments for changes in industry and Government stocks. Apparent consumption in U.S. equals mine production plus old scrap minus net import reliance.

[8]Source: U.S. Bureau of Mines. Nonferrous Metal Prices in the United States through 1988. Spec. Publ. 1989, pp. 125-130.

[9]Data do not include ores and secondary consumed, data not available.

[10]Data do not include secondary consumed, data not available.

TABLE 43

APPARENT PER CAPITA CONSUMPTION OF ZINC METAL FOR SELECTED YEARS

Year	World population	Zinc production (kilograms)[1]	Kilograms per person
1800	[2]910,000,000	[e]2,000,000	0.002
1850	[2]1,130,000,000	[e]49,000,000	.043
1900	[2]1,600,000,000	494,000,000	.31
1920	[2]1,800,000,000	618,000,000	.34
1940	[2]2,200,000,000	1,673,000,000	.76
1950	[3]2,564,000,000	1,980,000,000	.77
1960	[3]3,050,000,000	3,044,000,000	1.00
1970	[3]3,721,000,000	4,848,000,000	1.30
1980	[3]4,476,000,000	6,130,000,000	1.37
1985	[3]4,882,000,000	6,673,000,000	1.37
1990	[3]5,329,000,000	[e]7,041,000,000	1.32
2000	[3]6,285,000,000	[e]8,500,000,000	[e]1.35

[e]Estimated.

[1]Three-year production average centering on the year of population estimate, i.e. production for 1980, production in 1979, 1980, and 1981 was averaged. Production for 1990 and 2000 are not averages but estimates for these years only.

[2]Source: World Almanac and Book of Facts, 1982.

[3]Source: Bureau of the Census, Center for International Research.

ZIRCONIUM AND HAFNIUM

By David A. Templeton

Mr. Templeton is a physical scientist with the Branch of Industrial Minerals. He has covered zirconium and hafnium for about 3 years. Domestic survey data were prepared by Imogene P. Bynum, Chief, Section of Nonferrous Metals Data, and Jean K. Moore, Mineral Data Controller. World production data were prepared by Harold D. Willis.

Zirconium and hafnium are sister metals of Group IVB on the Periodic Table of Elements and have atomic numbers 40 and 72, respectively. Their predominant commercial ore mineral is zircon, a zirconium silicate usually containing 65% to 66% zirconium and hafnium oxides combined. Hafnium is always present in zircon minerals, usually accounting for about 2% of the mineral composition. An ancillary source is baddeleyite, the naturally occurring oxide of zirconium, and as such is quite valuable. It contains better than 95% zirconium oxide. Other possible ore minerals for which economic deposits have been discovered include eudialyte and gittinsite, though the mineral beneficiation techniques for these have yet to be commercialized. The zirconium oxide content of these ores is quite low (roughly 1% to 4%) compared to zircon and baddeleyite, but are considered economic because of the high value of coproduct yttrium (less than 1% yttrium oxide).

Zircon is mined as a byproduct of heavy-mineral sand deposits, which almost always contain titanium and rare-earth minerals as well. The highly abundant titanium minerals, sought for their use in pigment and metal markets, are the primary product. The deposits are mined using dredges or typical earth-moving equipment. Once ore is extracted, the suite of heavy minerals, normally composing about 10% or less of the deposit, is separated from the gangue (nonresource ore) by nature of its higher specific gravity, or weight. The heavy minerals are concentrated in a wet treatment plant using equipment such as jigs, cones, or spirals. Dredged ore is pumped to the plant and processed as a watery slurry. Ore that is not dredged, but rather is mined with heavy equipment, is trucked to the plant and mixed with water. The plant equipment is designed to selectively remove the heavy minerals from the water stream, and unwanted material, about 90% of what was mined, is pumped back to the dredge pond or to a tailings pile. After the heavy minerals are concentrated, they are dried and sorted from one another using magnetic and electrostatic principles.

Zircon sand is the primary ore for the production of zirconium and hafnium metal, but this use accounts for very little of total zircon consumption. Zircon is also the main raw material source for the production of zirconia (zirconium oxide, or ZrO_2) and zirconium chemicals. Milled zircon, or flour, is used as a foundry mold wash to protect the mold facings, to provide a cleaner finish on the casting surface, and to make it easier to separate the casting from the mold. Zircon grains and flour can be mixed in a slurry and applied over wax patterns in multiple layers to make molds for high-quality investment castings. After the wax is removed, molten metal is poured into the mold, allowed to solidify, and removed by breaking the mold. This is a rapidly growing industry owing to the quality products so manufactured. Zircon bricks and special shapes are important refractories in the steel and glass industries, though the former has many comparable substitutes available to it, particularly high-magnesia spinel. The glass industry is relatively dependent on zircon refractories due to the lack of suitable substitutes.

Zirconium and hafnium found unique roles in the nuclear industry in the 1950's, and this continues to be their mainstay to this day. While they both retain excellent metallurgical properties and corrosion resistance in the extreme environment of a reactor core, they are used because each has exactly the opposite effect on the thermal neutrons that drive the fission process of nuclear energy: Zirconium is relatively transparent, and hafnium is an excellent sink, or absorber. Hence, the former is used to clad fuel rods, and the latter is used in control rods to regulate the rate of fission within the reactor. Zirconium has also found wide usage in the chemical process industries because of its corrosion resistance to harsh chemicals, and hafnium is used as a additive in several superalloys to improve their high-temperature properties.

Hafnium is refined from zircon sand just as zirconium is, by chlorination, and then separated using solvent extraction. This is done primarily because of the need to produce hafnium-free zirconium for nuclear fuel cladding. There is also a persistent need for hafnium as a control rod medium and as an alloy addition in superalloys. Hafnium metal can be produced by the Kroll process (magnesium reduction of the tetrachloride), as can zirconium, to produce sponge metal. Sponge metal, called so because of the spongelike pores produced by the process, is then vacuum distilled to remove the reacted magnesium chloride salts, crushed, and compacted to form a first ingot. This ingot is then remelted more than once with small additions of other alloying elements by electric arc and electron beam furnaces to further refine it. Both metals can also be produced as crystal bars, a process first described in 1925 by its developer, deBoer-van Arkel. The only difference is that more hafnium crystal bar is produced because of the high-purity requirements of superalloys and hafnium's greater use therein. To do so, hafnium metal is placed in a 200° C to 300° C iodine atmosphere alongside a superheated hafnium filament at 1,300° C. Gaseous metal halides (hafnium tetraiodide) gradually sublime from the feed by the attack of the hot gas. When these come in contact with the wire, the hafnium is deposited in crystal form, freeing the iodine to repeat the process until the feed has been completely transferred to the crystal bar.

For the most part, hafnium metal has only been used as control rods in nuclear reactors and as a constituent in superalloys. The former arises from the fact that hafnium is an excellent absorber of thermal neutrons and retains its metallurgical properties while doing so. The latter is done to strengthen grain boundaries between the metal crystals in the alloy; this refinement improves the alloys properties of creep resistance, tensile strength, and high-temperature ductility. As regards neutron absorption, it is a striking coincidence that

zirconium and hafnium have exactly opposite effects here, yet they are sister elements. Zirconium, as mentioned above, is used to clad nuclear fuel rods because of its transparency to thermal neutrons. This allows reactors to run at optimum efficiency. Any hafnium not removed from the zirconium during refining would slow down neutron activity within the reactor's core. Aside from nuclear and chemical process industry uses mentioned earlier, zirconium metal also has minor uses in photographic flash bulbs, fireworks, military ordnance, lesser use than hafnium in superalloys, and as a getter in vacuum tubes. Because of the two metals' similar properties, they can be used interchangeably or combined in most applications except nuclear; but, commercially pure zirconium, which contains hafnium, has wider usage because of its lower cost.

Nonmetallic uses of hafnium have been quite limited so there is much opportunity for growth in this area. While hafnium-carbide is used to coat tungsten-carbide cutting tools, perhaps the most promising nonmetallic use is in hafnium oxide refractories. It has a higher melting temperature than zirconia, second only to thorium oxide. Thoria melts at about 3,300° C and hafnia at 2,900° C, while zirconia's is 100° lower than magnesia, or 2,700° C.

Zirconium oxide, or zirconia, is used largely in refractories, ceramics, abrasives (when alloyed with alumina), and electronics. It is produced from zircon by removing silicon dioxide. (Silica, SiO_2, and zirconia, ZrO_2, combined make zircon, $ZrSiO_4$). Several methods are commercially employed to accomplish this. These include both electric arc and plasma arc dissociation and chemical methods such as caustic fusion and chlorination. The process used depends on the quality of zirconia necessary for the desired end product. Although baddeleyite does not require the removal of silica, some beneficiation is needed to remove trace quantities of impurities. This mineral is used in special applications for refractories, abrasives, ceramic colors, and chemicals.

ANNUAL REVIEW

It was indeed an active year for zircon and its related forms. Areas of activity concerned domestic and foreign mine closings and expansions, exploration in North Carolina and Virginia, lifting of the trade embargo on parastatal baddeleyite from the Republic of South Africa, two company acquisitions, and a significant reduction in the price of zircon.

Legislation and Government Programs

On January 17, 1990, zircon, baddeleyite, and zirconium-bearing materials were added to the list of materials deemed essential for the economy or defense of the United States. (Public Notice 1150 was issued in the Federal Register on January 18th.) This certification exempted certain items grown, produced, marketed, or otherwise exported from parastatal organizations in the Republic of South Africa. Baddeleyite produced by Foskor Ltd., one of only two free world producers, was henceforth permitted U.S. importation. Foskor and the Palabora Mining Co. both mine the same deposit in the Transvaal and together produce about 20,000 metric tons of baddeleyite per year.

Production

In Florida, E.I. du Pont de Nemours & Co. Inc. announced plans to expand its operations onto a 7,200-acre property acquired in 1985. The Maxville extension is just north of the Trail Ridge deposit, which Dupont has mined for the past 30 years. Beginning in 1992, a portion of the current operations, which include both the Trail Ridge and Highland deposits, will be closed as the Maxville site is commissioned. A 50% increase in production is expected. The Ellicott Machine Corp., Baltimore, MD, was to supply a 2,100-ton-per-hour dredge to complement the two already operated by Dupont. It will outproduce both of the existing dredges combined. Dupont expected the new property to produce until the year 2010.

Associated Minerals (USA) Ltd. doubled the capacity and improved the efficiency of the wet-treatment plant at its mine in Green Cove Springs, FL. (Wet plants are concentrators and dry plants are separators of mineral sands.) The $20 million upgrade, performed while the facility remained online, was made so that lower ore grades could be processed with utmost efficiency.

Heritage Minerals Inc. completed its processing of stockpiled tailings at an old ilmenite mine in Lakehurst, NJ. The original ore deposit still contained reserves of zircon, but the company had made no definite plans to dredge those resources, an activity that could extend its presence there another 6 years. Market stability was awaited before a decision would be made. Nord Ilmenite Corp. completed its first full year of similar reprocessing in Jackson, NJ, after commencing operations last December.

There was much activity in southern Virginia generated by a handful of compa-

TABLE 1

SALIENT U.S. ZIRCONIUM STATISTICS

(Metric tons)

	1986	1987	1988	1989	1990
Zircon:					
Production:					
Concentrates	W	W	117,606	118,388	102,073
Milled zircon	46,970	42,394	64,393	54,699	43,886
Exports	15,852	20,054	21,794	r48,071	30,195
Imports for consumption[1]	68,764	67,917	76,331	r73,129	26,783
Consumption, apparent[1]	143,335	132,800	176,991	r145,683	107,822
Stocks, December 31: Dealers and consumers[2]	28,074	39,218	34,370	r32,133	22,972
Zirconium oxide:					
Production[e 3]	7,148	5,226	4,438	r10,030	7,483
Exports	1,648	1,206	1,809	NA	NA
Imports for consumption	464	1,274	1,089	NA	NA
Consumption, apparent	6,078	3,800	3,548	NA	NA
Stocks, December 31: Producers[e 3]	2,002	1,213	r507	r502	737

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

[1]Includes insignificant amounts of baddeleyite.

[2]Excludes foundries.

[3]Excludes intermediate oxide produced by zirconium metal producers.

TABLE 2

ESTIMATED CONSUMPTION OF ZIRCON, BY END USE, BASED ON TOTAL APPARENT CONSUMPTION

End use	1989	1990
Zircon refractories[1]	23,000	17,000
AZS refractories[2]	12,000	9,000
Zirconia and AZ abrasives[3]	W	W
Alloys[4]	W	W
Foundry applications	41,000	31,000
Other[5]	50,000	37,000
Total	145,000	108,000

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.

nies in the exploration and development stages of heavy-mineral deposits, and it seemed almost certain that one, if not more, of the deposits would come on-line by the middle of the decade, depending on positive feasibility studies and permit approvals.

South East TiSand Joint Venture, composed of Becker Minerals Inc. (Cheraw, SC) and Consolidated Rutile Ltd. of Australia, began close-spaced drilling to prove up ore bodies, acquired mineral leases for its Ringwood and Roanoke Rapids, NC, deposits, and produced pilot plant concentrates for laboratory analysis. The deposit in Brink, VA, for which mineral leases were signed in November 1989, was the site of the pilot plant runs, which were performed on ore samples from other deposits as well. Soil reclamation studies were also furthered with the assistance of the Virginia Polytechnic Institute and State University. Preparations to secure the necessary permits were also made.

RGC (USA) Minerals Inc. continued exploration and development work on three separate deposits. Furthest along was the Old Hickory deposit, 90 kilometers (km) southwest of Richmond, VA, near Stony Creek, with an estimated 210 million tons of zircon and titanium mineral-bearing sands grading 6.5% on average. Zones with grades as high as 20% were said not to be uncommon, and a few contained as much as 60% to 70%. Ore body assessment, completed in July, and lease acquisitions had advanced such that the permitting process was begun toward year's end. At the same time, drilling of 2,400 new, close-spaced holes was begun, the analysis of which would be used to better mine the deposit. Studies continued at the Virginia Polytechnic Institute and State University to ensure that soil reclamation would sustain the type of crops currently grown on the farmlands. Property acquisition (leases) and drilling also continued at two projects in North Carolina near Aurelian Springs and Bailey. Pilot plant trials took place on-site at the former toward yearend.

On May 3d, Piedmont Mining Co. announced a tentative agreement with the Corona Corp. to explore for heavy-mineral deposits in North Carolina along the same ancient shoreline the deposits mentioned above are located on. The company began investigations in the region last August.

Magnesium Elektron, Inc. completed the expansion of its Flemington, NJ, zirconium chemical facility in May. The increase in capacity was necessary to meet current and future demand for this growing market. Zirconium chemicals are used in a wide variety of applications such as antiperspirants, kidney dialysis, oil well fracturing fluids, ink and paint dryers, food container coatings, leather tanning agents, and many others.

Coors Ceramics Co., Golden, CO, broke ground at yearend for production and office facilities to house its year-old consumer product division, Coors Ceramicon Design, Ltd. The 117,000-square-foot complex, composing only a portion of the Coors Technology Center, was scheduled for July 1991 commissioning. Ceramicon produces specialty zirconia ceramics such as golf putters, labware, and knife sharpeners.

The Norton Co. agreed to accept a $90-per-share tender offer from the French glass producer Compagnie de Saint Gobain after successfully defending repeated hostile takeover attempts by the British conglomerate BTR PLC. The announcement was made on April 25th and became effective on April 30th. Headquartered in Worcester, MA, Norton operates 113 plants in the United States and 25 worldwide. The plant at Huntsville, AL, which produces zirconia-toughened alumina for abrasives and zirconia for refractories and advanced ceramics, is one of the world's largest zirconia production facilities.

M & T Chemicals, Inc. of Andrews, SC, a leading domestic producer of milled and micronized zircon, was merged with two other chemical companies by its parent company, Europe's Elf Aquitaine and its subsidiary, Atochem S.A. The new company, Atochem North America, also absorbed the Pennwalt Corp. and Atochem Inc.

Stocks

Stockpiles of zirconium and hafnium held by U.S. Department of Energy totaled 949 tons and 34.5 tons, respectively. The stocks were held in various forms, but mostly as ingots and wrought shapes. The National Defense Stockpile continued to hold 14,507 tons of baddeleyite. Although there was no goal for raw ore materials, there also was no current legislative authority for its disposal.

Markets and Prices

Record prices and insufficient supply, conditions that plagued raw material consumers in the past few years, abruptly reversed in 1990. Lower demand, reduced by lagging economies, and an increase in supply, brought to market by new and expanded operations, coupled to deflate prices significantly. Producers, especially in Australia, the world's largest producer, sought to mitigate the price collapse and curtailed production at some mines by extending yearend, holiday-season closures, thus bringing the supply-demand balance more in line. (It was thought by some industry observers that similar moves in the mid-eighties had been purposefully implemented to undersupply then-current demand, thereby instigating price increases.) Other factors were attributed to the record-high prices seen at the end of the decade too: the sinking of the *Singa Sea* off the coast of Australia in July 1988 (13,400 tons of zircon onboard), the general media/industry hype about a shortage, and consumer attempts to build inventories during the purported shortage. Yearend prices of zircon are given in table 3.

One manifestation of short supply, whether real or not, was the emergence of a spot market and its highly inflated prices. Prices as high as $1,000 per ton for nonbulk standard grades were reported. This represented about a 30% to 40% premium over contractual prices for similar material. Another result of the tight supply was shortened contract periods, down from semiannually or yearly to quarterly or semiannually. All in all, had the world's primary consumers maintained and utilized substantial inventories of zircon, the effect of this past boom-bust cycle would have been much less severe, or at best would not even have occurred.

TABLE 3

PUBLISHED YEAREND PRICES OF ZIRCONIUM AND HAFNIUM MATERIALS

Specification of material	1989	1990
Zircon:		
Domestic, standard-grade, f.o.b. Starke, FL, bulk, per short ton[1]	$320.00	$368.00
Domestic, 75% minimum quantity zircon and aluminum silicates, Starke, FL, bulk, per short ton	[r]204.00	204.00
Imported sand, minimum 65% ZrO_2, f.o.b., bulk, per metric ton[2]	[r]395.00- 474.00	309.00- 386.00
Imported sand, minimum 65.5 to 66% ZrO_2, f.o.b., bulk, per metric ton[2]	395.00- 474.00	348.00- 425.00
Imported sand, minimum 66% ZrO_2, f.o.b., bulk, per metric ton[2]	474.00- 790.00	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	350.00- 800.00
Baddeleyite, imported concentrate:[4]		
96% to 98% ZrO_2, minus 100-mesh, c.i.f. Atlantic ports, per pound	.85- 1.05	.60- .75
99%+ ZrO_2, minus 325-mesh, c.i.f. Atlantic ports, per pound	1.16- 1.30	1.07- 1.20
Zirconium oxide:[3]		
Powder, commercial grade, drums, 2,000-pound minimum, per pound	2.00- 7.00	2.00- 7.00
Electronic, same basis, per pound	3.50- 8.00	3.50- 8.00
Insulating, stabilized, 325° F, same basis, per pound	4.50	4.50
Insulating, unstabilized, 325° F, same basis, per pound	5.00	5.00
Dense, stabilized, 300° F, same basis, per pound	3.00	3.00
Zirconium oxychloride: Crystal, cartons, 5-ton lots, from works, per pound[3]	.91- 1.04	.91- 1.04
Zirconium acetate solution:[3]		
25% ZrO_2, drums, carlots, 15-ton minimum, from works, per pound	.97	.97
22% ZrO_2, same basis, per pound	.78	.78
Zirconium hydride: Electronic-grade, powder, drums, 100-pound lots, from works, per pound	.31- .75	.31- .75
Zirconium:[5]		
Powder, per pound	70.00- 150.00	75.00- 150.00
Sponge, per pound	12.00- 18.00	9.00- 12.00
Sheets, strip, bars, per pound	16.00- 45.00	20.00- 50.00
Hafnium: Sponge, per pound[5]	75.00- 135.00	75.00- 95.00

[r]Revised.
[1]E. I. du Pont de Nemours & Co. Inc. price lists. Oct. 1, 1989, and Apr. 1, 1990, respectively.
[2]Industrial Minerals (London). No. 267, Dec. 1989, p. 75; and No. 279, Dec. 1990, p. 79.
[3]Chemical Marketing Reporter. V. 236, No. 26, Dec. 29, 1989 p. 26; and v. 238, No. 27, Dec. 31, 1990, p. 40.
[4]The Applegate Group and American Vermiculite Corp. baddeleyite price lists.
[5]American Metal Market. V. 97, No. 252, Dec. 30, 1989, p. 6; and v. 98, No. 251, Dec. 28, 1990, p. 6.

World Review

Exploration and development of ore deposits continued despite reduced demand and faltering prices. Even so, some expansions were completed and others were planned, and a few new projects were commissioned.

The situation in which supply exceeded demand, as was expected by some because of additional capacity coming on-line, was exacerbated by the industrial nations' recessionary economies. So, both supply and demand were moving in opposite directions, and consequently, prices suffered from the imbalance. Reaction to this condition was seen at yearend when a few producers temporarily ceased operations, perhaps to add some price-stabilizing support to the market.

Australia.—Australian producers implemented yearend mine closures to bolster prices and bring supply in line with demand. Temporary closings included Westralian Sands Ltd.'s North Capel and Yoganup Extended Mines (planned to restart in 1991 and 1992, respectively), and Cable Sand's dry plant operations at Bunbury were halted during the holiday season. AMC Mineral Sands ceased operations at Capel and Eneabba also during Christmas and later announced that Eneabba North would stay off-line for 12 months duration, a sizable reduction in supply because this mine produces roughly 100,000 tons of zircon per year. There were no changes planned for the 1991 commissioning of the lower cost Eneabba West deposit, which contained an estimated 920,000 tons of zircon. Similar closings were expected to be exercised by other producers in 1991.

In September, RZ Mines (Newcastle) Pty. Ltd. commissioned a new bucketwheel suction dredge that increased the throughput of its five operations in New South Wales by about 200 tons per hour. The 800-ton-per-hour dredge supplied feed to an existing wet-treatment plant at Tomago that was upgraded from its original 600-ton-per-hour constant feed rate. New total capacity of the five operations was 1,630 tons per hour.

CRA Ltd.'s subsidiary Wimmera Industrial Minerals Pty. Ltd. made significant new finds in the Murray basin in the Wimmera Region of Victoria. The WIM projects now total five and have the follow-

ing designations, grades, heavy-mineral tonnages (in millions), and reserve types, respectively: WIM 050, 3.5%, 25, inferred; WIM 100, 5.9%, 50, inferred; WIM 150, 4.0%, 30, measured; WIM 200, 7.2%, 31, indicated; and, WIM 250, 5.3%, 67, indicated. The flagship project, the WIM 150, has been estimated to contain 5 million tons of zircon. The ore minerals of these resources, composed almost entirely of fines, required innovative processing methods to make the projects viable. The company has developed novel techniques to overcome the obstacles of separating the fine sand grains from the gangue minerals and of processing the titanium minerals for use in the manufacture of pigment-grade titanium dioxide. The initiation of environmental studies was, as is usual, interpreted as a positive indication of the company's intent to proceed with the project.

Centenary International Mining, Perth, Western Australia, discovered heavy-mineral deposits rivaling those in the Perth basin, which supply an estimated 40% of the world's heavy-mineral sands. Focusing its efforts near South Balladonia in the Eucla basin, consistent zircon grades of 25% to 30% have been found in mineral suites ranging from 3.6% to 4.5% total heavy minerals. Beach and dune sands of Doubtful Island Bay yielded heavy-mineral grades as high as 38% and 3%, respectively. The former suite was indicated to contain 100,000 tons of heavy minerals, composed of 70% ilmenite and 20% zircon.

A mine with a zircon capacity of 10,000 tons per year came on-stream in April at Newrybar, New South Wales. Established by Australmin Holdings Ltd., the mine was assumed by Newmont Australia Ltd. early in the year. Mine output was separated in a 45,000-ton-per-year dry separation plant at Woodburn.

Heavy-mineral exploration licenses were issued to Broken Hill Pty. Co. Ltd. (BHP) for an area on the western boundary of a 1950's era atomic test site in the South Australian desert near Maralinga. The issue of the licenses was contingent on BHP reaching an agreement with the Maralinga Tjarutja, the aborigines to which the State returned the land (outside the test site) in 1984. The agreement permits BHP to survey sacred grounds under the inspection of the Aboriginal people.

Brazil.—The mineral sands industry in Brazil has recently expanded, and more growth is expected in the coming years. Zircon production between 1986 and 1989 doubled from 15,116 to 32,970 tons, and more growth is expected in the next few years as new projects come on-line.

Two Japanese companies entered a consortium with the State of Bahia and Multiquartz Minerãçao, based in Rio de Janeiro, to mine heavy-mineral sands near the coastal towns Valença and Itacaré. Kawatetsu Co. and Sumitomo Corp., along with the Brazilian company and the State concern, were to lease the properties for 25 years in exchange for a 3% royalty and a complete evaluation of the reserves. The deposit has been estimated to contain 3 million tons of ore, but further exploration hoped to increase this to 10 million tons.

Paranapanema subsidiary Minerãçao Taboca SA has been mining the tin mineral cassiterite at its Ptinga deposit in Amazonas since 1982, and in April of last year, began processing the zircon-bearing stockpile that had accumulated. The mining activity performed until about the middle of this year was conducted to remove the resource-bearing overburden covering the primary hardrock ore body, which also contains zircon (4 million tons estimated) as well as tin and rare-earth mineralization. Minable reserves of zircon also were in placer deposits washed away from the ore body. In processing the stockpile, the company expected to produce about 170,000 tons of concentrate in 3 or 4 years from a plant with a 3,500-ton-per-month capacity. The company also planned to begin production of zirconia at its Minebra facility in 1991, using output from the mine, at a rate of 1,300 tons per year, later increasing to 4,000 tons by 1994.

Pending approval, zircon production of 5,000 tons per year is expected to commence in 1991 on the Sapucaí river near São Gonçala in southern Minas Gerais. SA Minerãçao da Trindade (Samitri), an established iron ore producer, estimated that reserves in the channel and adjacent banks contained 115,000 tons of zircon as well as other heavy-mineral sands (ilmenite, 630,000 tons, and monazite, 50,000 tons). The company also was active in the exploration of seven sites on the country's northeastern and eastern coasts. Established reserves in a northeastern dune project comprised 145 million tons grading 4% heavy minerals. These included 1.7 million tons of ilmenite, 398,000 tons of zircon, 48,000 tons of monazite, and 59,000 tons of rutile.

Canada.—The Iron Ore Co. of Canada entered an agreement with Acadia Mineral Ventures Ltd. to continue development of its unique deposit on the Quebec-Labrador border 250 km northeast of Schefferville, Quebec. High grades of zirconium oxide contained in the mineral gittinsite range between 2.99% and 3.25%. Reserves containing the former grade were put at 55 million tons and 1.5 million tons for the latter. The calcium-zirconium-silicate mineral was said to be digestible in weak sulfuric acid at low temperature (80° C) and standard pressure; zirconia of 99.5% purity could then be obtained via solvent extraction. The deposit also contained reserves of rare earths.[1]

Denmark.—Norstral Minerals A/S (incorrectly stated as Morstral by the reference cited in the 1989 chapter) continued exploration of heavy-mineral deposits, 10 to date with one-half showing some promise. The company, granted mining rights in exchange for exploring potential mineral deposits, expected to conclude exploration within 2 years and hoped to commence production within 5. Geophysical surveys were conducted using a special radar capable of penetrating to depths approaching 50 meters. The georadar was successful in detecting heavy minerals in gravel deposits, some with grades as high as 10% to 15%. One particular deposit that was drilled was found to contain low-grade ilmenite, rutile, poor-quality zircon, and garnet. The deposit also was said to be "juvenile," meaning that it has not been reworked by the forces of nature to create a clean ore body (few organics) with clearly defined horizons of heavy minerals.[2]

Greenland.—The unique zirconium and yttrium mineralization (eudialyte) of the Illmaussaq Igneous Complex has been under investigation in recent years as world demand for zirconia and the rare earth has increased. (A deposit in New Mexico, U.S.A., also has been studied.) The 3-million-ton ore deposit at Gardar (near Narssaq) contains four delineated ore bodies grading 2% to 3.5% zirconia on average, a grade reportedly second only to a deposit in the U.S.S.R. Pilot-plant trials were to have begun in March at Lakefield, Ontario, using 60 tons of the sulfuric acid-soluble ore. Zirconium and yttrium could then be won using liquid-liquid solvent extraction. However, past attempts to beneficiate eudialyte, predominantly a silicate mineral, have proven difficult because of the formation of a silica gel. The deposit's development, economic assessment, and pilot-plant trials were the affairs of a triventure com-

posed of Platinova Resources Ltd., Highwood Resources Ltd., and A/S Carl Nielsen. Initial plans called for an on-site plant capable of producing 2,000 tons of zirconia per year, expanding to 4,000 tons within 5 years. Ore grinding and magnetic separation would increase the ore grade from 4% to 8% ZrO_2. Sixty tons annual production of yttrium concentrate also is expected.[3]

Madagascar.—The capital financing required to place and upgrade the infrastructure necessary to transport and export, respectively, the heavy minerals from QIT-Fer et Titane Inc.'s (QIT) deposit continued to hold up the advancement of this project. QIT had already agreed to pay for the construction of electrical power generating facilities, but a 100-km tarmac road from the mine to the port is needed because of the wet season, and an estimated $100 million port upgrade is required as well. QIT reportedly was considering building the road if it were granted special concessions by the National Military Office for Strategic Industries (OMNIS). However, the port financing would have to be raised by OMNIS from an outside source, because the cost would be exorbitant for the company to bear. Annual zircon production of 24,000 tons is expected if the deposit, located near Toalagnaro, is ever developed and commissioned.

Malaysia.—The oversupply of tin on world markets nearly halved the price of this commodity and led many companies to idle their dredges, whilst others operated at a loss. This is important regarding the country's zircon production because it is a byproduct of mining cassiterite for tin. In 1990, zircon production was drastically reduced to 4,279 tons, a 77% decline from 1989's level of 18,704 tons. However, the decline in tin production was only 11%, from 32,034 tons in 1989 to 28,468 in 1990. Still, there could have been other factors that would have led to such low zircon production: lower ore grades, tin tailings stockpiled in favor of processing because of low demand and/or prices, or the fact that gravel pumping of ores showed large declines (treatment plants are predominantly associated with this method of mining as opposed to dredging).

Mozambique.—Dublin, Ireland-based Kenmare Resources PLC received word in November, 1 year after announcing the positive completion of its feasibility study, that its expected 51% joint-venture partner for the Congolone deposit, Johannesburg Consolidated Investments (JCI) PLC, was denied the backing of the Credit Guarantee Insurance Corp. (CGIC) of the Republic of South Africa. Because CGIC already has other investments in the country and JCI's valuation of the project supported Kenmare's, the refusal was thought not to be politically related, but rather for reasons of financial diversity.[4] JCI was chosen from a field of a few interested companies which now may be reconsidered. In unrelated events, Kenmare's interest in the project was increased from 71.25% to 95%, and Yugoslavia's geological survey (Gelolski Zavod), the discoverer, from 3.75% to 5%. The Mozambican Government previously held a free-carried 25% stake in the project.

Netherlands.—RZM Europe was founded by its Australian parent company to manufacture and market micronized zircon. Micronized zircon typically ranges in size from 1 to 10 microns and is about 5 to 50 times smaller than zircon flour (325 mesh or 45 microns). This form of milled zircon is used for the opacification of tile, sanitaryware, and tableware. Because of the very fine particle size, a small quantity of material covers a large area. A 7,000-ton-per-year mill was installed on the grounds of the Eggerding & Co. in Amsterdam.

South Africa, Republic of.—Richards Bay Minerals new dry mill was commissioned in October, nearly doubling zircon capacity to 300,000 tons per year. Also being added was a new facility to produce 60,000 tons of "prime-grade" zircon. Lower iron impurities will be attained by acid leaching, and titania and alumina will be reduced through additional separation techniques.

In August, the Palabora Mining Co., which produces byproduct baddeleyite (naturally occurring zirconium oxide) from its open pit copper mine in the Transvaal, began in August sinking a shaft for the purpose of conducting underground exploration. A drilling program and tunneling from the shaft are also planned. Reserves at the mine, currently about 400 meters deep, are expected to be exhausted by the year 2002 at a depth of 800 meters. The tentative date for sinking a production shaft, pending exploration findings, is 1995. Foskor Ltd. also produces baddeleyite from the Phalaborwa Complex as a byproduct of phosphate mining. Still, this deposit is the world's only current source of this invaluable mineral. A pilot plant in Brazil is planned, but production would probably remain captive even if a tentatively planned expansion to 1,000 tons per year is executed. A Russian deposit at an iron ore mine on the Kola Peninsula could possibly produce about 3,000 tons per year, harsh climate permitting, but potential domestic customers reported that although the mineral is of exceptional quality, a 30% premium over the price for South African product was not justifiable.

Foskor Ltd. completed construction of a world-class (third largest) fused zirconia plant that was designed on technology acquired from Fukushima Steel in Japan. The 3,000-ton-capacity plant, using feed from Phalaborwa (baddeleyite) or Richards Bay (zircon), is capable of producing monoclinic, stabilized, or electrofused hollow zirconia.

United Kingdom.—It was reported last year that Butte Mining PLC had purchased a zircon milling concern, Gramcol Zircon Ltd., with a mill capacity of 1,500 tons per year. The public limited corporation has now formed Zirceram Ltd. as a result of that purchase and soon is to commission a new wet mill capable of producing 2,250 tons per year of micronized zircon using a recently developed zirconia grinding media. The mill's product was reported to be capable of covering 34 square meters with just 1 gram of material.

Vietnam.—In July, the State Committee of Sciences and the Ministry of Heavy Industry approved Hong Kong-based Crusader Investments Ltd.'s proposal to conduct heavy-mineral exploration along 1,300 km of southern coastline.

Even more promising news regarding exploitation of the country's resources came to light when the Australian company W.T. Exporters Pty. Ltd. was granted a license to develop a $16 million ilmenite and zircon sand processing and upgrading facility in the Nghe Tinh Province with a combined yearly production of about 27,000 tons. The company expected to place other such projects as it had concluded negotiations with other Provinces too.

Sixteen deposits totaling more than 1/2 million tons of zircon have now been measured, indicated, or inferred, and concentrations with ilmenite to zircon ratios as close as 3:1 have been found (ilmenite fraction typically much higher). To date, Vietnam's captive consumption has been limited to use as an opacifier in ceramic glazes.[5]

TABLE 4

U.S. EXPORTS OF ZIRCONIUM, BY CLASS AND COUNTRY

Class and country	1989		1990	
	Metric tons	Value (thousands)	Metric tons	Value (thousands)
Ore and concentrates:				
Argentina	650	$679	177	$276
Australia	261	r184	—	—
Belgium	r1,949	1,394	1,979	1,223
Brazil	538	943	25	20
Canada	2,979	1,456	2,284	2,066
Chile	90	200	90	159
Colombia	1,950	2,562	879	1,449
Costa Rica	140	93	27	68
Dominican Republic	201	176	116	197
Ecuador	779	758	274	358
Egypt	519	308	141	195
France	781	514	651	591
Germany, Federal Republic of	9,414	6,292	8,508	6,609
Hungary	306	389	—	—
India	12	6	—	—
Indonesia	99	41	—	—
Ireland	38	10	43	8
Italy	5,874	1,623	387	283
Japan	3,388	1,749	3,834	932
Korea, Republic of	531	369	219	167
Mexico	8,327	4,760	6,391	3,618
Netherlands	1,041	759	13	22
Pakistan	54	103	36	49
Peru	18	45	54	68
Portugal	78	62	—	—
Singapore	19	8	277	152
Spain	1,773	1,878	43	5
Taiwan	2,187	1,564	945	572
Thailand	18	35	18	22
U.S.S.R.	1,234	610	989	674
United Kingdom	2,147	809	892	400
Uruguay	18	41	18	35
Venezuela	515	576	759	732
New Zealand	r63	r32	—	—
Other	r82	r106	125	151
Total[1]	r48,071	r31,134	30,195	21,101
Unwrought zirconium and waste and scrap:				
Belgium	36	395	25	240
Canada	14	317	2	113
France	—	—	1	20
Germany, Federal Republic	6	54	5	189
Italy	—	—	26	152
Japan	83	3,050	48	1,052
Netherlands	—	—	27	146
Sweden	30	680	—	—
Switzerland	3	41	2	71
Taiwan	2	63	8	179
Thailand	7	179	(2)	5
United Kingdom	43	1,011	35	778
Other	r7	r186	7	114
Total[1]	r232	r5,974	188	3,057

rRevised.
[1]Data may not add to totals shown because of independent rounding.
[2]Less than 1/2 unit.
Source: Bureau of the Census.

Current Research

In recent years, rare-earth-doped fluorozirconate fibers have made great inroads in optical communications as attenuation losses have been greatly reduced and fiber laser amplifiers have extended the distances between necessary repeaters. Now inroads are being laid in nontelecommunication applications, and British Telecom Research Laboratories in Martlesham Heath, United Kingdom, has issued an exclusive license to Galileo Electro-Optics in Sturbridge, MA, for such use. British Telecom has also developed a new method to mass produce cast preforms. The fibers so developed recorded losses of 0.65± 0.25 decibels per kilometer in a 110-km length, which was said to be a record. The license to Galileo involves using fluoride fibers (mole ratio hafnium-zirconium fluoride: 40% to 60%; balance: barium, lanthanum, sodium, and lead fluorides) to monitor specific manufacturing processes. This would include gasoline refining and the curing of printed circuit boards or other plastics and resin-fiber composites. The molecular vibrations in these processes release energy in the form of infrared radiation, which is precisely where these fibers are the most transparent (2.59 microns). Then, by monitoring the molecular activity, manufacturers can maintain better control and awareness of the production process and its various stages.

Scientists at the Argonne National Laboratory in Illinois developed a new process that can produce ceramic fibers from any type of sinterable ceramic compound. The "universal ceramic fiber process" is similar to the continuous casting of metals and includes the following basic steps: micron-size metal oxides are mixed with a plastic binder, injected into an airstream, and then fired at the temperature necessary to sinter the compound. Fibers thus produced typically range from 1 to 10 microns in diameter. Success was reported in manufacturing what is believed to be the first magnesium oxide fibers ever. This is significant because not only does this material have a higher melting temperature than zirconia (2,800° C compared with 2,700° C), but the process is claimed to be less costly than current batch methods for producing zirconia fibers (e.g., spin melting or using natural and/or synthetic fibers as substrates which, after being impregnated or coated with zirconia, are burned away). Metal carbides, nitrides, and such could also be produced by this process if the firing were

to occur in a controlled atmosphere; otherwise, carbon and nitrogen monoxides and dioxides would form. The developers have formed a new company, Sky Fibertech, Plainfield, IL, to manufacture and market ceramic fibers.

In other ceramic-related developments, Ceramatec, Inc., Salt Lake City, UT, won the "R & D 100" award for its new NZP (sodium-zirconium-phosphate) advanced ceramic, LE-1500. One of its extraordinary abilities is that it can be heated to 1,250° C and then emersed in ice water without experiencing any loss of strength, elastic modulus, or thermal expansion qualities. The thermal shock resistance and tolerance to low mechanical stresses at temperatures above 1,400° C, combined with the near-zero isotropic thermal expansion, make this material suitable in numerous applications. NZP can be manufactured or applied using a variety of standard methods.

A solution to the problems of strength and toughness degradation, which arises in ceramic monoliths and fibers when microstructural grains grow in size at elevated temperatures, may have been found. Air Force-sponsored research at Lehigh University, Bethlehem, PA, led to the development of a ceramic material, AZ50 (50% alumina and 50% cubic zirconia), that showed no change in grain size or loss of strength after 100 hours at 1,650° C. Mechanical testing showed that many of the material's property attributes were enhanced. Creep, the plastic deformation under loading at elevated temperatures, did not occur on samples tested at 1,150° C. AZ50's resistance to creep was said to be comparable, if not superior, to that of commercial alumina. Hardness tests carried out at 1,250° C indicated fourfold and 25% increases over cubic zirconia and alumina, respectively, and very little structural damage was observed around diamond indentations. The mechanism by which AZ50 is able to maintain its fine microstructure at high temperatures is described as "interpenetrating phase mixtures."[6]

Conversely, specially prepared zirconia of another type may one day be exploited for its high-temperature ductility. Two types of superplasticity occur in metals and ceramics: crystal phase transformation and structural. The former was demonstrated more than 20 years ago by the monoclinic-tetragonal, temperature-induced phase change in zirconia. (Transformation-toughened zirconia, TTZ, is a unique structural ceramic that volumetrically expands in dimension upon strong impact by transforming from the tetragonal to the monoclinic phase. This expansion arrests the propagation of fractures that would otherwise destroy the ceramic body.) Structural superplasticity, expressed by tensile elongation, was documented in Japan in 1985. Extensive and ongoing research to determine the mechanism enabling some samples to stretch up to three and one-half times their original length has found some commonality in the materials and processes at work. First, an extremely small grain size, 1 micron or less, is prerequisite. Second, although other compositions will exhibit superplastic flow, yttria-stabilized, tetragonal zirconia polycrystal (Y-TZP) has received the most attention because of its superior performance. Yttria stabilization of 3 mole percent (3Y-TZP), with or without various other metallic oxide dopants, has been the benchmark specimen for research. Finally, it appears that structural superplasticity involves an "intergranular glassy phase that gradually transforms through a thin liquid phase." Although work to date has covered small ranges of both temperature and strain, continued investigation may expand both of these parameters and thus allow widespread use of this unique material. One application was developed where a Y-TZP bar was fabricated around a silicon carbide disk at 1,450° C to form a piston ring.[7]

The magnetic properties of cobalt-zirconium-boron alloys and their structural re-

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF ZIRCONIUM AND HAFNIUM, BY CLASS AND COUNTRY

Class and country	1989		1990	
	Metric tons	Value (thousands)	Metric tons	Value (thousands)
Zirconium ore and concentrates:[1]				
Australia	51,446	$21,149	11,998	$5,600
Belgium	18	13	—	—
Canada	112	24	20	15
France	—	—	76	349
Germany, Federal Republic of	52	44	—	—
Malaysia	250	262	—	—
South Africa, Republic of	20,833	11,840	14,381	5,833
United Kingdom	416	569	293	574
Other	r2	r17	14	37
Total[2]	r73,129	r33,917	26,783	12,407
Zirconium, unwrought and waste and scrap:				
Canada	10	r112	41	299
France	11	53	46	209
Germany, Federal Republic of	36	r340	—	—
Japan	r45	447	5	98
Sweden	—	—	25	198
United Kingdom	40	388	11	74
U.S.S.R.	92	740	—	—
Other	27	r128	—	—
Total[2]	r259	r2,209	128	880
Hafnium, unwrought and waste and scrap:				
France	4	806	8	1,436
Germany, Federal Republic of	(3)	151	1	215
Switzerland	(3)	19	—	—
United Kingdom	—	—	(3)	12
Total[2]	4	976	9	1,662

rRevised.
[1]Excluding Australia, Malaysia, and the Republic of South Africa, countries are believed to be point of shipment rather than point of origin.
[2]Data may not add to totals shown because of independent rounding.
[3]Less than 1/2 unit.

Source: Bureau of the Census.

semblance to rapidly solidified alloys have recently received attention. Some qualitative property analyses have found Curie temperatures of 500° C, anisotropy fields of 34 thousand Oersteds, and coercivities of 6.7 thousand Oersteds, properties that equal and, in some cases, better those of the rare-earth magnets. Hafnium can substitute for zirconium and additions of silicon yield further gains in some properties. It is unfortunate that cobalt is the magnetic atom in these alloys because of its import dependence, a factor that hinders availibility and cost. Iron would be preferred. However, they further extend the list of magnetic alloys in which rare-earth atoms are unnecessary in order to yield outstanding properties. Others include cobalt-platinum, iron-platinum, and manganese-aluminum.[8]

Specialty Metals Processing Consortium Inc. was formed to address problems in melting and processing "high-technology" metals (viz. superalloys). Composed of metal and superalloy producers, including zirconium producer Teledyne Wah Chang Albany, and aerospace engine builders, the consortium will work with the U.S. Department of Energy and Sandia National Laboratories. Specific areas of research to be conducted at Sandia's Process Metallurgy facility included vacuum arc and electroslag remelting, plasma arc and electron beam melting, precision investment casting, and fluid flow computer modeling. The goal of the 5-year project, funded through company contributions and government subsidies, is to secure a domestic competitive advantage in high-temperature metallurgy.

Zircon has recently been used as a geologic indicator mineral in two specific instances. After conventional techniques failed to determine the age of Canadian rocks collected near the Great Slave Lake, United States geologist Dr. Samuel Bowring and his Canadian colleagues used a one-of-a-kind device developed at the Australian National University in Canberra. The Sensitive High-Mass-Resolution Ion Microprobe (SHRIMP) determined the infinitesimal amount of lead that had formed in the zircon minerals within the rocks through the radioactive decay of uranium, an element usually found in zircon only in trace quantities. The instrument, which was designed and constructed over a 7-year period, analyzed each layer of the minerals' growth (each a few thousandths of a millimeter thick) to determine the ratios of uranium and its decay product, lead. It was these ratios that indicated, by knowing uranium's half-life, the age of the rocks at about 4 billion years.

Another exploitation of zircon came to light in a research project on diamond exploration that was sponsored by the Geologic Survey of Canada and resulted in a five-volume Open File report (No. 2124, released January 23, 1990). The international study was conducted by C. F. Mineral Research, Kelowna, British Columbia. Volume 5 of the report listed new diamond-indicator minerals to complement those currently known and which may be destroyed, thus rendered useless, in certain potassium-rich lamproites, an intrusive igneous rock conducive to diamond formation. Among the new minerals that may be used to indicate a host rock favorable to the formation of diamonds was pink- to purple-colored zircon of Archean age.

Silica Products Group, Somerville, NJ, developed a new pigment, or pigment additive, which essentially is a coprecipitate of silicon and zirconium oxides, 80% and 20%, respectively. The zirconium silica hydrogel is durable against abrasion, corrosion, and weathering. These qualities were attributed to an impermeable film that resulted from chemical reactions with the organic polymers used to formulate paint. Because the gel is a recovery product of another process, it is relatively inexpensive to produce.[9]

Another pigment, produced by SCM Chemicals, Inc., Baltimore, MD, also derives some benefits with zirconia. The titanium dioxide that composes no less than 92.5% of the pigment is coated with zirconia and other compounds through a proprietary precipitation process licensed from a European patent. The zirconia aids in preventing ultraviolet light from breaking the bonds of the polymers used to formulate paints. The zirconia also replaces soluble silicate coatings that have been commonly used to impart a high resistance to chalking, or weathering. And zirconia, because of its exceptional stability under ultraviolet light, has pushed titania aside in some special military uses.

Specifically, the Valspar Corp., High Point, NC, has obtained a license, also from overseas, to produce a special camouflage coating that is especially useful in arctic environments where infrared (IR) signatures are very pronounced and ultraviolet radiation is quite harsh. Ultrapure zirconia is complemented with other metal oxides to produce this IR-absorbing pigment. The white coating presently is applied only to netting.

Beginning in 1989, certain television cathode-ray tube faceplates manufactured in the United States began incorporating small quantities of zircon sand. When added to the batch glass melt, zirconium replaces lead as an electronic browning inhibitor in the faceplate and rids the processor of the environmental and health concerns regarding lead.

A new zirconia-base ceramic was introduced specifically for application to low-

TABLE 6

ZIRCONIUM MINERAL CONCENTRATES: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1986	1987	1988	1989[p]	1990[e]
Australia	451,824	456,590	480,049	511,000	442,000
Brazil[2]	15,116	r18,131	28,029	32,970	33,000
China[e]	15,000	15,000	15,000	15,000	15,000
India[e]	16,000	10,000	15,000	r17,200	18,000
Malaysia	12,633	17,828	25,671	18,704	[3]4,279
South Africa, Republic of[e 4]	140,000	140,000	150,000	r180,000	180,000
Sri Lanka[e]	4,000	4,000	r3,000	r3,000	3,000
Thailand	1,705	1,532	5,098	1,496	2,000
U.S.S.R.[e]	85,000	90,000	90,000	90,000	90,000
United States	W	W	117,606	118,388	[3]102,073
Total	741,278	753,081	929,453	987,758	889,352

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

[1]Includes data available through May 10, 1991.

[2]Includes production of zircon and caldasite.

[3]Reported figure.

[4]Includes production of zircon and baddeleyite.

temperature metals. Developed by the Kaman Sciences Corp., Colorado Springs, CO, MAC-1000 (multiattribute ceramic) is applied in slurry form and subsequently fired at about 270° C. Metal parts so treated inherit many of the qualities of zirconia ceramics: wear, corrosion, and thermal shock resistance, low thermal conductivity, and increased hardness. Also, the coating resists caustics and most acids (not hydrofluoric or boiling sulfuric) and is not wetted by molten glass.

Oxygen sensors made primarily of zirconia have long been used to monitor oxygen levels in boilers, furnaces, and combustion chambers. They are now incorporated into virtually every car manufactured in the world today in order to control fuel efficiency and emissions. The devices produce voltage proportional to the current of ionic oxygen flowing through a zirconia electrolyte sandwiched between two platinum electrodes. Now it appears that commercial devices exploiting the reversal of the same process are set for market introduction. By applying a voltage to the same apparatus, oxygen can be extracted from atmospheric molecules and conducted through the electrolyte, recovered, and stored for medical, welding, or other uses. One such unit was said to have operated continuously for 26 months and was expected to be commercialized in 1991.

A refractory-free metal-melting system was introduced by Inductotherm, Inc., Rancocas, NJ. Developed jointly with the University of Alabama in Tuscaloosa, the process, magnetic suspension melting as it is called, works on the established technology of electric induction. The improved method does not require refractory containers (e.g., crucibles) to hold the melt; the induction also provides magnetic suspension currently capable of handling 30 pounds. And because there is no contact, there is no chance for refractory contamination of the melt. Superalloy producers demand the highest quality zircon and zirconia to mitigate the effects of iron, aluminum, and titanium on their products. They typically melt superalloys in a zirconia crucible and pour the liquid metal into an investment casting made up of alternating layers of zircon grains and flour. While the new process may one day eliminate the need for zirconia crucibles, it will not obviate investment casting, or zircon products use in, as an indispensable foundry method for producing near-net-shape components.

A method developed in the eighties for casting aluminum engine blocks has provided a new foundry demand for zircon sand. The process, developed by Cosworth Castings Ltd. of Worcester, England, is a low-pressure die-casting method that uses zircon because of its low thermal conductivity and dimensional stability at high temperatures. These properties provide good crystallization and accurate castings. Moreover, no mold wash (zircon flour) is needed, and the sand is completely recyclable. Furthermore, the flour produced by the recycling process is a salable commodity. The Ford Motor Co. planned to implement this process in 1994 at a plant under construction in Windsor, Ontario.

Research begun in 1983 to investigate the effects of zirconia on dolomite (calcium-magnesium oxides) refractories has, in recent years, led to increased use of bricks containing both materials. The J.E. Baker Co., York, PA, found that by adding small amounts of zirconia (less than 5%) to its dolomite bricks, which are primarily used in cement kilns, the resistance to thermal shock was significantly increased. The gains were attributed to the formation of "microcracks" in the brick's structure, not the phase transformation of zirconia. Upon formulation of the brick, a volume expansion caused by the formation of calcium zirconate creates some fractures, and then upon firing, differing degrees of thermal expansion between the constituents causes more fracturing.

Global efforts to prevent counterfeiting have extended the use of zirconia to paper currency in Canada. An optical variable device, similar to the holograms used on credit cards, in the upper lefthand corner changes color from green to gold depending on the angle of incident light. The reflective panel is composed of five alternating layers of silica and zirconia welded together by an electron beam. The $50 and $100 bills were introduced in December of 1989 and 1990, respectively, and a new $20 bill is expected to be in circulation by 1993.

OUTLOOK

The demand for zircon appears to be quite steady, and even with the drastic price fluctuations of late, the market seems to be well established in all sectors. The only niches where somewhat equal performance can be realized with substitutes are in steel refractories and certain foundry uses. It is widely accepted that those who would choose to substitute have already done so, given two cycles of rising prices in the 1980's. Aside from raw-form utilization, remains the fact that zircon is the primary feed for the production of zirconium metal, chemicals, and zirconia. The latter two, because of expanding markets and new uses, should experience moderate to marked growth. And regarding stagnant demand for nuclear metal and steel refractory substitutions, growth in investment casting and new foundry uses should more than offset the weakened demand in these sectors.

Supplies of zircon have markedly risen in the past few years, and with a great deal of new mine capacity in place or planned, they can be expected to remain at or near present levels. The temporary mine closings seen in 1990 and expected in 1991 are merely short-term moves to stabilize zircon prices by matching demand more closely. Long-term market stability seems virtually unattainable, but not impossible, given all its variables and nuances (e.g., titanium mineral byproduct, and hence subject to those demands; producer competition; and, continuously shifting demand within consuming markets).

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